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PERPORMANCE EVALUATION OF NANO-LUBRICANTS AT THRUST SLIDE-BEARING OF SCROLL COMPRESSORS

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ABSTRACT

This paper presents the friction and anti-wear characteristics of nano-oil with a mixture of refrigerant oil and carbon nano-particles in the thrust slide-bearing of scroll compressors. Frictional loss in the thrust slide-bearing occupies a large part of total mechanical loss in scroll compressors. The characteristics of friction and anti-wear using nano-oil is evaluated using a thrust bearing tester for measuring the temperature of friction surface and the coefficient of friction at the thrust slide-bearing as a function of normal loads up to 4,000N and orbiting speed up to 3,200 rpm. It is found that the coefficient of friction increases with decreasing orbiting speed and normal force. The friction coefficient of carbon nano-oil is 0.015, while that of pure oil is 0.023. It is believed that carbon nano-particles can be coated and improved the lubrication on the friction surfaces. Carbon nano-oil enhances the characteristics of the anti-wear at the thrust slide-bearing of scroll compressors.

1. INTRODUCTION

Scroll compressors are being used widely for small and middle sizes room air-conditioners. The performances of scroll compressors are better than that of other compressors, for example, reciprocating type or rotary type compressors in points of high efficiency, low vibration and low noise. Figure 1 shows the cross-sectional view of the low-pressure typed scroll compressor being kept with its suction pressure. So the pressure of the space between the fixed scroll and the orbiting scroll is higher than that of overall space of the hermetic compressor. And this pressure difference is firmly pressed and causes normal load to the thrust bearing.

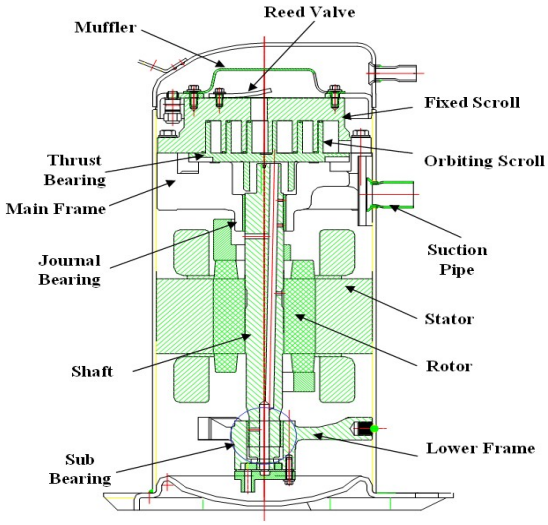


Figure 1: Cross-sectional view of the low-pressure typed scroll compressor

It is occurred that the thrust bearing of a scroll compressor has been failed. This problem causes higher frictional losses so that the efficiencies of compressors and air-conditioners are lowered down. It is reported that the frictional loss at the thrust bearing is most large among the friction losses at sliding elements. But the characteristic of the friction loss at the thrust bearing of scroll compressors has not been well studied. Thus, many researchers have been trying to reduce losses at the thrust bearings and studying the lubrication mechanism, anti-wear characteristics at the thrust bearings and the behavior of the orbiting scroll of scroll compressors in detail. The lubrication property of nano particles has been studied by Liu (2004) and Tarasov (2002). They have reported that nano particles can improve the characteristics of friction by adding and dispersing those particles to some kinds of lubricant.

In this paper, the friction and anti-wear characteristics of nano-oil with a mixture of refrigerant oil and carbon nano-particles in the thrust slide-bearing of scroll compressors are investigated using the tribo-tester for the lubrication test. The lubrication tests are conducted by measuring friction surface temperature and the coefficient of friction at the thrust slide-bearing as a function of normal load and orbiting speed. Also, the friction surfaces of the slide-bearing are observed to examine the profile and image of wear.

