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Short communication

Friction and wear of the lubricated vane and roller materials in a carbon dioxide refrigerant

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ABSTRACT

Due to environmental concerns, carbon dioxide (CO_2), a natural refrigerant, is an attractive alternative refrigerant to replace the current HFC refrigerants that are used in air conditioning systems. This paper investigated the friction and wear characteristics of sliding surfaces between a vane and an orbiting roller in a compressor in order to develop a new compressor, and especially a rotary type. The sliding tests were performed using various sliding speeds and refrigerant pressures. Two types of lubricants were used in these tests, namely POE (polyol ester) oil and PAG (polyalkylene glycol) oil.

The PAG oil under the CO_2 refrigerant had better lubricity than did the POE oil. It is believed that the amounts of the CO_2 refrigerant dissolved in the POE oil were larger than those dissolved in the PAG oil. As a result, the viscosity of the PAG oil was less reduced than that of the POE oil due to the dissolved CO_2 refrigerant. The reduction in the oil viscosity was associated with the formation of the relatively thin lubricating films on the sliding surfaces. Therefore, this thin film was associated with higher friction forces and rates of wear. Surface damage during the CO_2/POE tests was one of the reasons that the wear volume was increased in this specimen. The formation of a thicker oxide layer caused less wear on the surface of the pin. It is possible that as the pressure increased, the viscosity of the POE oil dropped and the lubricant film on the sliding surface became thinner. As a consequence, the friction and the wear increased as the real area of the metallic contact increased. However, the friction and wear were nearly constant regardless of the CO_2 pressure in the CO_2/PAG mixture environment.

1. Introduction

Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are widely used as refrigerants in cooling systems because these refrigerants are both mechanically efficient and low in cost. Moreover, they require minimal lubrication since these refrigerants contain chlorine, which reacts with iron surfaces and forms ferrous chloride layers [1]. However, it was previously revealed that CFCs and HCFCs used as refrigerants cause ozone depletion. HFCs have been used as alternative refrigerant for a few years, but they were also found to significantly contribute to global warming, so other gases have been proposed [2]. Water, ammonia, nitrogen and carbon dioxide (CO_2) are among the possibilities since they cause no harm to the global environment. Therefore, their application as refrigerants is positively investigated [3]. Among the natural substance, carbon dioxide is currently favored as an alternative refrigerant [4–6]. It is almost harmless and can be used with the conventional oils used in a compressor [7,8]. There was an investigation to compare the effects of R134a, carbon dioxide, nitrogen and oxygen environments within a non-lubricated condition as part of the tribological studies of the carbon dioxide environment. The result of these studies on a carbon dioxide environment showed a positive effect on surfaces due to the formation of a chemical film [10].

In this study, the effects of both POE and PAG lubricants, which have been used commercially as lubricants for compressors, on the tribological characteristics of the surfaces of a vane and a roller are evaluated by varying the sliding speeds and the operating pressures under a CO_2 refrigerant.

2. Experimental details

In a rotary type compressor, severe wear occurs on the contact surfaces between the vane and the orbiting roller within the driving part of the compressor. The pin-on-disk geometry was used in the sliding tests in order to evaluate the friction and the wear between the vane and the roller surfaces. The disks used in the tests were cut from the cylindrical bar of the roller material. The pin sample was also machined from the vane material that was used in the real compressor. The vane material was made of a high speed tool steel and it had a hardness in the range of 750–760 HV. The roller material was made of Ni–Cr–Mo gray cast iron and had a hardness in

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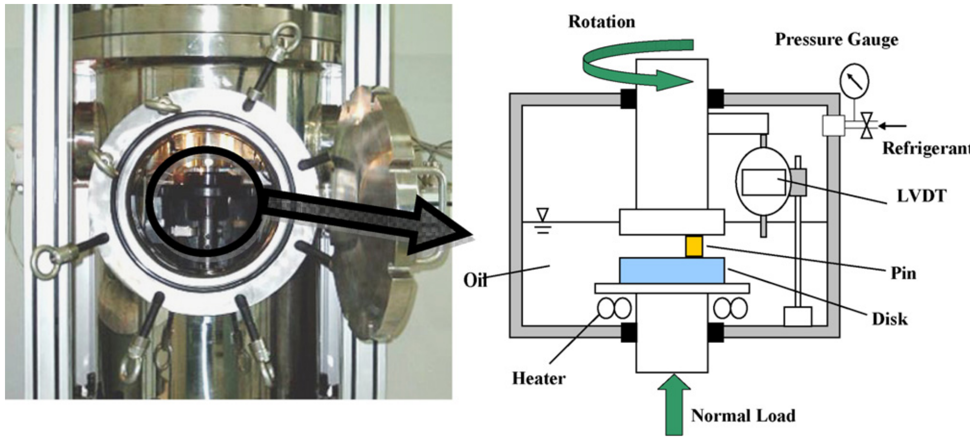

Fig. 1. Pin-on-disk type sliding tester.

the range of 550–580 HV. The surface of the roller disk was ground to have a roughness of 0.14 μm Ra, which was close to the original roughness of the roller. The radius of curvature of the pin (vane) tip was 4.9 mm and the thickness and the width of the pin were 4.7 mm and 9.5 mm, respectively.

