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PREFACE

This report details investigations conducted and results obtained in efforts to compare the relative deteriorative effects of typical suppliers' lots of MIL-H-6083 and MIL-H-46170 hydraulic fluids on off-the-shelf elastomeric seal compounds obtained from various vendors. Concurrent comparative studies were conducted using NBR-L, a standard reference compound cited in Aerospace Materials Specification (AMS) 3217. Volume change data for each of the fluid/seal compound iterations were supplemented by measurement of ultimate deteriorated physical properties—tensile strength, elongation, modulus, and hardness. Significant observations made and conclusions derived are summarized herein.

Acknowledgement is given to PVT Michael Robinson, who performed the laboratory seal/compound/fluid immersion testing, and to all seal vendors who supplied the compounds used in this work.

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SECTION I. BACKGROUND

The degree of adequacy employed in military specifications for hydraulic fluids when attempting to correlate fluid performance criteria with those of system seals and O-rings has often been questioned. Specifications for seals are quite comprehensive, citing both requirements for original physical characteristics and limitations on the amount of acceptable deterioration after a period of seal/fluid exposure under accelerated conditions. Hydraulic fluid specifications properly reference essential factors such as the chemical nature of constituents, viscosity, and other flow-related parameters. At most, these documents only casually consider the critical elastomeric components of hydraulic systems. This is usually in the form of a limiting value for volume change at a specified temperature, usually 70°C, of a standard reference material such as NBR-L, cited in AMS 3217. Obviously, requirements for fluids and for seals are both dictated by the needs of the particular hydraulic system-configuration, operating temperatures, and pressures encountered. The formulations for the NBR-L and other reference compounds have remained unchanged for several years, while seal suppliers have continually upgraded their product's performance. Thus, it is felt that volume change requirements of the fluid specifications are meaningless. A gap may have been created between the two interdependent and highly-specialized fields of seal and hydraulic fluid formulation.

Voluntary consensus standards organizations in the elastomer, POL, and related fluids areas—such as SAE Committees G-4 and A-6, and ASTM Committees D-11 and D-2—have recently increased their efforts to promote mutual understanding of the complexities of rubber/fluid compatibility. *Ad-hoc* committees comprised of members from both sides have been formed and, when possible, joint sessions of the relevant main committees have been held. Concurrently, fluid compatibility studies, such as detailed herein, have been conducted to ascertain areas of agreement and disagreement relative to fluid and seal specification performance criteria.

SECTION II. INVESTIGATION

MATERIALS USED

Examples of typical seal compounds, furnished as ASTM test slabs, were solicited from industry suppliers. A total of 17 materials encompassing nitrile, silicone, and fluorocarbon were received from the following sources:

<i>CR Industries</i>	Elgin, IL
<i>Federal Mogul</i>	Detroit, MI
<i>International Packings</i>	Bristol, NH
<i>John Crane</i>	Morton Grove, IL
<i>Parker Seal</i>	Lexington, KY
<i>Precision Rubber</i>	Lebanon, TN
<i>Acushnet</i>	New Bedford, MA
<i>Greene Tweed</i>	Kulpsville, PA

In addition to the above, two other compounds were included: the NBR-L reference compound previously cited, and a hydrogenated nitrile, which was developed in-house for other applications but known to have good fluid resistance properties.

Alphanumeric codes were assigned to all compounds. Numbers are not sequential because other compounds were solicited for concurrent grease studies. Thus, resultant data can be furnished to vendors without violating their proprietary rights.

The nine hydraulic fluids used in the study were categorized according to two types:

- Four fluids (H-6000, H-6001, H-6002, and H-6004) were furnished in accordance with MIL-H-6083, *Hydraulic Fluid, Petroleum Base, For Preservation and Operation*.
- Five fluids (HF-4, HF-12, HF-15, MF-13, and MF-14) were furnished in accordance with MIL-H-46170, *Hydraulic Fluid, Rust Inhibited, Fire-Resistant, Synthetic Hydrocarbon Base*.

TESTS CONDUCTED

A modified test procedure, based on ASTM D-471, *Test Method for Rubber Property—Effect of Liquids*, was followed. Specimens were immersed for 14 days at 212F (100°C), after which volume change and retention of original physical properties were determined. Specimens were allowed to cool to room temperature while still immersed, and kept under these conditions until weighing and testing were completed. Each fluid/seal combination was run in triplicate. The same micro dumbbell specimens used to determine volume change were then extended to break on an Instron testing machine to obtain physical property change data.

