Kasper GÓRNY*, Przemysław TYCZEWSKI*, Wiesław ZWIERZYCKI*

CHARACTERISTICS OF STANDS FOR WEAR TESTS OF MATERIALS FOR REFRIGERATION COMPRESSORS ELEMENTS

CHARAKTERYSTYKA STANOWISK DO BADAŃ ZUŻYCIOWYCH MATERIAŁÓW NA ELEMENTY SPRĘŻAREK CHŁODNICZYCH

Key words:
refrigerant compressors, compressor oils, friction and wear, testing device

Summary
A desirable feature of oil lubricating refrigeration compressors is its solubility in refrigerant in the full range of working temperatures. It en-

* Poznan University of Technology, Department of Food Engineering and Food Transportation, ul. Piotrowo 3, 60-965 Poznań.
ables the majority of oil “pumped out” to the refrigeration circuit to return to the lubrication system. However, oil separated from the refrigerant and introduced to the lubrication system contains a certain amount of the refrigerant, so we can state that the compressor elements are lubricated with the mixture of oil and refrigerant of properties being surely worse than the ones of pure lubricating oils.

In the days of changing old refrigerants to the new ones, being more environmentally friendly, it is very important to use them with the proper compressor oils. Apart from the mentioned requirement of “solubility,” it is also necessary to ensure the right anti-friction and anti-wear properties (concerning “oil–refrigerant” mixtures). That is why the paper analyses literature information on test stands, enabling us to make a quantitative evaluation of this problem, and there are formulated assumptions for the construction of our own universal testing device.

**INTRODUCTION**

The Montreal Protocol signed in 1987 and introduced in use in 1989 demanded the elimination of refrigerants of the CFC group according to the determined schedule and on longer period also the HCFC refrigerant in order to protect the ozone layer. In Poland the above directive is realised by the act concerning substance reducing the ozone layer [L. 1], determining among others, the date to which the application of the determined refrigerant is allowed. The refrigerant of the HCFC group (e.g. R22) can be applied only till the end of 2009, whereas the restored and regenerated refrigerant of this group can be applied till the end of 2014 unless the European Committee shortens the term [L. 2]. At present, the refrigerant being safe for the environment are introduced and they substitute the ones being withdrawn from the market.

There are some basic requirements concerning oils applied in refrigeration systems (lubrication, cooling) but also many others at different parameters of the refrigeration installation. The basic problem is the application of oil being solidification resistant in low temperatures occurring in the evaporator. Oils must be oxidation resistant and cannot cause carbon deposit and sludge collection. Besides, they should characterize with proper purity and small acid value. Further, oil miscibility with the refrigerant should be checked as well as oils compatibility with refrige-
rants. Moreover, oils must have the right lubricating properties ensuring the creation of an oil film on friction elements as well as the ability to return from the refrigeration system to the compressor. Oil should also have certain hygroscopicity due to the possibility of water appearance in the system [L. 3].

Now, there are many new refrigerants on the market. Apart from proper thermodynamic properties they should also characterise with the following features: chemical inertness in relation to lubricating oils and construction materials in the device, ability to dissolve a small amount of water, zero value of ozone destroying potential (ODP), possible low potential of the greenhouse effect creation GWP (Global Warning Potential referred to carbon dioxide GWP = 1) and a very important property, namely the refrigerant should be able to create a mixture with lubricating oil.

TRIBOLOGICAL STAND TESTS OF REFRIGERATION COMPRESSORS MOVING PAIRS

The list of literature contains works in which they analyse the elements wear in the atmosphere of the refrigerant in the presence of lubricating oil [L. 4–16]. The authors use various test stands. During the tests, they usually use the tribological system of the pin-on-disc type. All the devices are situated in special chambers ensuring the influence of the refrigerant and oil on the moving elements wear. The friction pairs can be subjected to the right pressures and speeds. The refrigerant pressure and temperature in the chamber can be controlled (Table 1).

The Table 1 contains the collection of the most important information on the valid stand tests concerning elements of the refrigeration compressors operating in the atmosphere of the oil and refrigerant mixture. The table presents: measurement stand, kind of motion occurring on the stand, testing environment (oil, refrigerant), materials of the friction pair, measurement parameters (pressure, temperature, speed, time), measured values and methods applied to determine them. In order to determine the wear mechanisms in the refrigeration compressors they usually used the following auxiliary measurements: electron scanning microscopy (SEM), Aguer’s electron spectroscopy (AES), X-ray spectroscopy (EDX), X-ray photoelectron spectroscopy (XPS). These methods enable the determination of the chemical constitution of worn surfaces and wear products.