The wear tester with its pin-on-disk geometry was installed in a high pressure chamber that was capable of sustaining pressures up to 2 MPa, as is shown in Fig. 1. The pin specimen was fixed to the upper shaft that produced rotation of the pin and the disk specimen was fixed on the lower shaft that produced a normal load onto the disk. The pin and disk specimens were submerged into a lubricant. The two types of lubricants used here were POE oil and PAG oil. These oils are used commercially as conventional compressor oils. The viscosity grades of the oils corresponded to ISO VG 100 (100 mPa s at 40 °C). The sliding tests were carried out using the repeated-pass sliding mode under various sliding speeds and various refrigerant pressures in both CO_2/POE and CO_2/PAG mixed environments. The load was kept constant at 500 N in these tests. Prior to testing, the oil bath in the chamber was filled with the lubricant, and then the refrigerant was charged to 0.5 MPa and it was allowed to dissolve in the lubricant for 30 min with an initial temperature of 50 °C. Then the sliding tests were performed under the various sliding speeds of 500 rpm (0.725 m/s), 1000 rpm (1.425 m/s) and 2000 rpm (2.85 m/s) in the CO_2/POE and CO_2/PAG mixed environments. The test duration was 2 h and multiple tests were conducted for each of the test conditions.

In order to study the influence of the operating pressure, high pressure tests were conducted at pressures of 0.5 MPa, 1.0 MPa and 1.5 MPa in the CO_2/POE and CO_2/PAG mixed environments. Even though the test pressures were lower than the operating pressure of the real compressor, these pressures were enough to monitor the influence of pressure on the oils. In order to accelerate the wear rate, the normal load and speed were set to 500 N and 2000 rpm, respectively during 2 h tests. This test conditions were determined from the initial preparation tests. These preparation tests were performed in order to determine the conditions where the amounts of wear of the vane materials could be monitored and to ensure that these conditions produced the same order of wear depth on the surfaces as compared to the tests results from a real rotary compressor after 500 h.

3. Results and discussion

The wear depth and the friction coefficients of the pin were measured according to the various rotating speeds under the CO_2/POE and CO_2/PAG mixed environments, as shown in Fig. 2. Increasing the speed led to a decrease of the wear depths despite the longer sliding distances. The friction coefficients also decreased as the speed increased. There were effects from elasto-hydrodynamic lubrication because the vane tip had a radius of curvature, which was 4.9 mm. The oil film thickness was affected by the sliding speed. As the speed increased, the film thickness increased, and this protected the sliding surface from severe wear and high friction. It is well known that full fluid lubrication is achieved when the sliding velocity is high enough [11].

From these tests, it is evident that the PAG oil in CO_2 refrigerant produced better lubricity than the POE oil. The amount of the CO_2 refrigerant dissolved in the same amount of the two types of oil was larger for the POE oil than it was for the PAG oil [8,11]. The viscosity of the PAG oil was not reduced as much as that of the POE oil due to mixing with the CO_2 refrigerant. The reduction of the viscosity produced a thin oil film that lead to the high friction and wear.

The worn surfaces of the disk tested at the 500 N load are shown in Fig. 3. Fig. 3a, there was some plastic deformation on the surfaces

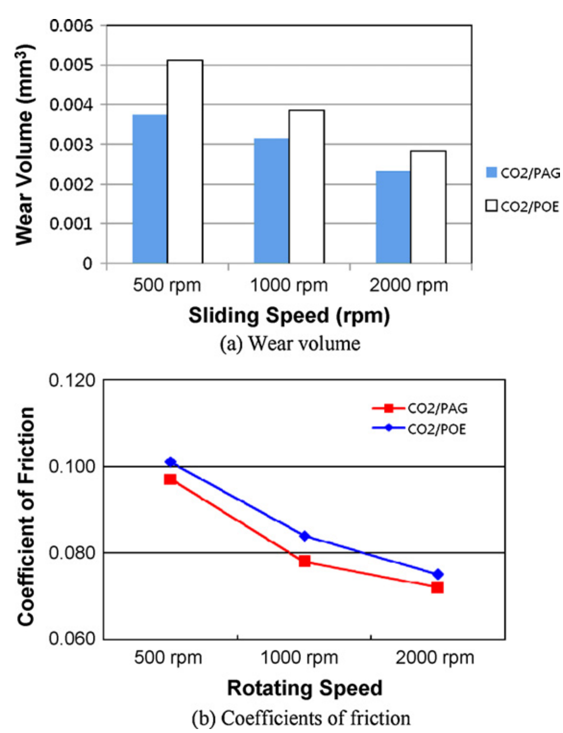

Fig. 2. Wear depths and friction coefficients of the vane according to the rotating speeds under the CO_2/POE and CO_2/PAG mixed environments.