RESULTS

Data generated in this study are summarized in Tables 1 through 14 (see Appendix). Tensile and modulus retention percentages in Tables 2 through 10 are based on swollen cross-sectional area, as cited in Federal Test Method Standard (FTMS) 601, *Rubber: Sampling and Testing*, Method 6111, *Tensile Strength and Elongation Immediately After Immersion in Liquids*, rather than computed directly as under ASTM D-471. Modulus retention is based on the 200% determination unless otherwise indicated. If specimen average break was less than 100%, no modulus retention could be determined.

SECTION III. DISCUSSION

PERFORMANCE FACTORS

Acceptance criteria used to analyze the test data evolved were:

- Candidate materials shall retain at least 80% of original tensile strength and elongation;
- Modulus and Shore A hardness changes shall not be excessive (i.e., more than 10 hardness points, or greater than 20% modulus change); and
- Volume change shall be confined to a maximum of 10 to 15% swelling, with any sign of shrinkage signifying immediate rejection.

ORIGINAL PHYSICAL PROPERTIES

Examination of the initial physical properties data of Table 1 indicates that typical seal compounds as supplied by the industry tend to display moderate tensile strength, averaging slightly above 2,000 psi. Elongation was generally low, with some compounds having values well below 200%. Shore hardnesses were in the 65 to 86 points range, while 100% or 200% moduli were indicative of a high state of vulcanization. This correlated well with intended application. Sealing effectiveness is contingent upon retention of integrity while allowing a limited degree of "fluidity" to conform to the configuration of the area to be sealed.

DATA TRANSLATION

The extensive data generated are difficult to analyze and discuss as summarized in Tables 2 through 10. Comparisons of seal material performance either within each fluid type (MIL-H-6083 or MIL-H-46170), or between types, would likewise be difficult. For these reasons, Table 11, a 1-page summarization of all negative effects of the test fluids on measured physical properties, was prepared. Here, the numbers 1 through 8 identify changes deemed excessive and thus detrimental to seal performance, using the limits cited in the previous paragraph. Blocks containing no numbers thus signify full acceptability of the fluid/rubber combination identified therein. Use of this convention obviously excludes any reference to the magnitude of nonconformance.

INTERPRETATION OF DATA

Examination of Table 11 reveals the emergence of certain patterns or trends in seal material performance. Compound 8F-29 evidenced only one failure—excessive tensile loss in fluid H-6002—and thus would head any ranking according to preference. Compounds 8F-1, 8F-4, and

8F-5, which displayed shrinkage or essentially very low swelling, would be disqualified for general use. The latter two compounds however, might be considered marginally acceptable for MIL-H-6083 use only, assuming that instances of modulus increase are not deemed critical factors. Compounds 8F-10, 8F-12, and 8F-31 (the NBR-L reference material) displayed practically identical performance patterns. Poor retention of tensile and elongation correlated with excessive swelling and softening (decrease in hardness). Compound 8F-13 was the only compound found failure-free in the MIL-H-6083 grouping. Three candidates—8F-22, 8F-29 and 8F-32—met all criteria in the MIL-H-46170 fluids. Excessive elongation loss was the most frequently observed deficiency, occurring 81 times, and at least once for all compound iterations except 8F-13, 8F-22, 8F-23, 8F-29, and 8F-32. High tensile strength losses and pronounced increases in modulus were the next most frequently occurring type of failure, but never simultaneously within a specific compound/fluid combination. The lower frequency of occurrence and erratic patterns displayed elsewhere in Table 11 are indicative of subtle differences in formulation within the two types of fluids and perhaps a tendency for suppliers to adhere as closely as possible to performance limitations.