2. EXPERIMENT

Figure 2 shows the schematic view of the thrust slide-bearing tester for understanding and evaluating the lubrication characteristics in scroll compressors. It is simplified and designed to two plates which are the orbiting plate and the fixed plate. Then the surface between two plates replaces the frictional surface of the original thrust bearing in scroll compressors. The tribo-tester consists of a closed test chamber, an air cylinder, two loads cells, a servo motor, oil and refrigerant suppliers, and heaters. The lubricant oil is supplied by oil pump to the frictional surface from inside of the friction surface to outside of it. Two plates are located in a closed chamber and inside space of chamber is being kept pressurized by refrigerant gas R-22 at the pressure of 5 bars. A balance weight is attached to the eccentric shaft to reduce vibration. The normal load is operated by the air-cylinder system and controlled by the PID controller which can control the pressure of air in high accuracy. And the exact value of the normal load can be measured by the load cell located under the air-cylinder. The orbiting speed can be controlled and indicated by the inverter of the servo motor. The friction force is a significant value and can be measured by another load cell located in a closed chamber. The drag force is acted on the frictional surface by the orbiting motion of the orbiting plate and by the action of the normal load.

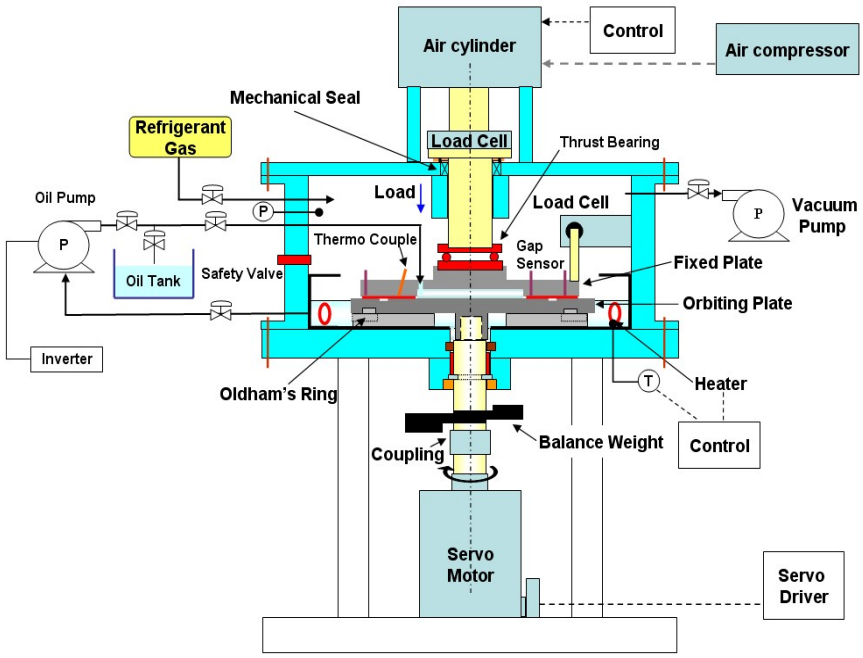
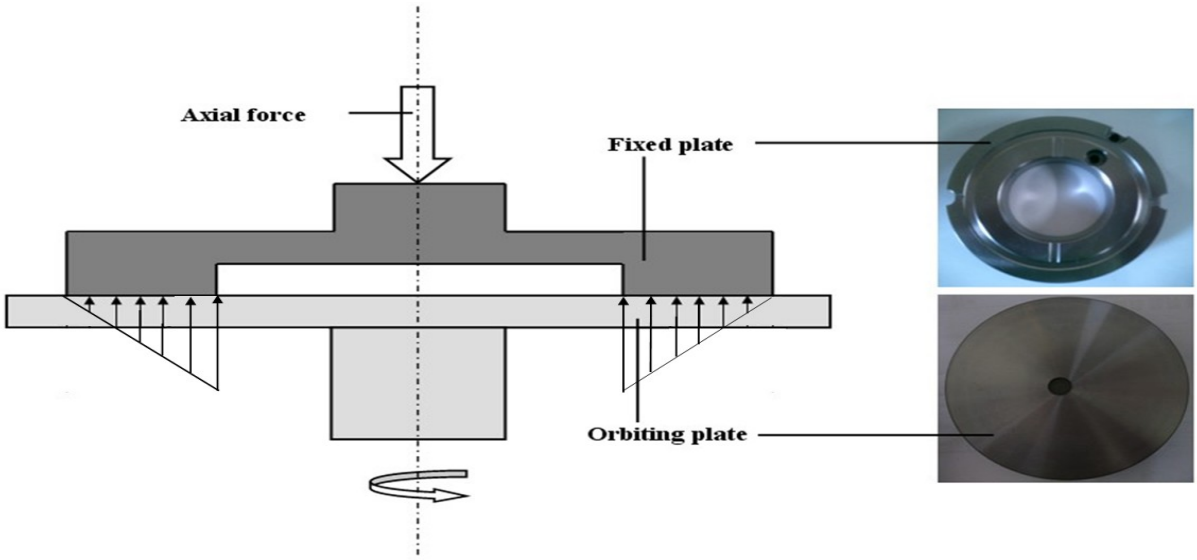