<table>
<thead>
<tr>
<th>Kind of motion</th>
<th>Stand scheme</th>
<th>Source</th>
<th>Refrigerant</th>
<th>Compressor oil</th>
<th>Construction materials</th>
<th>Measuring parameters</th>
<th>Auxiliary methods</th>
<th>Purpose of measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>rotation and pulsation</td>
<td>[4]</td>
<td>R134a</td>
<td>MO AB PAO PAG POE</td>
<td>Steel/steel</td>
<td>3.58 6.792 10.8</td>
<td>70 45 0.94</td>
<td>GZ ST WT</td>
<td>SEM PP</td>
</tr>
<tr>
<td>rotation and pulsation</td>
<td>[5]</td>
<td>CO2</td>
<td>PAG POE</td>
<td>Grey cast iron/ tool steel</td>
<td>0.5 1 1.5</td>
<td>500 0.725 2.85</td>
<td>7200 GZ WT</td>
<td>AES SEM Vickers’</td>
</tr>
<tr>
<td>rotation and pulsation</td>
<td>[6]</td>
<td>R134a</td>
<td>POE</td>
<td>Grey cast iron/grey cast iron AI390-Tb65200</td>
<td>0.172 from -10 to 130</td>
<td>88.9 2.4 600</td>
<td>Test performed till scuffing</td>
<td>SEM AES Vickers’ Rock- well’s</td>
</tr>
<tr>
<td>Experiment</td>
<td>Lubricant</td>
<td>Type</td>
<td>Notes</td>
<td>Temperature</td>
<td>Wear</td>
<td>Physics</td>
<td>Method</td>
<td>Altitude</td>
</tr>
<tr>
<td>------------</td>
<td>---------</td>
<td>------</td>
<td>-------</td>
<td>------------</td>
<td>------</td>
<td>---------</td>
<td>--------</td>
<td>----------</td>
</tr>
<tr>
<td>[7]</td>
<td>R134a</td>
<td>POE</td>
<td>(100/102Cr6)/LM13AE109</td>
<td>0.8-4</td>
<td>5-110</td>
<td>5</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>[8]</td>
<td>R134a</td>
<td>POE</td>
<td>PTFE/ grey cast iron</td>
<td>0.172</td>
<td>60</td>
<td>45-225</td>
<td>2.4</td>
<td>600</td>
</tr>
<tr>
<td>[9]</td>
<td>CO2-R410A</td>
<td>POE</td>
<td>A1390-T652100</td>
<td>0.34-1.4</td>
<td>60</td>
<td>222-3336</td>
<td>2.4</td>
<td>600</td>
</tr>
<tr>
<td>[10]</td>
<td>R410A</td>
<td>POE</td>
<td>Grey cast iron / tool steel</td>
<td>2</td>
<td>295</td>
<td>400</td>
<td>685</td>
<td>0.1425</td>
</tr>
<tr>
<td>[11]</td>
<td>R134a</td>
<td>PAG</td>
<td>A1390-T652100</td>
<td>0.17</td>
<td>121</td>
<td>222.5 (co 15s +222.5N do zatarcia)</td>
<td>2.4</td>
<td>600</td>
</tr>
<tr>
<td>Rotation and position</td>
<td>12</td>
<td>R600a</td>
<td>MO</td>
<td>AISi6S/100C6</td>
<td>277</td>
<td>75</td>
<td>30</td>
<td>0.05</td>
</tr>
<tr>
<td>----------------------</td>
<td>----</td>
<td>-------</td>
<td>----</td>
<td>--------------</td>
<td>-----</td>
<td>----</td>
<td>----</td>
<td>------</td>
</tr>
<tr>
<td>rotation and position</td>
<td>13</td>
<td>R407C</td>
<td>POE</td>
<td>--</td>
<td>3.4</td>
<td>21-22</td>
<td>54</td>
<td>2.4</td>
</tr>
<tr>
<td>rotation and position</td>
<td>14</td>
<td>R134a</td>
<td>POE</td>
<td>--</td>
<td>4.9</td>
<td>20</td>
<td>70</td>
<td>0.09</td>
</tr>
<tr>
<td>rotation and position</td>
<td>15</td>
<td>--</td>
<td>POE</td>
<td>--</td>
<td>0.1</td>
<td>20</td>
<td>60</td>
<td>4.8</td>
</tr>
<tr>
<td>rotation and position</td>
<td>16</td>
<td>R134a</td>
<td>POE</td>
<td>--</td>
<td>1.6</td>
<td>81</td>
<td>118</td>
<td>45-450</td>
</tr>
</tbody>
</table>

