Confinement and Avoidance of Lubricants in Reciprocating Compressors

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1. ABSTRACT

The content of lubricant in a compressed gas leaving compressor should be either limited to a minimum or restricted to zero what would be the best condition for some new refrigerants. The desired limit of lubricant content can be reached either by means of an oil separator in discharge line of lubricated typical compressor or by confinement amount of lubricant supplied to the compressor with special system. The amount of lubricant in discharged gas can be reached zero only with application of non-lubricated compressor. A new technology of gas compression using reciprocating compressor in which cylinder and piston rings are specially designed and modified for stable operation while either confined lubrication or entire avoidance of lubricant were examined [1] is presented and discussed in the paper.

2. INTRODUCTION

Reduction of lubricant discharged by a compressor to the ambient air or into the inside of refrigerating installation, particularly to a condenser and an evaporator, can be reached by proper reduction of amount of oil fed for lubrication. Some former experimental investigations proved that the most promising method for confinement of lubricant amount in the gas leaving compressor is a periodical dosage of small portions of lubricant sprayed just over the working surface of the cylinder. On the other hand this method gives possibility to dose precisely defined small portion of lubricant. This is very important because experimental observations proved that in the range of so called limiting friction and mixed friction phenomena the additional portion of lubricant causes sudden drop of friction factor of the sliding surfaces. On the basis of this observation the hypothesis was formulated that there is a close correlation between friction factor and temperature of surfaces in sliding friction [2]. The correlations for three sliding material associations are shown on the graph (Fig. 1).

3. SLIDING FRICTION IN A CYLINDER

To confirm this hypothesis experimental investigations were made with three different sliding associations applicable in compressors. Our diagnostic experiments were made with an open-type twin-cylinder air compressor with automatic dosage of lubricant. Compressor cylinder diameter was 65 mm, rotational speed 1400 rpm, and discharge pressure was 0.2 MPa. Dosage of lubricant was
controlled by a temperature of sliding cylinder surface $t_0$ a representative parameter expressing thermal characteristic of a compressor. When the temperature rised to an arbitrary chosen value $t_g$ the dose of 4.0 mg of lubricant mist was sprayed over cylinder bearing surface and temperature dropped down again to previous value $t_0$. Then the feeding of lubricant stopped until the next temperature rise to $t_g$. In our investigations we accepted the rise of temperatures: $t_g = t_0 + (1.0 \text{ and } 1.6) \text{ K}$.

\textbf{Fig. 1.} Temperature and friction factor versus lubricant layer

\textbf{Fig. 2.} Friction factor versus dimensionless layer thickness

The other data of the experiments and important results are given in Tables I and II [3]. It is evident from the Table II that the best results were reached with sliding association PTFE-modified used for pistons and aluminum oxide layer on working surface of the cylinder made of aluminum alloy. The oxide layer was made using the electrolytic oxidation method. The achieved layer thickness was 80 to 100 $\mu $m and was accompanied with adequate friction characteristic parameters such as: hardness, grindability, anticorrosivity, adhesion and wettability of lubricating oils.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
\textbf{Sliding association} & \textbf{Cylinder bearing surface material} & \textbf{Piston ring material} \\
\hline
I & cast iron & cast iron \\
II & cast iron & modified PTFE \\
III & aluminum oxide & modified PTFE \\
\hline
\end{tabular}
\caption{Sliding associations of materials in cylinder}
\end{table}
<table>
<thead>
<tr>
<th>Sliding association (Table I)</th>
<th>Number of doses per 100 hours</th>
<th>Mass of lubricant [mg]</th>
<th>Mass of lubricant in suction line [mg/cub.m of air]</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>250</td>
<td>1025</td>
<td>1.5</td>
</tr>
<tr>
<td>II</td>
<td>94</td>
<td>385</td>
<td>0.5</td>
</tr>
<tr>
<td>III</td>
<td>8</td>
<td>33</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Piston rings in our research work were made of modified PTFE. 15% of graphite and 2.5% of molybdenum disulphate were used as modifying components. With an increase of lubricant feeding the friction of applied sliding associations changed starting from limiting friction to mixed friction and finally to fluid friction character. The change of friction factor in relation to dimensionless thickness of lubricant layer is shown on the graph (Fig.2) where: \( h_R = h_{lubricant}/(h_1+h_2) \) the sum of roughness of both materials.