Figure 2: Schematics of a thrust slide-bearing tester for evaluating the characteristics of friction of pure oil and nano-oil



(a) Fixed plate and orbiting plate (b) Test pieces

Figure 3: Simplified model of the fixed plate and orbiting plate showing the axial force and the distribution of pressure acting on the friction surfaces in the thrust slide-bearing of scroll compressors

Table 1: Major specification of lubrication tests in the thrust bearing tester in this study

Axial force [N]	0 ~ 4000
Orbiting speed [rpm]	0 ~ 3000
Orbiting radius [mm]	3
Refrigerant oil	Pure oil, Nano-oil
Refrigerant	R22

That force makes the fixed plate to rotate in same direction of the orbiting plate. But the fixed plate can not rotate since it is forced to be fixed by the load cell which is fixed to the wall of a closed chamber. Therefore, the friction force acted on the surface can be measured by the load cell. The temperature of the frictional surface is measured by two thermocouples fixed to the fixed plate. The gap between the fixed plate and the orbiting plate is measured by the gap-sensors which can measure and evaluate the distance between two solid materials in micro scale. The coefficient of friction and surface temperature are measured as a function of orbiting speed and normal load.

Figure 3 shows a simplified model of the fixed plate and orbiting plate showing the axial force and the distribution of pressure acting on the friction surfaces in the thrust slide-bearing of scroll compressors. The pressure distribution along the fixed surfaces decreases with increasing plate diameter with the maximum value at the inner surface which causes a wedge formation between the friction surfaces. The pressure distribution can adjust by the axial force through loading the air cylinder. The material of the fixed plate and the orbiting plate is gray cast iron. And the surface roughness of two plates is 1.3 ㎛ and 2.1 ㎛, respectively.

Table 1 shows the major specification of lubrication tests in the thrust bearing tester in this study. At the beginning of tests, the temperature of supplied oil must be reached to 80℃ on the purpose of keeping the equivalent condition of the operating temperature of oil in real scroll compressors. The normal force and the orbiting speed can be controlled up to 4,000 N and 3,000 rpm, respectively. The friction coefficients, the friction surface temperature and the gap between two plates are measured as a function of the orbiting speed at the range between 300 rpm and 3,000 rpm at the normal force of 3,200 N. These tests are performed using both pure oil and nano-oil. The physical properties of mineral oil are the density of 0.915 g/㎤, the kinematic viscosity of 54.6 ㎟/s at the 40℃and of 6.06 ㎟/s at the 100℃.

Table 2: Results of extreme-pressure test of pure oil and nano-oil based on ASTM D2670

Oil type	Solvent	Nano-particles	Breaking pressure of the oil film
Pure oil	Mineral oil	None	below 120 kgf/㎠
Nano-oil Ⅰ	Mineral oil	0.1 wt% carbon nano-particles	270 kgf/㎠
Nano-oil Ⅱ	Mineral oil	0.3 wt% carbon nano-particles	270 kgf/㎠

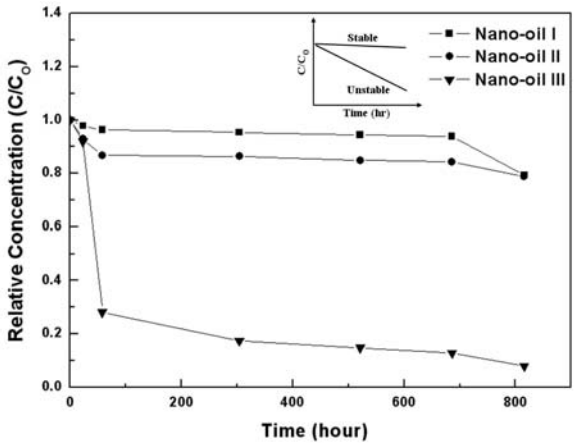


Fig. 4 Results of suspension stability of nano-oils with UV-via spectrophotometer

