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ACCELERATED SCREENING METHODS FOR PREDICTING LUBRICANT PERFORMANCE IN REFRIGERANT COMPRESSORS

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ABSTRACT

As the result of a thorough literature search and consultation with manufacturers of compressors, a specimen testing program is proposed to simulate specific contacts in components of compressors. Specimen testing will be conducted using a high pressure tribometer. Specific components to be simulated, with their approximate operating and environmental conditions, are identified. A list of references, related to compressors lubrication, friction and wear, is given in the Appendix.

SCOPE

The scope of this report is to propose a specimen testing program which serves as a basis for recommending a bench tester to screen lubricants of refrigerant compressors.

PROPOSED SPECIMEN TESTING PROGRAM

A. Objective

The main objective of this report is to recommend a testing program which will aid in the selection of an effective bench tester for screening lubricants used in compressors of air-conditioning and refrigeration systems.

B. Introduction

In working toward a final recommendation for a bench tester, the following approach has been proposed:

1. Thoroughly search the open literature for tribological data, both component and specimen, related to compressors of air-conditioning and refrigeration systems.

2. Interact with compressors manufacturers to determine which components are more likely to have tribological problems in practice.

3. Collect from the manufacturers as much tribological data as possible about these critical components. Among these data could be type of tribological failures, approximate operating and environmental conditions under which these failures occurred, materials in contact, contact geometry and surface topography.

4. From the data collected, select representative contact geometries to be tested. The maximum number of contact geometries would be four, i.e., point, line, conformal and area.

5. With input from manufacturers of compressors, select oils to be screened and refrigerants to be used.

6. Test the contact geometries with selected oil-refrigerant mixtures, using the high pressure tribometer simulating as closely as possible the operating and environmental conditions experienced by the corresponding components in the compressors.

7. Tribological effectiveness of each oil-refrigerant mixture will be compared to data obtained from component tests. If the latter tests do not exist, it is hoped that the compressors manufacturers, who have cooperated in Steps 2, 3 and 5 above, will conduct these tests, with the same oil-refrigerant mixtures, for comparison purposes.

8. Recommendations concerning a specific bench test facility which can be used for accelerated oil screening will be based on the correlation obtained in Step 7.

This report focuses on items 1 through 5 since this portion of the research program is nearly complete. These items will be briefly discussed below in the order listed.

The literature search has been completed and a list of references pertinent to the lubrication of compressors of air-conditioning and refrigeration system is given in the Appendix. This list excludes those references which are already listed in the ARTI refrigerant database. As expected, in this area, the number of references in the open literature is rather limited.

In order to better understand future lubricity problems envisioned by compressor manufacturers, as well as present method for screening lubricants and testing compressors, four manufacturers were visited. These visits were to Trane on 12/1/92 (Mr. Richard Ernst, host), Tecumseh on 12/14/92 (Dr. Keshav Sanvordenker, host), Carrier on 1/11/93 (Mr. William Walter, host) and Copeland on 1/12/93 (Mr. Sonny Sundaresan, host). In all of these visits, in addition to the hosts, a number of other people responsible for research, technology, design and reliability of screw, scroll, rotary and reciprocating compressors were present during the meetings. The

discussion mainly focused on lubrication failure modes of components, test methodologies used for approval of a lubricant and general lubrication requirements in compressors. The objectives of this report are to give an overview of these visits and to suggest a testing program which will aid in the selection of an effective bench tester for screening lubricants.

C. General Observations Derived From Visits

1. Tribological Components. In compressors of air-conditioning and refrigeration systems, there are numerous tribo-contact pairs which may fail. Some of the more critical of these contact pairs are:

   a. Wrist pin-bearing contact in reciprocating compressors.

   b. Vane-roller contact in rotary compressors.

   c. Thrust bearing-Oldham coupling, involute flanks and tip seals contacts in scroll compressors.

   d. Male-female rotors interface and slide valve contacts in screw compressors.

A number of other tribo-contacts, such as those found in journal bearings and especially those in rolling element bearings, are presently not perceived as being problem areas.

2. General Lubrication Requirements and Test Methodology. Past lubrication performance, using mineral or alkylbenzene oils, has not been of great concern to manufacturers of compressors. These lubricants performed well with both R-12 and R-22 and decisions concerning which oil to use were often based on price rather than their lubricity. As the result of miscibility problems of these oils with ozone-safe refrigerants, a major effort is underway to identify synthetic lubricants which can be used with such refrigerants. The main lubricant candidate at this time is the ester family, especially pentaerythritol ester. A number of steps are followed in selecting a lubricant for a compressor. These steps can vary somewhat depending on the manufacturers. However, many of the steps are quite similar among the companies visited. A representative set of chronological steps is given below.

   a. Initial lubricant screening using specimen testers. Even though most of this screening is done in-house, independent laboratories are also used. The most popular bench tester is the Falex pin and vee block with refrigerants fed through the oil. Tests are generally conducted at atmospheric pressure in a controlled environment. Various materials combinations are used for the pin and vee block. Other specimen bench testers used are the four-ball and block-on-cylinder machines.

b. Accelerated or abuse testing using compressors. These tests can run from one to several months under various conditions. Tests at relatively high loads and/or high temperatures, or under refrigerant-rich, oil-refrigerant mixtures are the most common. After each test, the compressors are taken apart and critical tribo-contacts as well as the lubricant are carefully evaluated.

c. Limited field trials to observe lubricant performance under actual operating conditions.

d. After passing the steps above, the lubricant is accepted for general use.

e. As a general rule, it is preferable to use one lubricant for all compressors made by a manufacturer.

