COMPARATIVE PHYSICAL AND TRIBOLOGICAL PROPERTIES OF THREE PENNZANE® FLUIDS, SHF X-1000, SHF X-2000, AND SHF X-3000

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Abstract

Pennzane® SHF X-2000, by itself or containing additives or formulated into a variety of greases, has become an often used lubricant for aerospace applications. A recent bibliography contains over 100 references to Pennzane® SHF X-2000 in the literature. This paper serves to announce that two new Pennzane® Synthesized Hydrocarbon Fluids, X-1000 and X-3000, will be available. Pennzane® SHF X1000 is about half as viscous at low temperature as Pennzane® SHF X2000, with almost the same low outgassing. Pennzane® SHF X3000 is a thickened version of X2000 having a viscosity at 100°C of 200 cSt, compared to that of X2000 at 14.5 cSt.

This paper will provide a listing of physical and tribological properties of all three Pennzane fluids, and will compare them to a linear perfluoropolyether (Brayco 815Z or Fomblin Z-25).

Physical properties include viscosities at high and low temperatures, vacuum outgassing weight loss and condensables, and thermal properties, among others.

Spiral Orbit Tribometry shows all three Pennzane fluids to have much longer useful lifetimes than PFPEs. Pennzane® SHF X1000 has significantly better low temperature bearing torque than X2000 and is comparable to Z-25 at –15°C.

Introduction

Proper lubrication is essential to the problem-free operation of moving mechanical assemblies (MMAs) in spacecraft (1). Since spacecraft normally operate in ultrahigh vacuum, it is essential that space lubricants have very low vapor pressures. A low vapor pressure hydrocarbon, Pennzane® Synthesized Hydrocarbon Fluid X2000, one member of the multiply-alkylated cyclopentanes family of compounds, was introduced in the early 1990s and has found wide acceptance as a hydrocarbon base oil for the development of lubricant oils and greases for these demanding applications (2).

Pennzane® SHF X2000 has become a common base material for the formulation of space lubricants because of its excellent lubricating characteristics and its very low vacuum outgassing. One problem identified by the space tribology community is that Pennzane® SHF X2000 has too high viscosity at low temperatures (below 0°C) for some applications. A second problem noted is that Pennzane® SHF X2000 is not viscous enough for some applications at or above 25°C. There is also anecdotal evidence that Pennzane® SHF X2000 pools or "runs out" of bearings in some higher temperature applications.

Materials that maintained the advantages of Pennzane® SHF X2000 listed below were sought (3).

- Low Outgassing
- Capability to dissolve additives
- Protection from corrosion
- Low light absorption

Recently, two new lubricants intended for high-vacuum applications, have been introduced. One, **Pennzane® SHF X1000**, is a lower molecular weight, less viscous, relative of Pennzane® SHF X2000. The other is a high viscosity liquid, **Pennzane® SHF X3000**, which is Pennzane® SHF X2000 thickened with a saturated hydrocarbon polymer.

This paper presents a comparison of the properties of these three materials.

Experimental

The Spiral Orbit Tribometer

The spiral orbit tribometer (SOT) appears in Figure 1. First introduced by Kingsbury (4) the SOT is essentially a thrust bearing with flat races (plates) and a single ball. The tribometer simulates rolling, pivoting, and sliding as seen in angular contact bearings. Accelerated tests are achieved by only using micrograms of lubricant on the ball. During the test, the lubricant is completely consumed, resulting in short test durations. The advantage of this type of acceleration is that operational test parameters, such as contact stress, speed, and temperature are similar to those in the final application.

The tribological elements of the system appear in more detail in Figure 2. The lower plate is stationary while the top plate can rotate at speeds up to 200 RPM. The top plate rotation drives the ball in a spiral orbit. Every orbit, the ball contacts the vertical guide plate, which returns it to the original orbit radius. The straight-line region where the ball contacts the guide plate is denoted as the "scrub". From the force that the ball exerts on the guide plate, the friction coefficient is calculated. After leaving the scrub, the ball's spiral orbit begins again. The spiral orbit and scrub constitute a track (Figure 2) that is stable, repeatable, and is traversed thousands of times by the ball. A detailed description of the tribometer and analysis of ball kinematics appear in References (4) to (7).