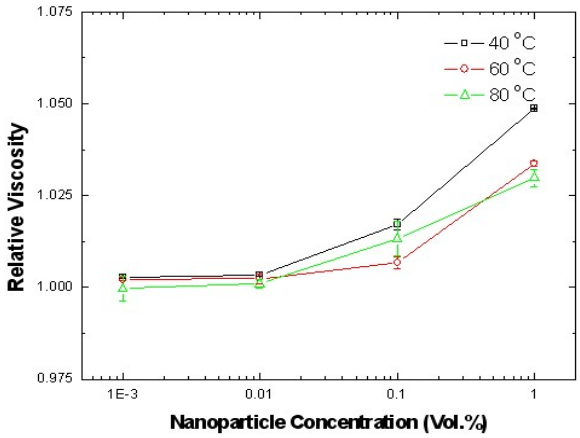


Fig. 5 Relative viscosity of nano-oil as a function of volume fraction for temperature ranging from 40 ℃ to 80 ℃

3. RESULTS

Table 2 shows the results of extreme-pressure tests of pure oil and nano-oil based on the standard of ASTM D2670. Nano-oil which contains 0.1 wt% and 0.3 wt% of carbon nano-particles increases in breaking pressure of the oil film up to 225%. It is harder for oil film of nano-oil to be broken than that of pure oil. It is believed that nano-oil has less opportunity to occur to metal contact than pure oil. It is an important factor to evaluate the property of lubrication and wear. It is proved that carbon nano-oil enhances the breaking pressure of the oil film.

Figure 4 shows the results of suspension stability of nano-oils with the UV-via spectrophotometer. It depicts the relative concentration of nano-oils as a function of sediment time. For nano-oil Ⅲ suspension, very fast settling occurs. At the 58 hours of tests, the relative absorption drops as much as 72%. On the other hand, much less precipitation is observed in nano-oil Ⅰ and Ⅱ suspension. At the 686 hours of tests, the relative absorption falls only

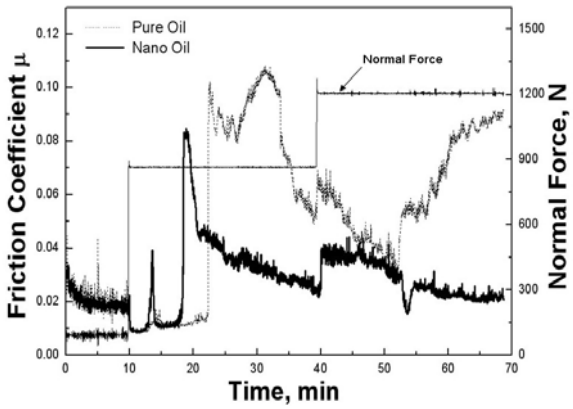
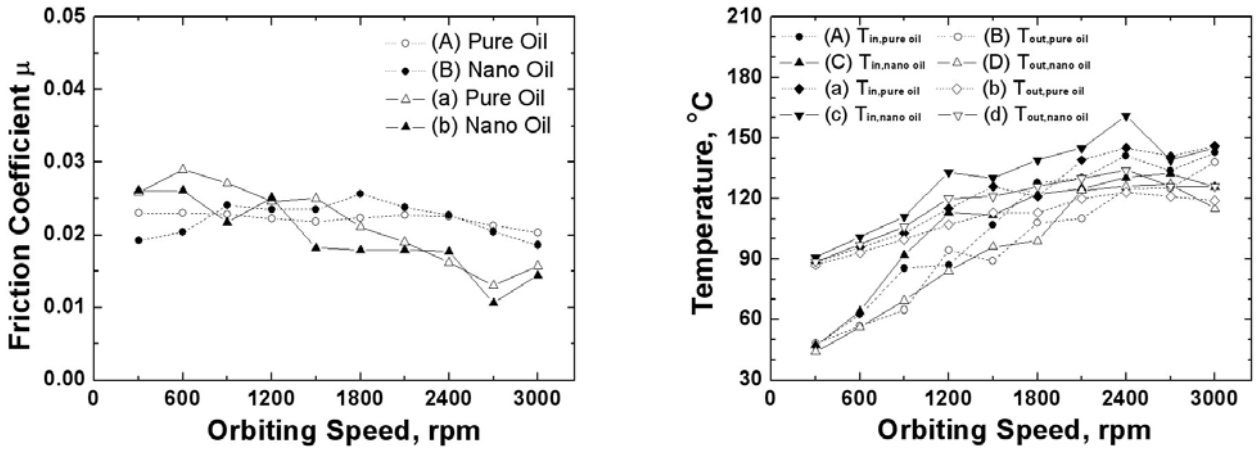