D. Specimen Testing Program.

As per the original proposal, the recommendation of a specimen bench tester to screen lubricants for compressors will be based on data obtained from a high pressure tribometer (HPT). The tribological evaluation will be based on friction and wear measurements plus examination of worn surfaces by means of X-ray Photoelectron Spectroscopy (XPS). The main advantage of the HPT over more standard bench testers is its capability of providing a controlled pressure and temperature environment during a test. Complexity and high costs are its main disadvantages. The emphasis of the testing program is to determine if the HPT can accurately predict lubricant performance in compressors by conducting tests under conditions which approximately simulate component operation. In order to determine if simpler and/or less costly bench testers can predict lubricant performance to the same degree as the HPT, a comparison will be made between data obtain on the Falex pin and vee block tester and the HPT to those obtained from component (compressor) testing. A detailed description of the proposed testing program is given below.

1. Compressors and their Critical Contents to be Studied. Even though not all data are presently available, the following compressors and tribo-contacts are the main candidates for study in this program:

   a. Reciprocating compressor: conformal contact of wrist pin and bearing.

   b. Rotary compressor: counterformal contact of vane and roller.

   c. Scroll compressor: area contact of thrust bearing and Oldham coupling.

   d. Screw compressor: counterformal contact of male and female rotors.

2. Oil-Refrigerant Mixtures to be Tested. Baseline data will be obtained by using R-12 and R-22 with mineral or alkylbenzene oils. The specific oils which will be used will correspond to those which have been or are being used in each compressor. The new oil-refrigerant mixtures will be mainly composed of R-32 blends and R-134a with ester oils, especially the pentaerythritol ester. Again, the specific oil-refrigerant mixture which will be used in the specimen testing program will be the same as the mixture used to obtain component data from compressor tests.

3. Materials for Contact Pairs. Since data obtained from the HPT will be compared to data obtained from Falex pin and vee block as well as to those obtained from component testing, two separate set of material contact pairs will be examined since materials used for the Falex tests might not correspond to those used in the actual components. To compare results obtained from the HPT to those of the Falex, the following material contact pairs will be tested:

   a. 380 die cast aluminum with hardened steel.

   b. 380 die cast aluminum with gray cast iron.

   c. Hardened gray cast iron with hardened steel.

   d. Hardened steel with hardened steel.

   The line contact geometry, load and oil-refrigerant mixture used in obtaining the Falex data will also be used to get data from the HPT. The latter data, however, will be obtained under environments and kinematic conditions which are more representative of actual components operation.

   To compare results from the HPT with those obtained from compressor testing, the following material contact pairs will be tested:

   a. 380 die cast aluminum with hardened steel, in a conformal contact, to simulate the wrist pin-bearing contact of reciprocating compressors.

   b. Mild steel with itself, in a line contact, to simulate the male-female rotors interface of screw compressors.

   c. Sintered ferrous metal with itself, in a line contact, to simulate the vane-roller contact in rotary compressors.

   d. Mild steel with Norplex, in an area contact, to simulate the thrust bearing-Oldham coupling in scroll compressors.

   All the operating and environmental conditions for the materials contact pairs above will approximately simulate component operation.

4. Operating and Environmental Conditions. Approximate operating and environmental conditions which will be used to test the contacts under item 3 above are given below.

Operating and Environmental Conditions	Wrist Pin-Bearing Contact: Reciprocating Compressor	Male-Female Interface Contact: Screw Compressor	Vane-Roller Contact: Rotary Compressor	Thrust Bearing-Oldham Coupling Contact: Scroll Compressor
Pressure or Load/Unit Length	2500 psi	40 - 120 lb/in.	1300 lb/in.	330 psi
Type of Motion	Oscillatory	Unidirectional	Oscillatory	Oscillatory
Speed	14 in./s (max)	40 - 80 in./x	20 in./s (max)	20 in./s (max)
Angular Amplitude	± 50°	----	----	----
Angular Frequency	58 Hz	----	----	29 - 58 Hz
Environ. Pressure	4.5 - 7 psi	50 - 400 psi	225 psi	85 psi
Environ. Temp.	325 - 350°F	50 - 250°F	175°F	50°F

It should be noted that not all of these operating and environmental conditions can be simulated in the HPT. The maximum operating temperature and pressure of the HPT are 300°F and 250 psi, respectively, while the maximum angular frequency is 5 Hz. It is felt, however, that these discrepancies will not significantly affect the results and conclusions drawn from this research program. For the purpose of repeatability and to effectively compare data obtained using different lubricants, all tests will be conducted such that the sliding contacts are submerged in the lubricants. Finally, the information given in this report is not complete since all the data requested from the various manufacturers of compressors have not been received or are not available at this time. It is hoped that these data can be obtained in the near future.

COMPLIANCE WITH AGREEMENT

The University of Illinois at Urbana-Champaign has complied with all terms of the grant agreement.

PRINCIPAL INVESTIGATOR AND STUDENTS EFFORT

Cristino Cusano (Principal Investigator) has denoted approximately 10 hours a week to this project.

Carl Poppe and Hyung Yoon have each devoted approximately 20 hours a week to this project. A large proportion of the students' time was spent on familiarization with the high presure tribometer, designing specimen holders, designing the instrumentation to measure the contact resistance between the rubbing specimens and thinking about designing the experiments.

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