Compatibility of Hydraulic System Materials

Compatibility studies of hydraulic materials (seals, metal and fluids) at temperatures of 275°F to 400°F are described. Elastomeric seals of butadiene-acrylonitrile, neoprene, and fluorocarbon types were immersed in MIL-H-5606, MIL-H-8446, MIL-H-83282, and MIL-H-27601 hydraulic fluids. The two methods of immersion which were employed are described. Physical properties and evaluations of the materials are presented.

INTRODUCTION

Materials are required by the Air Force which will perform satisfactorily for 1000 to 10,000 hours in hydraulic systems at temperatures ranging from -65°F to 400°F and above. Such materials will reduce costs through decreased maintenance, hazardous situations, and the need for cooling apparatus. A decreased need for cooling apparatus will decrease weight penalties and, consequently, increase performance.

This paper presents data from material compatibility studies conducted at 275°F to 400°F which are currently needed by industrial and governmental agencies and are preliminary to the ultimate goal of developing a hydraulic package (seal, fluid, and metal) for environmental parameters as described above.

MATERIALS

Elastomers

O-ring packings of the size MS28775-214 (0.139 in cross-section x 0.984 in ID) of various military specification qualified and experimental elastomers were used. These elastomers are coded and described under three different classifications as follows. The coding will be used hereafter in reference to each of the elastomers:

Butadiene-acrylonitrile (NBR)

This material qualified with Military Specification MIL-P-25732B, packing, preformed, petroleum hydraulic fluid resistant, 275°F.

Chloroprene (CR)

CR-B

This neoprene type material was used in the B58 hydraulic system.

Fluorocarbon (FR)

FR-A

This material qualified with Military Specification MIL-R-25897, Rubber, Fluorocarbon Elastomer, High Temperature, Fluid Resistant.

FR-B

This material qualified with Military Specification MIL-R-83248, Rubber, Fluorocarbon Elastomer, High Temperature, Fluid, and Compression Set Resistant.

FR-C

This experimental, high strength material is a special reinforced, peroxide cured fluorocarbon.

FR-D

This experimental material is a low temperature fluorocarbon.

FLUIDS

The following fluids were used:

MIL-H-5606B

Hydraulic Fluid, petroleum Base, Aircraft, Missile, and ordnance.

MIL-H-8446B

Hydraulic Fluid, Non-Petroleum Base, Aircraft.

MIL-H-27601-


MIL-H-83282A

Hydraulic Fluid, Fire Resistant Synthetic Hydrocarbon Base, Aircraft.

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2. Three seals were immersed under 1.5 percent stress by means of a jig of AISI 4140 steel and simultaneously each seal was sandwiched between washers of like metal under ten percent compression, (see Fig. 2). The surface finishes of the jig and washers were approximately fifteen microinches. The assembled jig was separated one inch from the bottom of the test tube by a 42-inch pyrex glass tube.

PHYSICAL PROPERTIES

The following physical properties were determined in accordance with ASTM test methods for rubber and fluid products:

<table>
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<th>PROPERTY</th>
<th>ASTM METHOD</th>
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<tbody>
<tr>
<td>SEALS</td>
<td>D1414</td>
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<tr>
<td>Tensile strength and</td>
<td></td>
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<tr>
<td>elongation</td>
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<tr>
<td>Hardness</td>
<td>D2240</td>
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<tr>
<td>Volume Change</td>
<td>D471-Except conducted on O-rings</td>
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FLUID

<table>
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<tr>
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<tr>
<td>Viscosity</td>
<td>D445</td>
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<td>Acid Number</td>
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</tbody>
</table>

DISCUSSION

The following will be discussed in order: (1) test procedures; (2) materials aged at 275°F; (3) neoprene materials aged at 350° and 400°F; and (4) comparison of data from experimental materials aged at 400°F vs. data from specification materials aged at 275°F.