**Notes:**
- MO: Temperature in °C
- AISi6S/100C6: Composition
- R600a, R407C, R134a: Refrigerants
- POE: Oil used
- CO2, Air, N2, H2: Gases
- Grey cast iron, grey cast iron
- SEM: Scanning Electron Microscopy
- EDX: Energy Dispersive X-ray
- AES: Auger Electron Spectroscopy
- XPS: X-ray Photoelectron Spectroscopy
- SOD: Surface Optical Properties
- EDX: Energy Dispersive X-ray
- Rema's grade: 499
- Grey cast iron / SKH51
- Steel / 12Cr1M0/5C/2100
- Grey cast iron / tool steel

**Diagrams:**
- Diagrams of different rotation and position configurations.
The authors of many analysed works [L. 6, 8–9, 11, 13, 16] used the same stand for their tests (Tab. 1). It made possible to apply power in the range from 45N to 4450 N. The disc could rotate with maximum speed 2000 rps and it could oscillate. There was the possibility to control the chamber temperature in the range from -20°C to 130°C with the use of liquid flowing through the upper rotating roller. The temperature was controlled by the outer thermostat. The chamber could work under pressure from 27 Pa to 1.72 MPa. The friction process was controlled with the computer. The friction element was the disc with the pin. The pin dimensions were: the diameter – 6.4 mm and the length – 8.8 mm. In order to locate a thermocouple in the pin, there was made a hole of 1 mm situated in the distance of 2 mm from the surface. The disc diameter was 75 mm, and its thickness was 6.4 mm.

The second stand (Tab. 1) enabled the authors of the works [L. 5, 10, 15] to test the wear of materials applied in rotary (blade) compressors in the friction pair created by the compressor blades and body. The used friction machine had a pressure chamber designed for maximum pressure being 20 bar. For the wear tasks they applied samples made of materials used for the production of the real compressor blades and bodies which ensured the reflection of such properties like hardness and roughness.

The tests presented in the work [L. 7] were carried out on a modernised machine Phoenix TE77. This device is based on the longitudinal motion of the pin or ball on the plate in the oil bath. The used friction connection models the pair of the hermetic compressor.

The work [L. 4] presents tests of the materials of which crankshaft bearings in piston compressors are made. The test stand was a friction machine with a high-pressure chamber where samples being in the refrigerant polluted oil bath were static loaded. The loading value was chosen so that its dynamic character referred to real compressors.

The article [L. 14] presents the situation where for the wear test they used a modified machine Falex in which a linear contact is obtained in the friction pair. The samples covered with coatings applied in the rotary compressors were located in the high-pressure chamber.

The authors of the works [L. 12] presented tests of the friction pairs of the block-on-ring type; the tests aimed at determining the wear value in the pair: crankshaft neck – connecting rod big end in the piston compressors. Beside the chemical constitution of worn surfaces and wear products they also analysed the influence of wear on hardness of mating materials.
3. DESIRED PARAMETERS OF OWN STAND

The Institute of Machines and Motor Vehicles of Poznań University of Technology plans to create a universal test device for a quantitative evaluation of anti-wear and anti-friction properties of mixtures: oil – refrigerant. In order to reflect conditions being in real systems the desired parameters of the own stand have been determined (Tab. 2).

Table 2. Desired parameters of own stand
Tabela 2. Pożądane parametry własnego stanowiska

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Kind of motion (pair)</th>
<th>rotation and pulsation</th>
<th>reciprocating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading range [N]</td>
<td>from 45 to 4450</td>
<td>from 5 to 20</td>
<td></td>
</tr>
<tr>
<td>Zakres prędkości względnych [m/s]</td>
<td>from 0.1425 to 2.85</td>
<td>from 0.098 to 0.13</td>
<td></td>
</tr>
<tr>
<td>Temperatures of working refrigerant [°C]</td>
<td>from -10 to 130</td>
<td>from 5 to 110</td>
<td></td>
</tr>
<tr>
<td>Pressures of working refrigerant [MPa]</td>
<td>0-10.8</td>
<td>from 0.8 to 4</td>
<td></td>
</tr>
<tr>
<td>Measured values describing the process</td>
<td>friction force, wear, electric resistance of contact</td>
<td>friction force, wear</td>
<td></td>
</tr>
</tbody>
</table>

Parameters specified in Table 2 are minimum values (ranges) for the desired parameters of built stand. An important aim is also to adapt this stand to size and shape of the samples which enables them to analyze the chemical composition of worn surfaces and wear products using the most popular spectrometers (SEM, AES, EDX). Currently completing loading component research device that meets the criteria on the research parameters set out in the paper.