Bearing Test Facility

The bearing test facility used for these experiments was first introduced by Jansen et. al (8) and is shown in Figure 3. The system is designed to operate at <$5x10^{-6}$ Torr and from temperatures of -40° to 100°C. The device has a computer data acquisition (DAQ) and control system based upon LabVIEW™. The DAQ monitors bearing temperature, torque, load, cross-bearing electrical resistance, and rotational speed. Motion is provided by a computer controlled stepper motor and ferrofluidic feedthrough. The system allows either a constant rotational speed between 0 and 1000 RPM or a precise dither at a desired angle. The rig uses a soft, dead weight loading system. For these tests, an 89N (20 lb) load was used.

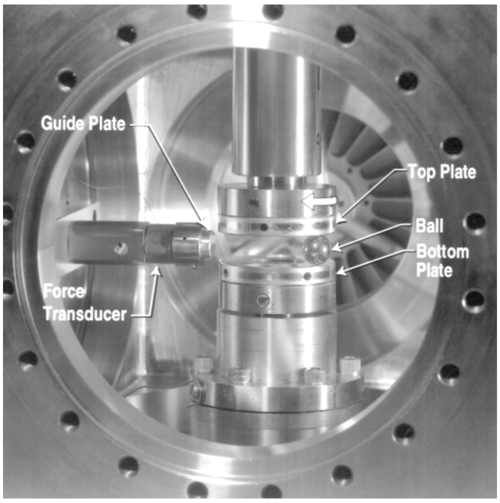

Figure 1 – Vacuum Spiral Orbit Tribometer (SOT)

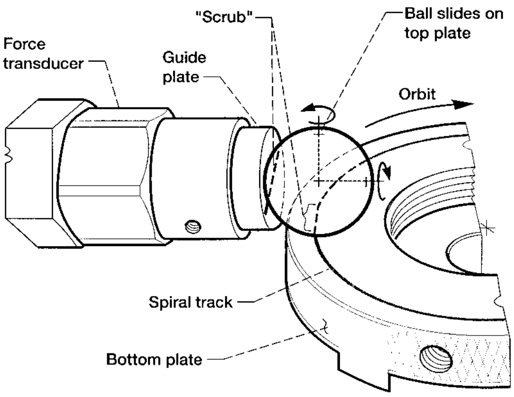

Figure 2 – Detailed view of the SOT components

Cross-bearing electrical resistance is monitored throughout the test. The inner race is electrically isolated from the rest of the rig. The outer race is grounded. A 1.5-volt supply is provided at the inner race though a 1.5 KΩ resistor. The voltage at the inner race is measured to obtain the voltage drop across the bearing and the cross-bearing resistance can be calculated. From the resistance data, the lubrication regime can be determined. A low contact resistance indicates operation in the boundary or mixed regime. A high or infinite resistance indicates either operation in the EHL regime or the build up of an electrically insulating friction polymer (9).

The system uses a single MPB 1219 angular contact bearing. It is mounted within a test fixture, also shown in Figure 3 that holds the outer race fixed and rotates the inner race. A thermocouple is mounted touching the inner race and measures bearing temperature. A cooling unit is mounted around the outside of the fixture. Liquid nitrogen is passed through the coil to cool the bearing. For these tests, a constant flow rate of liquid nitrogen was used, yielding a continual reduction in temperature as a function of time. The cooling rate decreased as the test progressed. Torque is monitored using an in-line torque meter. This system was used to measure low temperature torque.

