Effect of R600a on tribological behavior of sintered steel under starved lubrication

Kemal Sariibrahimoglu [a], Huseyin Kizil [a,*], Mahmut F. Aksit [b], Ihsan Efeoglu [c], Husnu Kerpicci [d]

[a] Department of Materials Science and Engineering, Istanbul Technical University, Maslak, Istanbul 34469, Turkey
[b] Faculty of Engineering and Natural Sciences, Sabanci University, Istanbul, Turkey
[c] Department of Mechanical Engineering, Ataturk University, Erzurum, Turkey
[d] Arcelik Research and Development Center, Istanbul, Turkey

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This paper describes the impact of the isobutane refrigerant on the wear performance of tribopairs at hermetic compressor bearings. The tribological behavior of 100Cr6 steel pin is investigated under starved lubrication condition in air and R600a environments when running against sintered steel which was treated with and without steam. EDS and SEM are carried out on pin and plate samples after wear tests. The results indicate that wear durability is lower for the tests with R600a than those with air. The adverse effect of R600a on wear rate is linked to the change in the viscosity and foaming characteristics of the oil in the presence of R600a as well as the lack of oxides.

1. Introduction

As energy costs increase rapidly, mechanical losses in refrigerator compressors attract renewed attention. Various surface treatments and oil-refrigerant compositions have been proposed to decrease friction and wear in closed type (hermetic) compressors [1–3]. On the other hand, research on the stratospheric ozone layer demonstrated the detrimental effects of conventional refrigerants containing halogens. Discharge or leakage of refrigerants containing chlorine, bromine, and other halogens affects the stratospheric ozone equilibrium [4], and their use has been restricted by Montreal and Kyoto protocols [5,6].

A conventional closed-type compressor uses CFC (chlorofluorocarbon) like R12, or HCFC (hydrofluorochlorocarbon) like R22. Typically these refrigerants work well with mineral oils to achieve desirable wear and friction levels. None chlorine substitute refrigerants mean that favorable lubrication properties of R12 or R22 can not be utilized. As conventional refrigerants phased out, isobutane (R600a) emerged as the main alternative in refrigeration industry. Hydrocarbons (HCs) such as R600a are viable substitutes as they possess favorable refrigerants properties. However, their compatibility and performance with compressor oils are being investigated.

Transition of refrigerants occurred in two phases. First, CFC-12 and HCFC-22 evolved to HFC-134a, and then HFCs were replaced with HCs (R600a). Although there are some research studies on HFCs, published literature on HC refrigerants remain very limited. This work aims to provide information on friction and wear performance of common compressor bearing materials under R600a atmosphere with common mineral oil.

Solzak and Polycarpou [7] have studied the tribological effects of connecting rod-wrist pin interface with HFC refrigerants. Their experiments with unlubricated and uncoated steel surfaces indicated high friction and wear suggesting the need for protective films. Tribological behavior of some hermetic compressor parts in R134a environment has been studied by a number of researchers [8–10]. These studies show an increase in surface temperatures resulting in the decomposition of thin lubricant films between contacting surfaces. The best wear performance was obtained with R134a with poly-ol-ester (POE) synthetic lubricants due to the release of the fluorides during sliding and decreasing frictional heating.

Alsaad and Hammad [11], Jung et al. [12], indicated that mixture of propane (R290)/butane (R600) and propane/isobutane (R600a) could be successfully adopted for the replacement of CFC-12/HFC-134a. Wongwises et al. [13,14] studied the application of hydrocarbon mixtures R290, R600 and R600a to replace HFC-134a in domestic refrigerators while maintaining low energy consumption. Garland et al. [15] has studied the tribological behavior of some hermetic compressor parts in R134a, R12, and R600a environments. The results indicated a superior coefficient of performance (COP) for R600a over R134a and R12, yet the long term wear and durability of equipment using this refrigerant needs further investigation. Zhelezny et al. [16] studied thermodynamic properties of R600a as a function of isobutane/Azmol concentrations. Garland and Hadfield [17] investigated the impact

* Corresponding author. Tel.: +90 212 285 3516.
E-mail address: kizilh@itu.edu.tr (H. Kizil).

of hydrocarbon refrigerants indicating that R600a mixture with mineral oil appeared to be an appropriate long-term candidate to replace R134a.

Although better COP values are achieved with HC refrigerants, wear life related issues need to be resolved since limited literature is available. Possible problem areas include motor/crankshaft journals; crank pin/connecting rod bearings, piston/cylinder sliding interface and the inlet/exhaust flapper valves [18].

Most sliding elements are usually fabricated from sintered iron in order to improve lubricant retention. Steam treatment is also implemented to improve scuffing resistance, prevent seizure, and prolong the life of the critical components. Sintered iron against 100Cr6 is one of the most common tribopairs used in hermetic compressors. This study aims to aid compressor designers in achieving extended life goals by shedding light on friction and wear performance of 100Cr6/sintered iron pairs under R600a atmosphere. With renewed attention to use less and less oil, friction and wear performance under starved lubrication and dry conditions are also presented.