4. SLIDING WITH CONFINEMENT OF LUBRICANT

For different sliding associations (Table I and II) different dose rate of lubricant should be used. It depends on anticipated kind of material on sliding association and on roughness of sliding surfaces. Process of running-in of the couple of aluminum oxide with modified PTFE can occupy considerably long period of time ranging of 200 up to 800 hours. In this period of time aluminum oxide working surface becomes more and more smooth and friction factor in the range of limiting and mixed friction character decreases. In consequence it causes decrease of necessary thickness of lubricant layer for mixed friction as it is shown on Figure 2. Within the period of 10 minutes after spraying lubricant on aluminum oxide working surface the lubricant layer becomes equalized. Primary thickness of the layer is 3 \( \mu m \), next after 20 minutes decreases to 1.5 \( \mu m \), and then after one hour up to 1 \( \mu m \) and decreases more and more very slowly. Thanks to this phenomenon spraying of the next dose of lubricant may be done after a couple of hours. Impurities, products of wear while running-in sliding association, are removed with lubricant.

5. SLIDING WITH TECHNICALLY DRY FRICTION

The association of aluminum oxide and PTFE offers a possibility to avoid lubrication in cylinder of a compressor and to discharge gas free of lubricant. Large wearing of PTFE noticed in such case at the initial period of working sliding becomes slowly smaller with the further laps of time and after 100 to 200 or so hours stabilizes and becomes insignificant. Next the basic period comes which is characteristic for operation time of a compressor and can last up to
dozen or so thousands hours as it was established in our investigations up to now. Constant reduction of wearing of the solid sliding aluminum oxide layer was observed during this period of time till to almost complete disappearance. Sliding association comes then into condition with substantial traces of wearing both of aluminum oxide surface and PTFE piston rings together with the lowest value of friction factor.

6. INVESTIGATIONS OF COMPRESSORS IN OPERATION

6.1. Air Compressors

Three compressors of air were redesigned using cylinders made of aluminum alloy and cylinder bearing surface covered with 80 \( \mu \text{m} \) electrolytic oxide layer of aluminum oxide. Piston rings specially designed for this purpose and made of PTFE are presented on schemes (Fig.3).

![Diagram of piston compressor](image)

**Fig.3.** New design of first and second stage piston compressor with piston rings made of PTFE and numbered I and II in Table IV.

Investigations of cylinders and piston rings wearing with the use of one cylinder and twin cylinder single-stage and double-stage compressors were performed in the conditions presented in Table III. The elaborated results are given in Table IV.
TABLE III
Compressor of air investigated for wearing

<table>
<thead>
<tr>
<th>Type 1</th>
<th>Single stage, twin-cylinder confined lubrication</th>
<th>Diameter of the cylinder 65 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 2</td>
<td>Single-stage, one-cylinder, technically dry friction</td>
<td>Discharge pressure 0.2 MPa Rotational speed 1450 rpm</td>
</tr>
<tr>
<td>Type 3</td>
<td>Double-stage, twin-cylinder, technically dry friction</td>
<td>Diameters of cylinders 72/32 mm Working pressures 0.1/2.0 MPa Rotational speed 1450 rpm</td>
</tr>
</tbody>
</table>

TABLE IV
Results of investigations

<table>
<thead>
<tr>
<th>Compressor</th>
<th>Wearing of cylinder surface µm/1000 km</th>
<th>piston rings mg/1000 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>1.5</td>
<td>70 to 140</td>
</tr>
<tr>
<td>Type 2</td>
<td>0.33 to 0.72</td>
<td>25</td>
</tr>
<tr>
<td>Type 3</td>
<td>I-stage: 0.33, II-stage: 1.7</td>
<td>see below</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mass wearing of piston rings in compressor Type 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring No</td>
</tr>
<tr>
<td>%/1000 hrs</td>
</tr>
</tbody>
</table>