First, the tests performed are not conducted in accordance with any particular O-ring specification, and, therefore, must not be construed in any way as qualification-test related. Of the two procedures used, however, one is somewhat comparative to standard oil aging procedures for aging O-rings in the free state. The second test is experimental in that the O-ring packings are aged statically under stress and compression, somewhat similar to the actual environment of the hydraulic system. It has several characteristics which are obviously advantageous over oil aging of O-rings in the free state. The seals, fluid and metal, which are to be used in hydraulic systems, are aged together. The combined effects of aging the materials simultaneously allows immediate compatibility screening. (A case history; normal oil aging of NBR seals in an experimental fluorocarbon fluid was satisfactory. However, catastrophic failure occurred when the metal, seals, and fluid were aged together). The effects on each material, such as physical property changes of the seal, with an additional feature of permanent set, can be determined. The characteristic changes of the fluid in the presence of seal and metal can be measured. Although corrosion is not accelerated by this procedure, corrosion and oxidation effects on the metal can be determined, all from the same test procedure. The data indicate that this procedure is not as rigorous with respect to elastomeric properties, in most cases, as the

METAL

The metal jig was entirely constructed of AISI 4140 steel.

PROCEDURES

Oil Aging

Oil aging was conducted in air and nitrogen atmospheres for 72 hours at 275, 400, and, in one case, at 350°F. 38 millimeter (mm) OD by 300 mm pyrex glass test tube was fitted with a stopper containing two lengths of 8 mm pyrex glass tubing, one 3 in. in length, the other 5 in. in length. The 3-in. tubing was extended through and 1/2 in. above the top of the stopper. The 5-in. tubing was extended through and 342 in. above the top of the stopper. A nitrogen atmosphere was provided through tygon tubing attached to the 3-in. glass tube at a flow rate of 0.5 liter per hour. 20 milliliters of oil per gram of rubber seal was used. The test tube was placed in an aluminum block heater in such a manner as to create convection currents in the oil. Two methods of seal immersion were employed as follows:

1. Three seals (packings) were suspended by means of a nichrome wire within 142 in. of the bottom of the test tube, (see Fig. 1).
first test procedure. The tensile, elongation, volume, and hardness changes are somewhat less; the reason being that O-rings are somewhat less exposed to the fluid and oxidation processes. But, one is reminded that these data are obtained from aging the seals, fluid, and metal simultaneously and together and more clearly simulate actual system conditions.

Second, to have some standard for the sake of guidelines in evaluating the overall data the following general requirements for hydraulic seals and fluids are listed:

PROPERTY PERMISSIBLE

O-RING SEALS

Tensile, elongation and hardness As determined

Permanent set, % 4 max

(aired aged)

Volume change, % 0 to 15

FLUIDS

Viscosity, CS @ 100 F, -5 to 20*

Change, %

* These values are those set for bulk fluid properties, within the hydraulic system and are taken from the oxidation/corrosion test procedures (not in the presence of elastomers). The permissible viscosity change of specification MIL-H-8446 is ±35 percent. Exact meaning of these values to those of oxidation/corrosion test is not known.

All the materials, rubber and fluids, shown in Table 1 are qualified materials to the pertinent military specifications. They have performed satisfactorily in the present 275°F hydraulic systems. The data indicate that the results meet all of the requirements shown above. The properties of the seals and fluids after aging in the MIL-H-83282 hydraulic fluids compare favorably to those obtained from aging in MIL-H-5606 hydraulic fluids, except the volume swell of the O-rings is considerably less than in the MIL-H-5606 fluid. The data in Table 2 indicate that chloroprene O-rings are not compatible with either MIL-H-5906 nor MIL-H-83282 hydraulic fluids. The volume swell and softening are excessive.

Third, the data in Table 3 indicate that chloroprene (CR-A) type O-ring property changes are excessive in MIL-H-83282 and MIL-H-27601 type hydraulic fluids at 400°F with little or no change in the viscosity of the fluids. The chloroprene (CR-B) type O-rings have been used satisfactorily in MIL-H-8446 hydraulic fluid in the B58 hydraulic system. The data indicate that the O-ring tensile, elongation, and permanent set changes are excessive when aged at 400°F, but acceptable at 350°F. The viscosity change of the fluid, however, is excessive both at 550°F and 400°F.