TENSILE PRODUCT

In order to further analyze both the subtle and apparent differences between fluid types and among candidate compounds, Table 12 was prepared. Here, tensile products [percent tensile strength retained *times* percent elongation retained *divided by* 1,000] are presented for all iterations. Table 12 also includes total row averages, MIL-H-6083 fluid averages, MIL-H-46170 averages, and differences according to fluid type. With the exception of compounds 8F-14 and 8F-16, which had statistically equivalent values for both fluid types, higher tensile products were noted for those materials exposed in MIL-H-46170 fluids. Compounds 8F-19 and 8F-22 showed the greatest amount of improved performance in this regard. The previously noted similar and poor performances of compounds 8F-10, 8F-12, and 8F-31 are again evident, while the highest aggregate tensile products are observed for 8F-22 and 8F-23. Performances of 8F-13, 8F-19, 8F-26, and 8F-29 are also considered good.

VOLUME CHANGE

A similar comparison but based on volume change data is presented in Table 13. A greater amount of swelling in the MIL-H-6083 fluids was noted in all cases except, of course, when shrinkage occurred in either or both types of fluid. Swelling correlated inversely with performance as indicated by tensile product; i.e., low for highly-rated 8F-22 and 8F-23, and extremely high for the worst compounds, such as 8F-10 and 8F-12. The presence of many intermediately grouped differences reflects the inadequacy of basing performance solely on volume change information. Conversely, referring back to Table 12, tensile product data is not always infallible. Relatively good tensile product values for 8F-1, 8F-4, and 8F-5, mask the aforementioned shrinkage. Table 13 also contains a comparison of NBR-L swell data, extracted from fluid suppliers' conformance testing reports, with values obtained in this work. As noted, tests were conducted at 100°C and 70°C,

respectively. The lower exposure temperature used by the suppliers consistently resulted in higher swell values, a sign that choice of test conditions is critical. Additionally, it is known that testing at 100°C may, in some cases, not duplicate certain in-service conditions which may be as much as 20 or 30°C higher, or even lower than the currently referenced 70°C. Insufficient data was generated here to conclusively establish any trends.

MIXED IMMERSIONS

Table 14 contains the results of a very limited attempt to access the effects of mixed immersion of two compounds, using one MIL-H-6083 and one MIL-H-46170 fluid—H-6002 and HF-15, respectively. Compounds 8F-5 and 8F-12 were immersed in each fluid for 1 week at 100°C and then tested. Ultimate volume changes for both were intermediate, but biased toward the MIL-H-6083 fluid. Hardness change for the 8F-5 was also intermediate but biased toward the MIL-H-46170 fluid, while the loss for 8F-12 after mixed immersion was less than found for either individual exposure. The final tensile product of 8F-12 was only slightly less and the corresponding value for 8F-5 deemed essentially equivalent to that observed when singly immersed for 2 weeks in the MIL-H-46170 fluid (HF-15). Changes in modulus retention paralleled those for hardness—intermediate for 8F-5, but outside of the range found for 8F-12. It is apparent that one cannot assume mixed immersions will always effect an across-the-board intermediate change in all physical properties. Therefore, indiscriminate use or improper citing of correct hydraulic fluids entails a certain amount of risk relative to the adequacy of seal performance.

GRAPHED DATA

To further emphasize performance differences between MIL-H-6083 and MIL-H-46170 hydraulic fluids and illustrate the shortcomings of NBR-L as a reference elastomer compound in fuel and fluid qualification work, Figures 1 and 2 were prepared (see Appendix pages A-16 and A-17). As indicated in Figure 1, higher tensile product averages for seal compounds exposed to MIL-H-46170 fluids generally correlated with lower volume changes. No compound immersed in MIL-H-6083 fluid evidenced a tensile product greater than 10. This plateau was reached by five materials when exposed to the MIL-H-46170 fluids. An intermediate group of compounds is readily discernable. These, such as 8F-2, 8F-3, 8F-14, and 8F-16, showed low volume changes, but tensile products were only fair. The tendency for compounds displaying shrinkage or very low swelling to generate reasonably good tensile product values (8F-1, 8F-4, and 8F-5) is also evident. Figure 2 compares performance of reference compound NBR-L (8F-31) against all other candidates in each fluid. The magnitude of difference (relatively inferior showing) of the NBR-L is quite apparent, indicating that the compound is not representative of the average quality of off-the-shelf seals. Currently, NBR-L is used to qualify fluids, but solely based on satisfying a stipulated volume change level. Volume change averages for all compounds in each of the fluid type groups were derived from Table 13 and compared with that for NBR-L in the following table:

