High-Viscosity Oil Filtration for Hydrostatic Bearings

H. D. McGinness and H. P. Phillips
DSN Engineering Section

In the operation of hydrostatic bearings, such as are used on the azimuth axis of the Deep Space Network 64-m antennas, the use of high-viscosity fluids offers advantages in operation clearances and in power consumption. One problem in using high-viscosity oils is that of appropriate filter selection. A test program was undertaken to determine the characteristics of commercially available filter elements used with high viscosity fluids. The test data forms the basis for selecting filter elements for use with fluids in the range of 2500 Saybolt second viscosity.

I. Introduction

In the operation of large hydrostatic bearings, such as are used to support the azimuth motion of the DSN 64-m antennas, the use of higher viscosity fluids provides a choice of higher film height between moving parts, lower power consumption by the high-pressure pumps, or a combination of these. However, the application of these fluids presents problems of filtration because of the high viscosities.

Typical filter elements for use with hydraulic oils are rated for fluids with viscosities in the range of 0.006 to 0.300 N-s/m^2 (30 Ssu to 1500 Ssu). For higher viscosities there is a tendency to extrapolate these ratings—a questionable practice when the viscosities to be used may range from 0.480 to 0.840 N-s/m^2 (2400 Ssu to 4200 Ssu). In order to develop a basis for the application of conventional filtering elements to these high-viscosity fluids, Fram Corporation, under contract to JPL, conducted a series of tests on flows, pressure drops, and effects of water entrainment on several types of filtering elements using a high-viscosity oil of a type applicable to hydrostatic bearings.

II. Effect of Viscosity on Hydrostatic Bearing Operational Parameters

A hydrostatic bearing consists of a recessed pad and a runner (Fig. 1). High-pressure oil is forced through the pad recess to escape as a thin film between the runner and the pad. The pressure in the recess is directly related to the load applied on the pad. In operation the pad will lift, increasing the film height, until the pressure required to force the fluid out through the film is in equilibrium with the pressure due to the load.

The bearing film height, h, is determined from laminar flow consideration to be

$$h = K_1 \left[\frac{Q \cdot \mu}{W} \right]^{1/3} \quad (1)$$

The pumping power, H, required to force the oil through the bearings is given by

$$H = K_2 \left[\frac{W^2 \cdot h^3}{\mu} \right] \quad (2)$$

Where K_1 and K_2 are constants related to the size and configuration of the pads and recesses, Q is the oil flow, W the applied load on the pad, and μ the absolute viscosity, all in compatible terms.

From these it can be seen that for a fixed fluid flow and bearing load the film height for a particular bearing configuration varies as the third root of μ, the fluid viscosity.

Similarly, if the film height is maintained constant, the pumping power will vary inversely with the oil viscosity.

III. Test Program

The tests were conducted using Exxon EP5 lubricating oil, having a viscosity of 0.820 N-s/m^2 (4107 Ssu) at 29°C (85°F). The temperature-viscosity relationship of this oil is shown in Fig. 2. The test set up is shown in Fig. 3.

The series of tests listed in Table 1 was conducted to establish the flow versus pressure drop relationship of various filters.

The data recorded for Tests 1, 3, 4, 7, and 8 were the flow rates at temperatures of 29, 32, 35, and 38°C (85, 90, 95, and 100°F), with differential pressures of 1.38×10^{-4}, 2.07×10^{-4}, and 3.45×10^{-4} N/m^2 differential (2, 3, and 5 psi).

The data recorded for Test No. 9 were the flow rate at temperatures of 29, 32, 35, and 38°C (85, 90, 95, and 100°F) with differential pressures of 0.69×10^{-4}, 1.38×10^{4}, 2.07×10^{-4} N/m^2 (1, 2, and 3 psi).

The data recorded for Tests 2, 4, and 6 are flow rates at 29°C (85°F), with differential pressure at 2.07×10^{-4} N/m^2 (3 psi), 32°C (90°F) at 2.07×10^{-4} N/m (3 psi), 35°C (95°F) at 2.07×10^{-4}, N/m^2 (3 psi), 38°C (100°F) at 2.07 N/m^2 (3 psi), and 29°C (85°F) at 1.38×10^{-4}, 2.07×10^{-4}, and 3.45×10^{-4} N/m^2 (2, 3, and 5 psi).