Figure 6: Results of friction coefficient of pure oil and nano-oil using disk on disk type tester under the condition of R22 refrigerant



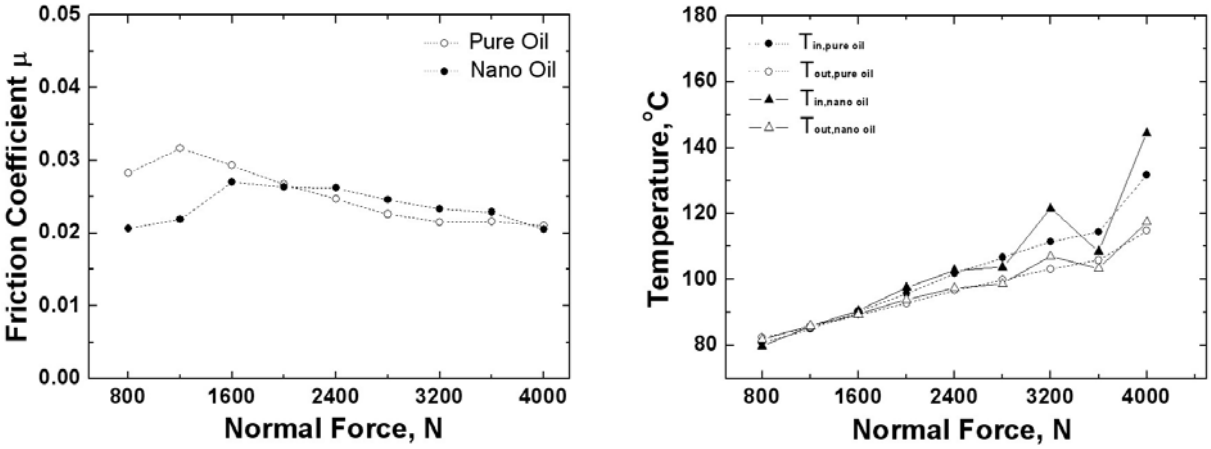
(a) Friction coefficient (b) Friction surface temperature

Figure 7: Lubrication results of friction coefficients and friction surface temperature as a function of the orbiting speed using the thrust slide-bearing tester at the normal force of 3200 N: A capital letter (A) (B) (C) (D) conditions in increasing of the orbiting speed from 300 rpm to 3000 rpm, a small letter (a) (b) (c) (d) conditions in decreasing of the orbiting speed from 3000 rpm to 300 rpm

6%. Thus an excellently stable suspension can be produced in case of nano-oil Ⅰ and Ⅱ. In this study, nano-oil Ⅰ is selected as test nano-oils due to excellently stable suspension. Figure 5 shows the relative viscosity of nano-oils as a function of volume fraction in suspension of nano-particles for temperature ranging from 40 ℃ to 80 ℃. The relative viscosity can be described by the ratio of the viscosity of nano-oil to the viscosity of pure oil. There is no considerable changing of relative viscosity in nano-oil under low volume fraction up to 0.1%, but the relative viscosity of nano-oil gradually increases up to about 5% at the volume fraction of 1 %. The relative viscosity increases in proportion to the volume fraction in general.

Figure 6 shows the results of friction coefficient of pure oil and nano-oil using disk on disk typed tester under the condition of R22 refrigerant. It is measured that the maximum of the friction coefficient for nano-oil is 0.085, while that of pure of is 0.11. The coefficient of friction decreases after occurring to the maximum of the friction coefficient, because both oils make disk on disk plates polish after occurring to the maximum of the friction coefficient. On the other hand, polishing phenomenon of nano-oil is better than that of pure oil. So nano-oil containing 0.1 wt% of carbon nano-particles has better properties of lubrication than conventional pure oil.