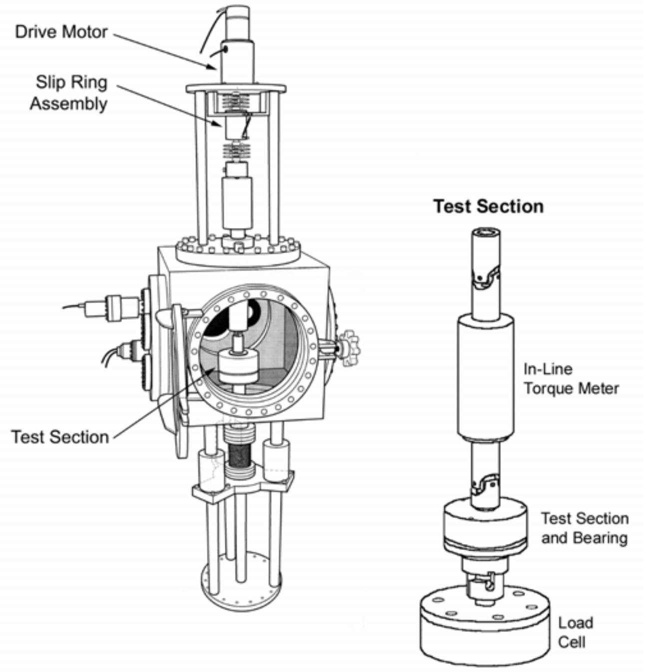

Figure 3 – Vacuum bearing rig facility and bearing fixture

Discussion

Physical Properties

Pennzane® SHF X2000 is chemically tris (2-octyldodecyl) cyclopentane, $C_{65}H_{130}$. It consists of three $C_{20}H_{41}$ alkyl groups on a cyclopentane ring. Lowering the molecular weight lowers the viscosity at a given temperature. Bis(2-octyldodecyl) cyclopentane, $C_{45}H_{90}$, having only two $C_{20}H_{41}$ alkyl groups on the cyclopentane ring, was selected as the lower molecular weight material (SHF X1000).

Comparing the properties of SHF X2000 and SHF X1000 in Table 1, it can be seen that X1000 is less viscous than X2000 at all temperatures. Particularly at –40°C, X1000 is only 240 poise while X2000 is 750 poise.

As a result of the lower molecular weight, X1000 is more volatile than X2000, though still at an acceptable level of 0.5% lost at 125°C at 10^{-5} Torr vacuum for 24 hours. The other properties dependent on volatility, flash point and fire point are slightly lower.

At 200 cSt at 100°C, SHF X3000 is considerably more viscous than SHF X2000. Since it consists of X2000 thickened with a polymer, intermediate viscosities between 14.5 cSt (X2000) and 200 cSt (X3000) are easily blended. Because the thickener in X3000 is essentially a non-volatile hydrocarbon, all of the volatility properties of X3000, outgassing, flash point, fire point, etc., are at least as good as those of X2000.

Tribological Properties

SOT

The normalized lifetimes, defined as the (total number of ball orbits divided by the amount of lubricant on the ball, obtained from the SOT facility are presented in Figure 4. The lifetimes of the SHF X2000 and SHF X3000 fluids are similar and about half of the SHF X1000 fluid. The SHF fluids have lifetimes from 60 to 120 times greater then the PFPEs (143AC and 815Z).

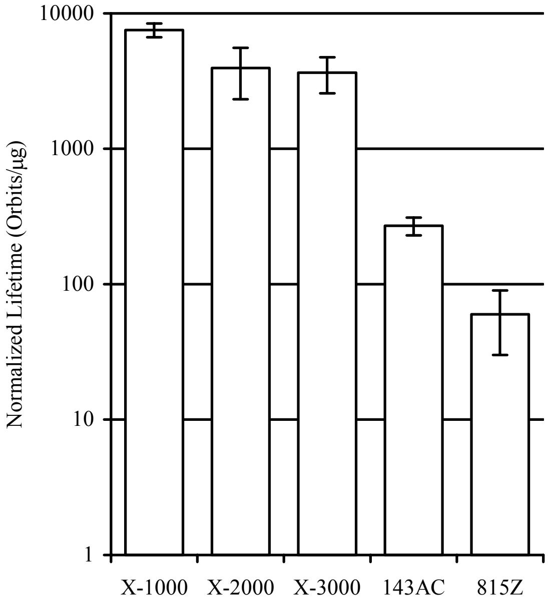

Figure 4 – Normalized lifetime for several lubricants from the spiral orbit tribometer

Torque-Tests

The vacuum bearing facility was used to measure torque as a function of temperature for SHF X1000 to -15°C (Figure 5) and Fomblin Z-25 to -35°C (Figure 6). Cross bearing resistance was also measured to indicate EHL transitions.