The flow rate for Tests 1 through 9 was accomplished by volumetric measurement of flow through the filter return line. The temperature was maintained using the ASTM 51F thermometer as the control.

The volumetric samples (3000 to 4000 ml) required to establish the flow rate through the filters were taken only when the temperature was within 0.06°C (0.1°F) of the required temperature and was stable. A minimum of four volumetric samples were taken over a minimum of one hour at each temperature-differential pressure setting 29°C (85°F) at 1.38×10^{-4} N/m^2 (2 psid), 29°C (85°F) at 2.07×10^{-4} N/m^2 (3 psid).

To determine the effects of water on the filter elements, the elements used for Tests 2, 4, and 6 were submerged in water for a minimum of twelve hours before testing was accomplished. Test results are summarized in Table 2.

Test No. 11 was viscosity versus temperature on Exxon Spartan EP5 Lube Oil. The results of this test are shown on Fig. 2.

IV. Conclusion

Commercial filters are satisfactory for filtering oil in the viscosity range of 2400 to 4200 Ssu. The test results provides satisfactory basis for selecting filter elements for such applications.

Table 1. Flow versus pressure drop tests

Test No.	Fram filter element	Type of test
1	C-744-15-0	Flow versus differential pressure
2	C-744-15-0	Flow versus differential pressure using a water-wetted element
3	C-709	Flow versus differential pressure
4	C-709	Flow versus differential pressure using a water-wetted element
5	C-788-40HTO	Flow versus differential pressure
6	C-788-40HTO	Flow versus differential pressure using a water-wetted element
7	C-703-10	Flow versus differential pressure
8	C-703-25	Flow versus differential pressure
9	C-703-40	Flow versus differential pressure
10	None	Viscosity versus temperature for Exxon EP5 Lubricating oil

Table 2. Test results

Temperature, °C	ΔP, N/m^2 × 10^4 (psi)	Test 1 C-744-15-0 15 μm paper	Test 2 C-744-15-0 15 μm paper (Water wet)		Test 3 C-709 25 μm paper	Test 4 C-709 25 μm paper (Water wet)		Test 5 C-788-40HTO 40 μm paper	Test 6 C-788-40HTO 40 μm paper (Water wet)		Test 7 C-703-10 10 μm screen	Test 8 C-703-25 25 μm screen	Test 9 C-703-40 40 μm screen
		Flow, m^3/sec × 10^4 (gal/min)											
29	0.69 (1)			0.757 (1.20)									3.89 (6.16)
	1.38 (2)	0.82 (1.30)	1.29 (2.05)	1.17 (1.85)	1.77 (2.81)		1.53 (2.43)	1.68 (2.66)		1.67 (2.64)	0.59 (0.94)	1.74 (2.77)	8.74 (13.86)
	2.07 (3)	1.17 (1.85)		1.94 (3.07)	2.50 (3.96)	2.93 (4.65)	2.21 (3.50)	2.51 (3.99)	2.64 (4.18)	2.52 (3.99)	0.95 (1.50)	2.50 (3.96)	12.49 (19.8
	3.45 (5)	1.94 (3.08)			3.90 (6.18)		3.53 (5.59)	4.20 (6.65)		4.20 (6.65)	1.75 (2.77)	4.37 (6.93)	
32	0.69 (1)												5.80 (9.2)
	1.38 (2)	1.07 (1.69)			1.97 (3.13)			2.20 (3.49)			0.65 (1.03)	2.08 (3.30)	9.37 (14.85)
	2.07 (3)	1.49 (2.33)	1.46 (2.31)		2.88 (4.57)		3.12 (4.95)	2.93 (4.65)		3.20 (5.08)	0.97 (1.54)	3.12 (4.95)	17.49 (27.72)
	3.45 (5)	2.34 (3.71)			4.68 (7.42)			4.72 (7.49)			1.87 (2.97)	5.00 (7.92)	
35	0.69 (1)												6.24 (9.9)
	1.38 (2)	1.18 (1.87)			2.50 (3.96)			2.51 (3.99)			0.83 (1.32)	2.34 (3.71)	12.49 (19.8)
	2.07 (3)	1.77 (2.81)	1.75 (2.77)		3.54 (5.61)		3.53 (5.59)	3.53 (5.59)		3.92 (6.21)	1.29 (2.05)	3.50 (5.54)	18.74 (29.7)
	3.45 (5)	3.03 (4.80)			5.35 (8.48)			5.87 (9.31)			2.19 (3.47)	6.25 (9.90)	
38	0.69 (1)												7.00 (11.1)
	1.38 (2)	1.59 (2.52)			2.88 (4.57)			3.32 (5.26)			0.95 (1.50)	2.91 (4.62)	18.74 (29.7)
	2.07 (3)	2.24 (3.55)	2.19 (3.47)		4.11 (6.51)		4.20 (6.65)	4.72 (7.49)		4.47 (7.09)	1.53 (2.42)	4.69 (7.43)	Over 19 (30)
	3.45 (5)	3.58 (5.67)			6.50 (10.30)			7.05 (11.17)			2.50 (3.96)	7.50 (11.88)	