Table of Volume Change Averages

	MIL-H-6083	MIL-H-46170
All compounds	12.06	5.22
NBR-L	23.90	17.15
Difference	11.84	11.93

The above figures include all outliers; i.e., compounds displaying shrinkage or very high swelling (8F-1, 8F-4, 8F-5, 8F-10, and 8F-12). If these were excluded from consideration, compound averages would be lower and the gap even greater. Thus, one would surmise that the state-of-the-art relative to selection of reference compounds is not consistent with the quality of off-the-shelf seal materials. Here, only two classes of hydraulic fluid have been screened. Whether this tendency persists throughout the range of other hydraulic fluid compliance standards is unknown. It is known that AMS 3217, the document citing NBR-L and other standard elastomer compounds, is considered outdated and, as demonstrated in this study, revision is needed.

SECTION IV. CONCLUSIONS

- Performance of typical suppliers' off-the-shelf seal compounds, in terms of volume change and retention of physical properties, is better in MIL-H-46170 hydraulic fluids than in fluids conforming to MIL-H-6083.
- Reliance on volume change as the sole criterion for seal/fluid compatibility is risky. Extent of swelling or shrinkage does not always correlate with exposure-inflicted deterioration in tensile strength and elongation, changes in modulus, and hardening or softening.
- The performance of standard reference compound NBR-L, cited in AMS 3217, in both types of hydraulic fluid used in this study was generally inferior to that observed for the representative suppliers' compounds.
- Fluid qualification, based on volume change data from NBR-L immersions, does not sufficiently focus on the actual in-service exposure conditions typically encountered.
- Use of one reference test temperature (70° or 100°C) may be inadequate to accurately assess potential in-service performance. Limited comparisons derived from this work indicate that volume changes at elevated temperatures are lower than at the cited levels.
- Likewise, use of one volume swell limit (such as 15% minimum swell) for differing classes or types of hydraulic fluid may, in some instances, be unrealistic.
- Alternating exposure of elastomeric seals to hydraulic fluids satisfying dissimilar qualification standards may effect synergistic changes in physical properties, rather than the assumed intermediate changes.

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Table 1. Original Physical Properties—Fluid-Resistant Compounds

Compound	Tensile Str. psi	Elong. %	100% Mod. psi	200% Mod. psi	Hardness Shore A
8F-1	2500.00	211.00	1390.00	2425.00	77.00
8F-2	2603.00	389.00	587.00	1525.00	69.00
8F-3	2487.00	140.00	1812.00	—	80.00
8F-4	2230.00	178.00	1260.00	—	67.00
8F-5	1990.00	178.00	1137.00	—	68.00
8F-9	2705.00	531.00	612.00	797.00	69.00
8F-10	1211.00	149.00	991.00	—	79.00
8F-12	2160.00	272.00	810.00	1713.00	66.00
8F-13	1916.00	170.00	1170.00	—	75.00
8F-14	1802.00	142.00	1290.00	—	74.00
8F-16	1981.00	73.00	—	—	86.00
8F-19	1983.00	204.00	970.00	1985.00	69.00
8F-22	1934.00	281.00	806.00	1413.00	70.00
8F-23	1761.00	166.00	1260.00	—	74.00
8F-26	2054.00	250.00	824.00	1823.00	65.00
8F-27	1930.00	120.00	1540.00	—	84.00
8F-29	1995.00	86.00	1302.00	—	79.00
8F-31	2896.00	242.00	1033.00	2428.00	71.00
8F-32	4967.00	484.00	588.00	1095.00	80.00