6.2. Refrigerant Compressors

Preliminary investigations were made with twin-cylinder compressors operating in refrigerating cycle in different conditions performed at the laboratory stand. There were two single-stage compressors: first compressor I and second compressor II, both of open-type redesigned for experiments with cylinder diameter 58 mm and 66 mm speed of 850 and 1400 rpm respectively. The stands with R12 were equipped with air cooled condensers and a brine chilling apparatus. The results of investigations are given in Table V.

TABLE V
Results of investigations of refrigerant compressors

<table>
<thead>
<tr>
<th>Parameters of operation</th>
<th>Characteristics</th>
<th>Full lubrication</th>
<th>Confined lubrication</th>
<th>Dry sliding association</th>
</tr>
</thead>
<tbody>
<tr>
<td>[t&lt;sub&gt;ev&lt;/sub&gt;/&lt;t&lt;sub&gt;amb&lt;/sub&gt;]</td>
<td>[D&lt;sub&gt;cyl&lt;/sub&gt;/stroke] = (58/52) mm</td>
<td>I compressor</td>
<td>II compressor</td>
<td>[D&lt;sub&gt;cyl&lt;/sub&gt;/stroke] = (66/23) mm</td>
</tr>
<tr>
<td>[-11/+20]°C</td>
<td>Chilling capacity</td>
<td>3250 W</td>
<td>3575 W</td>
<td>1660 W</td>
</tr>
<tr>
<td></td>
<td>Effective power</td>
<td>1270 W</td>
<td>1700 W</td>
<td>1260 W</td>
</tr>
<tr>
<td>[t&lt;sub&gt;ev&lt;/sub&gt;/&lt;t&lt;sub&gt;amb&lt;/sub&gt;]</td>
<td>[D&lt;sub&gt;cyl&lt;/sub&gt;/stroke] = (66/23) mm</td>
<td>I compressor</td>
<td>II compressor</td>
<td>[D&lt;sub&gt;cyl&lt;/sub&gt;/stroke] = (66/23) mm</td>
</tr>
<tr>
<td>[-23/+20]°C</td>
<td>Chilling capacity</td>
<td>2020 W</td>
<td>2163 W</td>
<td>mechanical sealing failure</td>
</tr>
<tr>
<td></td>
<td>Effective power</td>
<td>1360 W</td>
<td>1325 W</td>
<td></td>
</tr>
</tbody>
</table>
The thermodynamic characteristics were measured after 200 hours of continuous operation of the I compressor and after 70 hours of continuous operation of the II compressor. After 300 hours of operation wearing of the cylinder bearing surface was determined for compressor operating in confined lubrication condition. Cylinder number 1 of this compressor showed medium intensity of linear wearing 3 μm/1000 km, while cylinder number 2 showed wearing 1.8 μm/1000 km. The II compressor was inspected after 150 hours stable operating conditions and no particular changes of cylinder surfaces were observed. However the further experiment was stopped after 250 hours because of dry shaft mechanical sealing failure. The rest results of our investigations and not so preliminary with refrigerants will be reported after we finish our research work and we believe with success.

7. CONCLUSIONS

1. The results of our investigations indicate that the aluminum oxide cylinder bearing surface and PTFE piston rings can be used as sliding working association in reciprocating compressors of air, both with confined lubrication and technically dry sliding design.

2. There are premises verified to certain extend in our investigations that sliding association of aluminum oxide and PTFE can also be used in compressors for new refrigerants with both features of design: with confined lubrication and lubricant free.

3. To confirm this new possibility of design of oil-free compressors for application in refrigerating systems some design and technological problems have to be resolved yet. First of all non-lubricated mechanical sealing of open-type refrigerant compressors and some details with cooling electrical wiring in hermetic compressors.

8. REFERENCES