Two entries under Tests 2, 4, and 6 indicate different tests.

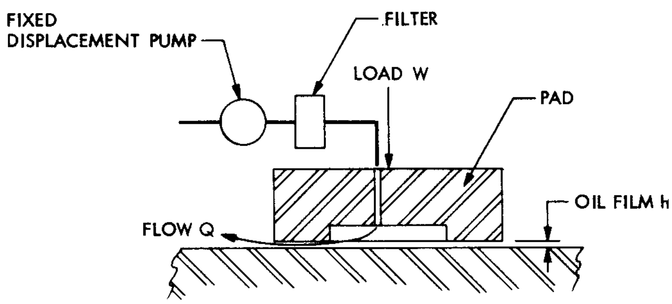
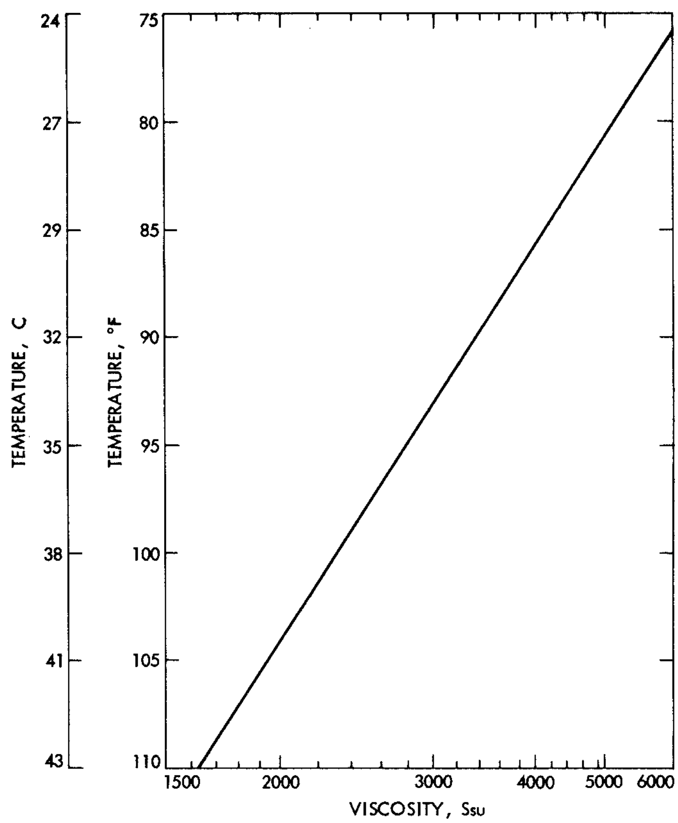