CONCLUSION

At present, there is no universal oil for refrigeration compressors. Oil should be chosen for the suitable compressor and refrigerant. Due to more severe rules concerning the application of refrigerants the new refrigerant appear. The influence of the mixture of new refrigerant and oils on the wear of the compressor elements should be investigated. For this reason, the construction of the stand pin-on-disc type is foreseen. The stand will be equipped with the chamber for testing the wear of the moving pairs in the presence of oil and refrigerant. For modelling the compressor operation conditions the chamber will be able to control the re-
frigerant pressure and temperature in order to control the state of the re-
frigerant phase. Besides, the possibility to control pressure force and pin
speed is planned. Also, detailed wear tests in the atmosphere of different
refrigerants are intended to be performed.

LITERATURE

1. Dz.U.2004.121.1263 z 20 kwietnia 2004. Ustawa o substancjach zubażają-
cych warstwę ozonową.
2. Florek R., Rzeszewski S.: Przegląd i analiza własności zębów w świetle
regulacji Protokołu Montrealskiego (cz. I – Wprowadzenie), Chłodnictwo
czynniki chłodnicze i nośniki ciepła. Własności cieplne, chemiczne i użytko-
4. Byung Chul Na, Keyoung Jin Chun, Dong-Chul Han: A tribological study
of refrigeration oils under HFC-134a environment. Tribology Interna-
tional, 30(9), 1997, s. 707–716.
5. Hong-Gyu Jeon, Se-Doo Oh, Young-Ze Lee: Friction and wear of the lub-
ricated vane and roller materials in a carbon dioxide refrigerant. Wear,
267 (5-8), 2009, s. 1252–1256.
and Al390-T6 materials used in compressor applications. Wear, 260(7-8),
2006, s. 735–744.
7. Garland Nigel P., Hadfield M.: Tribological analysis of hydrocarbon re-
frigerants applied to the hermetic compressor. Tribology International,
38(8), 2005, s. 732–739.
8. Cannaday M.L., Polycarpou A.A.: Tribology of Unfilled and Filled Poly-
meric Surfaces in Refrigerant Environment for Compressor Applications.
Tribology Letters, 19(4), 2005, s. 249–262.
refrigerant of tribologically tested Aluminum 390-T6 surfaces. Tribology
Letters, 21(3), 2006, s. 185–192.
10. Lee Young-Ze, Se-Doo: Friction and wear of the rotary compressor vane–
roller surfaces for several sliding conditions. 255(7–12), 2003, s. 1168–
1173.
11. Yoon H., Sheiretov T., Cusano C.: Scuffing behavior of 390 aluminum
against steel under starved lubrication conditions. Wear, 237(2), 2000,
s. 163–175.
12. Birol Y., Birol F.: Sliding wear behaviour of thixoformed AlSiCuFe al-
Streszczenie

Pożądaną cechą oleju smarującego sprzężarki chłodnicze jest rozpuszczalność w czynniku chłodniczym w pełnym zakresie temperatur roboczych. Umożliwia to powrót większości oleju „wypompowanego” do obiegu chłodnicznego do układu smarowania. Olej wydzielony z czynnika i wprowadzony do układu smarowania zawiera jednak pewną ilość, zatem można uznać, że elementy sprzężarek smaruje mieszanina oleju i czynnika chłodniczego o własnościami z pewnością gorszych niż własności czystych olejów smarowych.

W dobie wymiany starych czynników chłodniczych na nowe, bardziej przyjazne środowisku, duże znaczenie ma ich kojarzenie z odpowiednimi olejami sprzężarkowymi. Obok wspomnianego wymogu „rozpuszczalności” konieczne jest zapewnienie również odpowiednich własności przeciwtarczowych i przeciwzużyciowych (mieszanin „olej–czynnik chłodniczy”). Dlatego w referacie przeanalizowano informacje literaturowe o stanowiskach badawczych pozwalających ilościowo oceniać ten problem i sformułowano założenia do budowy własnego, uniwersalnego urządzenia badawczego.