As shown in the figures, SHF X1000 yielded a lower room temperature starting torque of 6 mN-m compared to Z-25 (~12 mN-m). The SHF X1000 test was terminated at -15°C due to inadequate liquid nitrogen flow rate. At -15°C, both SHF X1000 and Z-25 yielded similar torque values of 18 mN-m. The Z-25 test was extended to -35°C, where the torque reached a value of ~32 mN-m.

The EHL transitions occurred at approximately 0°C for SHF X1000 as indicated by the abrupt change in contact resistance. No transition was observed for the PFPE (Z-25) to -35°C.

It should be noted that these data are part of a larger, on-going low temperature torque (10) and therefore should be considered preliminary.

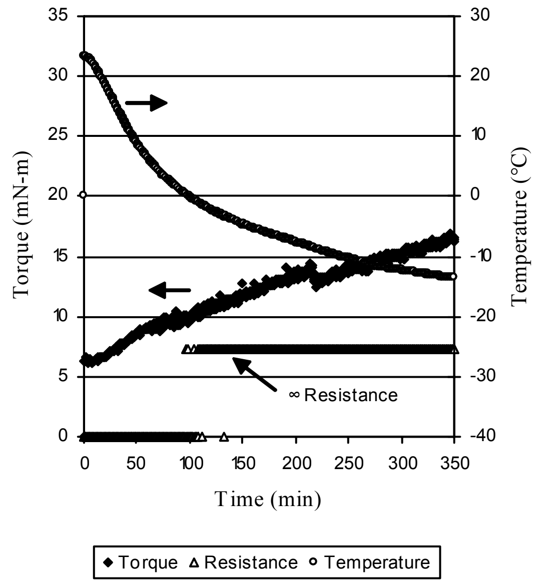

Figure 5 - Torque-temperature test for Pennzane SHF X1000

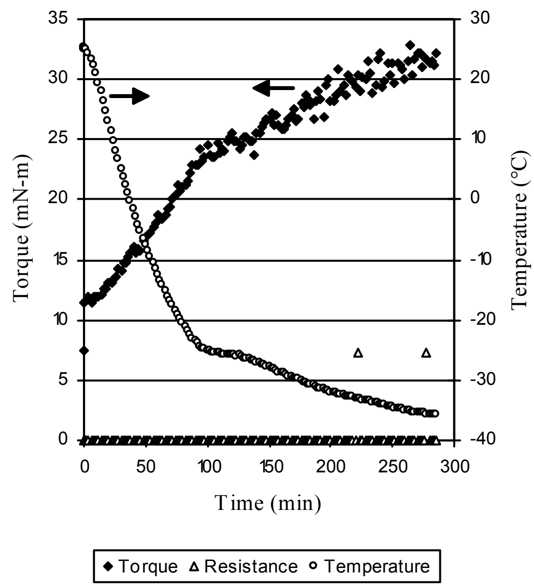

Figure 6 - Torque-temperature test for Fomblin Z-25

Concluding Remarks

Two new hydrocarbon base fluids for lubrication of space mechanisms, Pennzane® SHF X1000 and Pennzane® SHF X3000, are now available to supplement the use of Pennzane® SHF X2000. They maintain the essential superior properties of X2000, while providing flexibility in the selection of lubricant base fluid viscosity.

A bibliography of over 100 papers on Pennzane® fluids is available upon request.

References

(1) Marchetti, Mario; Jones, William R., Jr.; and Sicre, Jacques, "Relative Lifetimes of MAPLUB® Greases for Space Applications," *J. Soc. Trib. Lubr. Eng*, **59(6)**, 11-15 (June **2003**), and references therein.

(2) Casserly, Edward W.; and Venier, Clifford G., "Cycloaliphatics", in *Synthetic Lubricants and High-Performance Functional Fluids,* in Rudnick, L. R., and R. L. Shubkin, eds. Marcel Dekker, NY (**1999**).