Fig. 1. Typical hydrostatic bearing



TEMPERATURE, °C (°F)	DYNAMIC VISCOSITY, m^2/s	Ssu
25.6 (78)	0.001206	6000
29.4 (85)	0.00888	4107
32.2 (90)	0.00703	3255
34.9 (94.9)	0.00603	2793
37.2 (99)	0.00522	2400
43.3 (110)	0.00357	1600

Fig. 2. Viscosity versus temperature, Exxon EP5 lubricating oil

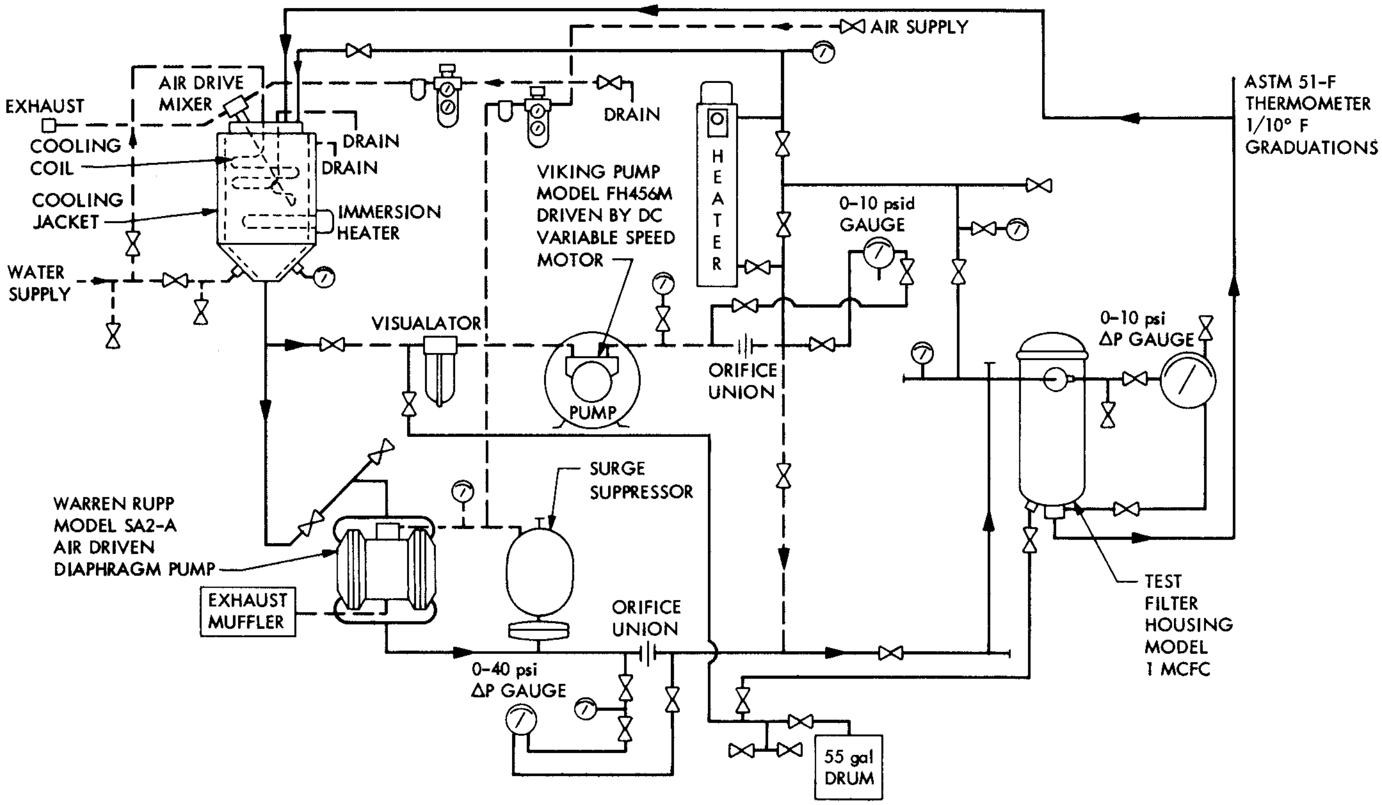


Fig. 3. Flow schematic of oil test facility