Figure 7 shows the lubrication results of friction coefficients and friction surface temperature as a function of the orbiting speed using the thrust slide-bearing tester at the normal force of 3,200 N. The fixed plate is pressurized at



(a) Friction coefficient (b) Friction surface temperature

Figure 8: Lubrication results of friction coefficient and friction surface temperature as a function of the normal force using the thrust slide-bearing tester at the orbiting speed of 1,800 rpm and the normal force up to 4,000 N

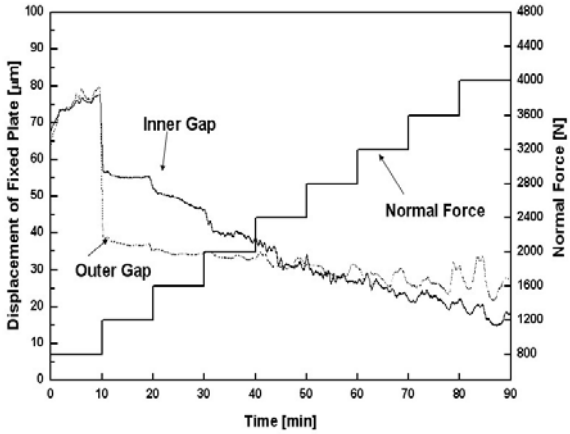
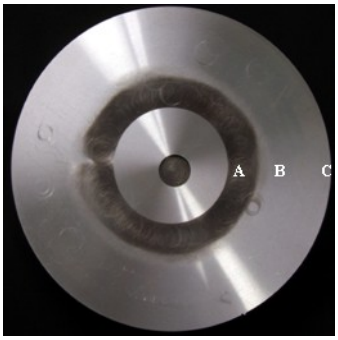


Figure 9: Results of displacement of the fixed plate as a function of the normal force using the thrust slide-bearing tester at the orbiting speed of 1,800 rpm and the normal force up to 4,000 rpm

the normal force of 3,200 N and the orbiting speed of the orbiting plate with the conditions of increasing or decreasing orbiting speed at the range of 300 rpm to 3,000 rpm. Figure 7 (a) shows the friction coefficient increases with decreasing rotating speed. It is found that the coefficient of friction increases with decreasing orbiting speed and normal force. The friction coefficient of nano-oil is 0.015, while that of pure oil is 0.023 under the conditions of refrigerant gas R-22 at the pressure of 5 bars. It is believed that carbon nano-particles can be coated on the friction surfaces and the interaction of nano-particles between surfaces can be improved the lubrication in the friction surfaces. Figure 7 (b) shows the surface temperature of thrust slide-bearing. There are no considerable difference of temperature between pure oil and nano-oil. But the surface temperature of the inner friction is higher than that of outer surface for both pure oil and nano-oil. These results of the surface temperature significantly suggest that a wedge is formed between the friction surfaces of the thrust slide-bearing, so that inner area occur attrition severely and on the contrast the outer area do not contact each other.

Figure 8 shows the lubrication results of friction coefficient and friction surface temperature as a function of the normal force using the thrust slide-bearing tester at the orbiting speed of 1,800 rpm and the normal force up to 4,000 N. The friction coefficient of carbon nano-oil and pure oil as shown in Figure 8 (a) is ranged from 0.02 to 0.03. Figure 8 (b) shows the surface temperature of thrust slide-bearing. The surface temperature increases with increasing normal force for both oils. It has the same tendency that the surface temperature of the inner friction is higher than that of outer surface for both pure oil and nano-oil. Figure 9 shows the results of displacement of the fixed plate as a