Table 2. Retention of Properties—Fluid H-6000

Compound	Tensile Ret. %	Elong. Ret. %	200% Mod. Ret. - %	Hard. Chge. pts.	Vol. Chge. %
8F-1	111.47	65.88	*167.86	11.00	-9.56
8F-2	97.10	75.32	124.94	-1.00	7.78
8F-3	89.42	50.71	—	-6.00	8.14
8F-4	105.10	85.96	*131.03	-2.00	5.31
8F-5	105.47	80.34	*133.46	.00	3.03
8F-9	83.06	72.50	115.01	-4.00	9.02
8F-10	48.21	67.11	*58.92	-20.00	63.06
8F-12	66.19	63.97	*133.46	-15.00	24.77
8F-13	105.82	91.18	*116.67	-5.00	7.67
8F-14	94.16	70.42	*129.84	-5.00	8.63
8F-16	96.67	82.19	—	-5.00	9.46
8F-19	65.03	78.92	*84.01	-5.00	9.73
8F-22	72.51	100.36	65.20	-5.00	7.21
8F-23	68.79	122.89	*69.54	-4.00	4.44
8F-26	80.33	50.00	*144.70	-6.00	14.50
8F-27	77.13	64.17	—	-4.00	6.45
8F-29	89.40	98.84	—	-7.00	10.82
8F-31	56.90	63.64	*98.19	-15.00	20.87
8F-32	76.87	92.15	94.63	-8.00	14.63

* = 100% Mod.

Table 3. Retention of Properties—Fluid H-6001

Compound	Tensile Ret. %	Elong. Ret. %	200% Mod. Ret. - %	Hard. Chge. pts.	Vol. Chge. %
8F-1	107.12	70.62	*148.78	11.00	-8.72
8F-2	95.59	81.23	108.85	-1.00	8.42
8F-3	74.80	70.71	—	-4.00	7.90
8F-4	103.33	87.64	*116.07	-1.00	6.69
8F-5	103.15	85.39	*117.76	1.00	4.06
8F-9	78.37	82.49	101.02	-2.00	9.04
8F-10	48.91	46.31	—	-18.00	65.25
8F-12	72.44	77.21	88.46	-12.00	27.08
8F-13	106.68	91.76	*106.24	-6.00	8.93
8F-14	99.22	85.21	*112.28	-5.00	10.06
8F-16	101.02	90.41	—	-6.00	9.26
8F-19	78.88	92.16	*85.36	-4.00	3.46
8F-22	86.81	110.32	76.58	-7.00	4.87
8F-23	75.96	138.55	*67.35	-6.00	3.99
8F-26	77.33	150.00	57.40	-11.00	15.64
8F-27	87.40	66.67	—	-5.00	8.67
8F-29	88.72	105.81	—	-7.00	12.35
8F-31	60.77	70.25	*84.31	-16.00	25.42
8F-32	71.64	95.45	84.57	-8.00	16.11

* = 100% Mod.

Table 4. Retention of Properties—Fluid H-6002

Compound	Tensile Ret. %	Elong. Ret. %	200% Mod. Ret. - %	Hard. Chge. pts.	Vol. Chge. %
8F-1	120.10	87.20	*150.95	7.00	-12.39
8F-2	94.17	71.98	123.28	-3.00	7.92
8F-3	79.67	70.00	—	-7.00	10.36
8F-4	101.34	85.96	*120.88	-3.00	7.26
8F-5	102.98	80.34	*126.79	-1.00	4.33
8F-9	76.24	79.47	97.55	-6.00	8.90
8F-10	47.39	36.91	—	-21.00	65.45
8F-12	69.85	66.18	*113.56	-14.00	27.91
8F-13	106.82	90.59	*115.03	-6.00	8.94
8F-14	85.45	64.08	—	-4.00	10.51
8F-16	94.48	79.45	—	1.00	9.62
8F-19	89.80	114.22	85.63	-1.00	1.79
8F-22	95.10	106.05	86.82	-4.00	2.36
8F-23	83.61	114.46	*83.07	-2.00	1.49
8F-26	78.45	138.40	60.74	-10.00	15.21
8F-27	88.81	78.33	—	-5.00	7.71
8F-29	68.63	80.23	—	-7.00	12.61
8F-31	53.59	58.68	*99.13	-18.00	25.74
8F-32	74.88	90.08	90.07	-9.00	16.50

* = 100% Mod.