2. Experimental details

The sintered disc material was prepared from the iron powder of 5–100 μm grade size at a constant compaction pressure of 475 MPa, containing (wt%) 0.30 C, 0.0043 S, 2.44 Cu, 0.21 Si, 0.54 Mn, and the remaining being Fe at a density of 6.8 g/cm^3. Sintering process was conducted in a mildly reducing atmosphere of 75% N_2+25% H_2 at a constant temperature of 1120 °C for 25–30 min. Then samples were cooled at 1.0 °C/s to room temperature in a H_2 atmosphere with a low dew point. As-sintered samples had a bulk hardness around 85 HRF. The surface roughness (Ra) of 0.50 μm was measured. Steam treatment involved 2 h of pre-heat process at 100 °C prior to steam oxidation for 1 h at 600 °C, and following 2 h of cool-down process in the furnace. Steam treated samples had a bulk hardness around 102 HRF.

A standard pin-on-disc test rig was used. A 100Cr6 steel pin (1250 HV), 7.89 mm in diameter and of a 5 mm in length, was rubbed sideways against a rotating sinter disc. Prior to each test, samples were cleaned in an ultrasonic cleaner for 15 min in acetone, followed by 15 min cleaning in ethanol. Dry sliding tests were conducted in an atmosphere with 60–70% relative humidity and at a temperature around 23 °C. For starved oil lubrication tests, mineral oil (We 7125 compressor oil), with a viscosity of 7cSt at 40 °C, was misted on the sliding surface for 1 s at 30 psi oil pressure through a fully controlled nozzle at the beginning of the each wear test. The amount of oil used at each test was measured to be 100 mg. No other oil was introduced throughout the test. Applied loads of 40 N and 50 N, as well as the speeds of 0.26 m/s and 0.8 m/s were chosen for these tests. New pin and disc were used for each test and the track diameter was kept constant for each sliding speed so as to eliminate this as a further variable. All of the disc specimens investigated in this study were kept in desiccators before and after their friction/wear tests.

The R600a gas pressure and composition inside the tribometer was monitored with a flow regulator. A large isolated Plexiglas cage was used to ensure atmosphere control to observe frictional behavior in isobutane atmosphere. Being heavier than air, R600a refrigerant was introduced from a lower point while excess atmosphere is bled through a higher exhaust to ensure that the entire test system is submerged in R600a atmosphere. To facilitate uninterrupted R600a exposure, refrigerant is continuously fed to the system.

The amount of wear was determined by appropriate measure of the weight of both specimens before and after each test (Table 1). Initial weight of pins and disc were measured after cleaning in acetone and ethanol followed by drying operation using an electronic weighing balance with 0.1 mg accuracy. The wear rates were obtained by dividing the wear volume by the load and the total sliding distance. Wear tests were conducted at normal loads of 50 N. A fresh abrasive surface was used in every test. The surface microstructures of the wear tracks of each specimen and its paired pin were investigated using JEOL JSM 7000F scanning electron microscope (SEM) with energy-dispersive X-ray spectroscopy (EDS).

Table 1
The test conditions of pin-on-disk tribometer tests.

Parameters	Conditions
Applied load (N)	50
Velocity (m s^{-1})	0.8
Rotational speed of substrate (rpm)	350
P.V. (MPa m s^{-1})	8
Wear track (mm)	21.90
Environment	Air, R-600a
Temperature (°C)	23–25
Humidity (%RH)	55–60

3. Results and discussion

In order to facilitate easier comparison of various cases, wear tests at identical conditions were conducted in both R600a and air environment. First, friction and wear performance of both pairs under dry conditions were tested [19]. The weight loss measurements were taken for applied loads of 40 N and 50 N. Fig. 1 illustrates weight loss against the test time at a constant sliding speed of 0.26 m/s. It is observed that the load increase changes the wear regime, and wear rate was more than doubled with 25% load increase. However, steam treatment had a favorable effect decreasing the wear rates by four-folds as compared to untreated sinter material. The lower wear rate for steam treated sinter sample was due to sealing of pores and formation of oxide layer during steam treatment, which in turn forms a smoother sliding surface. As shown in Fig. 2, accompanied by an excessive noise and vibration during testing, the coefficient of friction fluctuated more for the untreated sinter sample. This is due to the accumulation of laminar oxidized wear particles and smearing on track as seen in Fig. 3.

When dry tests were repeated in R600a environment, it has been observed that wear rate increases when compared with that in air (Fig. 4). The oxidation of iron contributed significantly to the reduction of wear rate for samples tested in air. The hard oxides form a protective layer, and increase wear life. However, under R600a environment, EDS analysis showed that the oxidation of iron was obstructed (Fig. 5). The results clarify that introduction of R600a degrades wear performance of sintered surfaces (Fig. 6).

As starved lubrication tests took much longer, test speed had to be raised to 0.8 m/s to achieve longer sliding distances in a shorter test period. Wear performance is established by comparing the sliding distance before the sudden increase and fluctuation of the friction curve. When plotted against the sliding distance versus COF, the transition in friction coefficient is noticeable in Fig. 5 for both air and R600a environments. Just as observed in dry test conditions, introduction of R600a during starved lubrication tests resulted in noticeable reduction in wear performance (wear durability). Adverse effect of R600a on wear is thought to be due to change in viscosity and foaming characteristics of the oil [20,21].

It is clear that the micro structural features of the sintered material greatly affect the properties of the oil absorbed layer,