(3) Venier, C. G., Casserly, E. W., Gunsel, S., "Tris(2-Octyldodecyl)-Cyclopentane, a Low Volatility, Wide Liquid-Range Hydrocarbon Fluid", *J. Synth. Lubr.,* **9**, 237-253 (**1992**).

(4) Kingsbury, E., "Tribology in Slow Rolling Bearings", *Mater. Res. Soc. Sym. Proc.*, **140**, 437-442, **(1989)**

(5) Jones, W.R., Jr., Pepper, S.V., Jansen, M.J., Nguyen, Q.N., Kingsbury, E.P., Loewenthal, S., Predmore, R.E., "A New Apparatus to Evaluate Lubricants for Space Applications – The Spiral Orbit Tribometer (SOT)", *SAE Int. Spring Fuels & Lub. Meet. & Expos.*, paper 2000-01-1828, June **(2000)**

(6) Pepper, S.V., Kingsbury, E., "Spiral Orbit Tribometry – Part I: Description of the Tribometer", *Tribo. Trans.*, 46, 1, 57-64, **(2003)**

(7) Pepper, S.V., Kingsbury, E., "Spiral Orbit Tribometry – Part II: Evaluation of Three Liquid Lubricants in Vacuum", *Tribo. Trans.*, 46, 1, 65-69, **(2003)**

(8) Jansen, M.J., Jones, W.R., Jr., Pepper, S.V., Predmore, R.E., Shogrin, B.A., "EHL Transition Temperature Measurements on a Geostationary Operational Environmental Satellite (GOES) Filter Wheel Bearing", NASA TM-2001-210670, January **(2001)**

(9) Konchits, V.V., Myshkin, N.K., "Evaluation of the Interface at Boundary Lubrication Using the Measurement of Electric Conductivity", *Wear*, 172, 29-40, **(1994)**

(10) Jansen, M.J., Jones, W.R., Jr., Predmore, R.E., "Low Temperature (-40°C) torque measurements of several space lubricants", NASA TM in process

Table 1 – Comparative Properties of Pennzane® Synthesized Hydrocarbon Fluids

Property	Method	X-1000	X-2000	X-3000	PFPE*
Kinematic Viscosity,cSt					
100°C	ASTM D445	8.7	14.5	200	41
40°C	ASTM D445	54	110	2100	140
Dynamic Viscosity, cp					
0°C		N/A	N/A	30,000	N/A
-20°C	ASTM D5133	2,800	6,200	N/A	1,900
-40°C	ASTM D5133	24,000	75,000	N/A	12,000
Viscosity Index	ASTM D2270	138	135	225	350
Pour Point (°C)	ASTM D97	<-45	<-45	N/A	-72
Flash Point (°C)	ASTM D92	290	315	**	Very High
Fire Point (°C)	ASTM D92	320	335	**	Very High
Autoignition Point (°C)	ASTM E659	400	>400	**	Very High
Density (gm/ml) @ 20°C	ASTM D1298	0.85	0.85	0.85	1.85
Refractive Index @ 20°C	ASTM D1747	1.4682	1.4691	1.4693	1.294
Outgassing Tendency					
Total Wt. Loss	ASTM E595	<0.5%	<0.2%	**	N/A
Vacuum Condesables	ASTM E595	<0.2%	<0.1%	**	N/A
Vapor Pressure Data					
125°C (Torr)	Calculated	$8x10^{-4}$	$4x10^{-7}$	**	$8x10^{-8}$
20°C (Torr)	Calculated	$1x10^{-7}$	$1x10^{-12}$	**	$3x10^{-12}$
Specific Heat	ASTM D2766	0.46	0.52	N/A	0.20
Thermal Conductivity	ASTM D2717	0.165	0.16	N/A	0.08
Thermal Expansion	ASTM D445				
Pressure-Viscosity Coefficient	Shell	N/A	11.6	N/A	9.0

* Bray 815Z, Data of Castrol Industrial North America

** Same as base fluid, Pennzane® SHF X2000

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