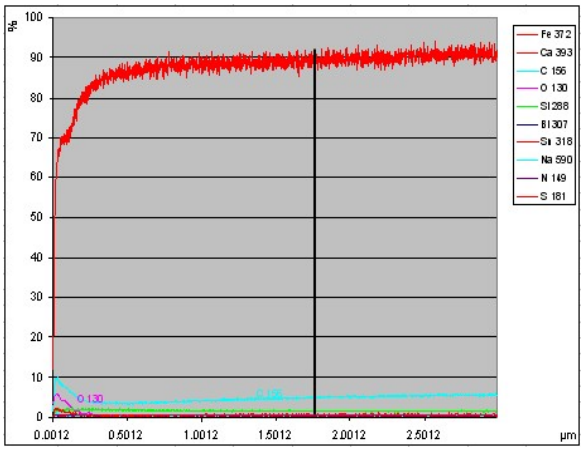
(a) Pure oil

(b) Nano-oil

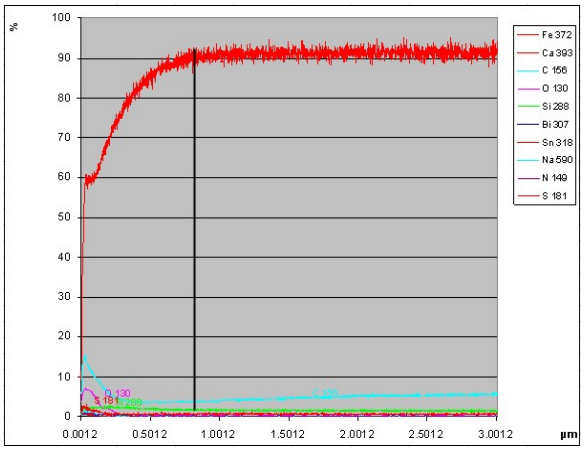
Figure 10 Image of wear and surface roughness of the orbiting plate at the orbiting speed of 1,800 rpm and the normal force up to 4,000 N after 90 minutes test period

Table 3: Surface roughness of orbiting plate at the orbiting speed of 1,800 rpm and the normal force up to 4,000 N after 90 minute test period (location A, B, and C are shown in Figure 10)

Description \ Location	A	B	C
Surface roughness [㎛] under pure oil	1.1	2.5	1.3
Surface roughness [㎛] under nano oil	1.0	1.1	1.2



(a) Pure oil



(b) Nano-oil

Figure 11: GDS profiling for measuring the depth of oil carbonization of the orbiting plate at the orbiting speed of 1,800 rpm and the normal force up to 4,000 N after 90 minutes test period

function of the normal force using the thrust slide-bearing tester at the orbiting speed of 1,800 rpm and the normal force up to 4,000 rpm. The displacement of the fixed plate decreases with increasing normal force. The displacement of the inner fixed plate is lower than that of the outer plate at the higher value than the normal force of 2,800 N. This result significantly proves that a wedge of the fixed plate is formed. It is relative that the friction surface temperature significantly increases after normal force 2,800 N as shown in Figure 8 (b).

Figure 10 shows the image of wear and surface roughness of the orbiting plate at the orbiting speed of 1,800 rpm and the normal force up to 4,000 N after 90 minutes test period. Black color circles in the image of the orbiting plate is placed the inside of the fixed plate and is believed as a mark of oil carbonization due to a wedge phenomena formed between the friction surfaces of the thrust slide-bearing. Table 3 shows the surface roughness of orbiting plate at the orbiting speed of 1,800 rpm and the normal force up to 4,000 N after 90 minutes test period The surface

roughness of the orbiting plate for pure oil distinctively decreases from 2.5 ㎛ at the middle area "B" to 1.1 ㎛ at the inside area "A", while for nano-oil decreases from 1.1 ㎛ to 1.0 ㎛. It is believed that carbon nano-particles can be coated on the friction surfaces and the interaction of nano-particles between surfaces can be prevented metal contact. To evaluate the depth of oil carbonization, the glow discharge spectrometer (GDS) is conducted. Figure 11 shows the glow discharge spectrometer (GDS) profiling for measuring the depth of oil carbonization of the orbiting plate at the orbiting speed of 1,800 rpm and the normal force up to 4,000 N after 90 minutes test period. The depth of oil carbonization in the orbiting plate for pure oil is about 1.7~1.8 ㎛, while for nano-oil is 0.7~0.8 ㎛. Therefore the nano-oil enhances the characteristics of the anti-wear and friction resistance at the thrust slide-bearing of scroll compressors.

4. CONCLUSION

Lubrication tests of the thrust slide-bearing of scroll compressors are conducted in the closed chamber with the refrigerant R22, focusing on the different property of lubrication between nano-oil and pure oil. The friction coefficient of carbon nano-oil is 0.015, while that of pure oil is 0.023 under the conditions of refrigerant gas R-22 at the pressure of 5 bars. It is believed that carbon nano-particles can be coated on the friction surfaces and the interaction of nano-particles between surfaces can be improved the lubrication in the friction surfaces. The depth of oil carbonization in the orbiting plate for pure oil is about 1.7~1.8 ㎛, while for nano-oil is 0.7~0.8 ㎛. Carbon nano-oil enhances the characteristics of the anti-wear and friction at the thrust slide-bearing of scroll compressors.

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