Fourth, Tables 4 and 5 show the results of aging fluorocarbon O-rings in MIL-H-83282 and MIL-H-27601 hydraulic fluids at 400°F. The data indicate that the O-ring seal properties meet the arbitrary requirements as set forth earlier in this discussion, except perhaps permanent set in the case of the experimental FR-C and FR-D seals. The permanent set requirement is one of aging in air and is strictly an arbitrary value and cannot be reasonably compared to permanent set after oil aging. Of interest is the comparison of data from aging the fluorocarbon O-rings at 400°F in MIL-H-83282 (A) and MIL-H-27601 hydraulic fluids, shown in Tables 4 and 5, with the data from aging NBR O-rings at 275°F in MIL-H-5606 and MIL-H-83282 (A) hydraulic fluids shown in Table 1. The latter materials have performed satisfactorily in 275°F hydraulic systems. The major and perhaps the most serious property change of the fluorocarbons, particularly FR-B, FR-C, and FR-D, after aging at 400°F in MIL-H-83282 (A) is the decreased hardness which is related to the high and changeable elongation. Generally, these properties can be changed by vulcanization and reinforcement of the rubber compounds. The fluorocarbons aged at 400°F effect the viscosity of the fluid little more than the NBR aged at 275°F. About the same can be said for the fluorocarbons aged @

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400°F in MIL-H-27601. However, the O-ring properties of the fluorocarbons are a little better balanced especially under a nitrogen atmosphere with minimum volume swell. Worthy of note is that MIL-H-27601 does not have oxidative stability above 350°F under an air atmosphere but is intended for use at temperatures up to 600°F under nitrogen atmosphere.

**SUMMARY AND CONCLUSION**

Two oil aging procedures have been employed in this work. In the first procedure, the O-ring seals are suspended in the oil in a “free state” and approximate oil aging of rubber required by several military specifications. Because the whole surface area of the seal is exposed to the oil, maximum changes in properties occur. In a second procedure, the O-rings are aged simultaneously under stress and compression by means of a steel jig. This procedure provides a reasonably simulated, static rubber-metal-oil environment of the hydraulic system. Because the seals are contained in the metal jig, under stress and compression, less surface area of the seal is exposed to the oil. Consequently, the changes in seal properties (tensile, elongation, hardness, and rubber swell) are less, depending upon the combined effects of the metal and oil, and considered much more realistic than the changes provided by the first procedure. In addition, since the hydraulic materials (rubber-metal-oil) are aged in contact and simultaneously, changes in the metal and oil can be determined in addition to seal properties after aging under stress and compression. With minor modification of the jig, including dimensional changes to allow better oil circulation, the second procedure will continue to be used in future screening of hydraulic materials at higher temperatures and inert atmospheric pressures.

The thermal stability of MIL-H-83282 hydraulic fluid precludes its use in hydraulic systems above 450°F. MIL-H-27601, a highly refined, deeply dewaxed mineral oil, is not stable in an oxidative environment above 350°F, but is the only hydraulic oil known to possess thermal stability within viscosity limitations in an inert atmosphere at temperatures up to 600°F. Therefore, at 400°F and above, an inert atmosphere will be required to maintain current material stability in hydraulic systems.
The fluorocarbons are the only elastomeric seals known to be compatible with MIL-H-83282 and MIL-H-27601 hydraulic fluids at temperatures above 350°F. After 72 hours at 400°F, the fluorocarbon seals age comparatively with NBR seals at 275°F. However, the known fluorocarbons available do not remain flexible at -65°F and sealing is precluded under dynamic situations. An experimental fluorocarbon, FR-D type, has been evaluated which has a sealing ability at -40°F to 400°F and above. Research is being conducted for modified fluorocarbons which will hopefully provide, in the near future, sealing capability from -65°F to above 400°F. Efforts will continue to alleviate problem areas in order to develop a satisfactory hydraulic package for high temperature hydraulic systems.

DISCUSSION

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This work is most interesting in that the four major components of rubber fluid sealing are dealt with in a very practical manner. To see the effect of (1) the rubber, (2) the fluid, (3) the metal, and (4) the type of atmosphere is getting into the data all major “elements” of the real world, so to speak.

Separate fluid/rubber considerations are not always satisfactory because metals are not even involved. Also, it has been known for some time that the type of atmosphere is most critical with oxygen being the major culprit to both fluid and rubber. Also, there have probably been cases where the fluid just does not have as bad an effect on the rubber as the rubber has on the fluid.

Since total system compatibility is the only worthy goal, this type of testing should be encouraged for future specifications work and for research and development studies. The author has made many contributions to proper testing of rubber with fluids in the past and should be encouraged to keep up the good effort.

EDITOR'S NOTE

Authors are furnished a copy of each discussion and invited to submit a closure.