TRIBOLOGICAL STUDIES OF COMPRESSOR SURFACES IN THE PRESENCE OF CARBON DIOXIDE UNDER EXTREME ENVIRONMENTAL PRESSURE CONDITIONS

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ABSTRACT
The refrigeration industry has shown an inclination towards the use of carbon dioxide (CO₂) as a refrigerant in some applications. While extensive thermodynamic studies exist, tribological studies with CO₂ are limited and tribological testing has further been restricted to low environmental pressures up to 1.38 MPa (200 psi) due to limitations in equipment capabilities. In this work, experiments were performed using an Ultra High Pressure Tribometer (UHPT) that was custom designed and built for tribological testing of compressor contact interfaces at very high environmental pressures up to 13.8 MPa (2000 psi). These tests demonstrate the possibility of testing at very high pressures similar to the internal pressures of CO₂ compressors.

1. INTRODUCTION
The interest shown in CO₂ can be attributed to the fact that it is an environmentally friendly, non-flammable, nontoxic, and economical alternative to harmful hydrofluorocarbon refrigerants (HFCs) [1]. Carbon dioxide has long been a viable refrigerant from a thermodynamic viewpoint and has been used in the past, but its applicability to refrigeration systems was limited because CO₂ systems have to be operated at very high pressures. While modern compressor designs have eliminated problems regarding design criteria so that they can safely be operated at high pressures, scuffing remains a major concern inside a compressor. Scuffing is a surface failure that has been documented to be a complicated process that goes through several stages and transitions [2, 3]. Scuffing initiates rapidly and usually leads to complete destruction of the sliding pair rendering the device nonfunctional. Therefore, there is a need for basic tribological understanding related to CO₂ environment.

In this work, controlled experiments in a CO₂ environment at different pressures were performed under constant normal loads. The effects of using CO₂ as a refrigerant on the tribological behavior of surfaces in contact in air conditioning systems were investigated at realistically higher pressures up to 6.9 MPa.

2. EXPERIMENTAL SETUP
The UHPT is specifically built for tribological testing at very high pressures and uses a lower stationary sample in contact with an upper rotating sample. The geometric configuration of the setup allows performing controlled friction, wear and scuffing experiments using compressor components under realistic compressor conditions, i.e., in the presence of refrigerant and lubricant in the boundary and mixed lubrication regimes. The test chamber is contained in a pressure housing capable of testing from atmospheric conditions to 13.8 MPa. Using a combination of heating and cooling elements, environmental chamber temperatures from 10°C to 100°C can be attained. The maximum recommended load for this machine is 4450 N. The maximum unidirectional rotational speed is 2000 rev/min, which for the geometry used in this work corresponds to a sliding linear speed of 5.3 m/sec. The UHPT is equipped with computer control of the axial load and the rotational velocity of the specimen and it can measure in-situ friction force, normal load, near-contact temperature and electrical contact resistance. A photograph of the UHPT is shown in Figure 1 with the inset of the photograph showing the contact geometry. A pin-on-disc contact geometry was used for the experiments in this study. The material combination used was AL390-T6 for the disk and 52100 steel for the pin. These are common materials used in automotive air-conditioning compressors.

Before initiating a test, the samples were pre-screened both optically and using a contact profilometer, to ensure they have minimal surface damage from scratches. The samples had an initial surface roughness (Rq) of 0.3-0.5 μm. Subsequently, the samples were immersed in a pool of acetone and ultrasonically cleaned, then rinsed with alcohol and dried using warm air. After the tribological testing the samples were again...
ultrasonically cleaned and used for wear quantification and surface topography measurements.

3. EXPERIMENTAL RESULTS

Typical experimental results of the wear tests performed using the UHPT are shown in Figure 2. In this figure, three 5-minute tests are shown. The first test was performed in atmospheric conditions without the presence of refrigerant. The second test was performed in the presence of CO₂ refrigerant at 4.1 MPa and the third test was performed at 6.9 MPa. For all cases a small amount of PAG lubricant (ISO VG 46) was used to ensure boundary lubrication conditions. The lubricant was applied directly to the surface by means of an absorbing medium.

![Figure 1. Ultra High Pressure Tribometer (UHPT).](image)

**Figure 1. Ultra High Pressure Tribometer (UHPT).**

0.086 when refrigerant was used. Furthermore, CO₂ refrigerant at the higher pressure of 6.9 MPa seems to be better than in the case of 4.1 MPa since the coefficient of friction was observed to be lower (average value of 0.049).

The electrical contact resistance (ECR) gives an indication of the state of lubrication at the interface. Specifically, if the samples are fully separated (by air or lubricant), the contact resistance is infinite. On the other hand, if the asperities experience significant contact, the contact resistance should theoretically be zero. A contact resistance of $10^{-2}$ ohms implies that a significant number of asperities are contacting, while $10^2$ ohms indicates that fewer asperities are contacting. These numbers are empirical and only relevant to the instrumentation and sensors in our laboratory. The ECR in Figure 2 (c) is constant throughout the duration of the experiments. This indicates that in all three cases, boundary lubrication conditions prevailed as the ECR was between $10^{-2}$ and $10^2$ ohms.

After the tribological testing described above, contact profilometry was used to examine the wear tracks on the disks. Since only minor burnishing took place, wear could not be used as an additional indicator for the tribological performance of CO₂. Quantifiable wear could have been obtained if the test duration was longer and/or higher normal load was applied in the contacting interface. Such experiments are currently under investigation.

CONCLUSIONS

The tests in this work demonstrate that testing at very high pressures similar to the pressures inside an automotive air-conditioning compressor is possible. Furthermore, these tests indicate that CO₂ at higher pressures has a positive effect on the tribological performance. This is a very important step in tribological testing in the presence of CO₂ that has not been undertaken before and will provide insight on the tribological behavior of CO₂ at very high pressures.

ACKNOWLEDGEMENT

This research work was supported in part by the National Science Foundation and the 30 member companies of the Air Conditioning and Refrigeration Center, an Industry-University Cooperative Research Center at the University of Illinois at Urbana-Champaign.

REFERENCES