Table 5. Retention of Properties—Fluid H-6004

Compound	Tensile Ret. %	Elong. Ret. %	200% Mod. Ret. - %	Hard. Chge. pts.	Vol. Chge. %
8F-1	111.41	78.67	*147.98	12.00	-8.97
8F-2	100.01	82.26	121.38	-2.00	7.62
8F-3	89.86	77.14	*109.91	-5.00	8.73
8F-4	99.65	88.76	*116.66	-1.00	5.36
8F-5	101.27	87.64	*118.08	1.00	2.97
8F-9	76.80	80.79	94.34	-3.00	9.34
8F-10	44.26	52.35	—	-18.00	65.17
8F-12	67.56	76.84	82.87	-5.00	23.94
8F-13	100.59	97.06	*100.55	-4.00	7.29
8F-14	98.11	88.73	*109.90	-4.00	8.17
8F-16	85.22	80.82	—	-3.00	8.26
8F-19	57.14	87.25	*69.79	-2.00	4.24
8F-22	78.28	103.20	73.18	-6.00	5.40
8F-23	64.61	138.55	*61.56	-6.00	4.55
8F-26	75.15	142.00	56.33	-7.00	13.44
8F-27	76.55	80.00	—	.00	5.48
8F-29	86.78	108.14	—	-4.00	10.10
8F-31	49.42	63.64	*80.20	-14.00	23.55
8F-32	74.39	93.18	88.17	-11.00	14.87

* = 100% Mod.

Table 6. Retention of Properties—Fluid HF-4

Compound	Tensile Ret. %	Elong. Ret. %	200% Mod. Ret. - %	Hard. Chge. pts.	Vol. Chge. %
8F-1	116.58	74.41	*78.18	11.00	-10.93
8F-2	103.64	70.95	142.53	2.00	3.71
8F-3	89.68	72.86	*119.39	4.00	4.52
8F-4	106.31	75.84	*144.09	3.00	.78
8F-5	119.75	79.78	*153.33	5.00	-2.26
8F-9	87.99	78.91	114.70	.00	5.27
8F-10	76.04	65.77	—	-14.00	20.71
8F-12	83.64	69.49	*124.41	-12.00	17.00
8F-13	111.70	82.94	*133.78	-3.00	3.16
8F-14	100.99	71.83	*138.27	1.00	3.66
8F-16	101.54	72.60	—	-4.00	3.94
8F-19	83.43	106.86	77.02	-8.00	2.97
8F-22	112.13	109.96	95.54	-5.00	3.01
8F-23	83.47	138.55	*75.78	-7.00	2.87
8F-26	83.83	123.60	70.28	-11.00	11.90
8F-27	85.02	67.50	—	.00	2.48
8F-29	95.40	97.67	—	-5.00	6.03
8F-31	76.14	72.73	*105.95	-14.00	17.97
8F-32	85.18	81.61	119.64	-6.00	11.30

* = 100% Mod.

Table 7. Retention of Properties—Fluid HF-12

Compound	Tensile Ret. %	Elong. Ret. %	200% Mod. Ret. - %	Hard. Chge. pts.	Vol. Chge. %
8F-1	116.58	74.41	*78.18	11.00	-10.93
8F-2	103.64	70.95	142.53	2.00	3.71
8F-3	89.68	72.86	*119.30	4.00	4.52
8F-4	106.31	75.84	*144.00	3.00	.78
8F-5	119.75	79.78	*153.30	5.00	-2.26
8F-9	87.99	78.91	114.70	.00	5.27
8F-10	76.04	65.77	—	-14.00	20.71
8F-12	83.64	69.49	124.41	-12.00	17.00
8F-13	111.70	82.94	*133.78	-3.00	3.16
8F-14	100.99	*71.83	138.27	1.00	3.66
8F-16	101.54	72.60	—	-4.00	3.94
8F-19	83.43	106.86	77.02	-8.00	2.97
8F-22	112.13	109.96	95.54	-5.00	3.01
8F-23	83.47	138.55	*75.78	-7.00	2.87
8F-26	83.83	123.60	*70.28	-11.00	11.90
8F-27	85.02	67.50	—	.00	2.48
8F-29	95.40	97.67	—	-5.00	6.03
8F-31	76.14	72.73	*105.95	-14.00	17.97
8F-32	85.18	81.61	119.64	-6.00	11.30

* = 100% Mod.

Table 8. Retention of Properties—Fluid HF-15

Compound	Tensile Ret. %	Elong. Ret. %	200% Mod. Ret. - %	Hard. Chge. pts.	Vol. Chge. %
8F-1	121.41	67.30	*184.26	6.00	-11.15
8F-2	105.29	81.23	128.82	-2.00	3.49
8F-3	91.09	69.29	—	-1.00	3.50
8F-4	114.73	87.64	*136.51	3.00	- .61
8F-5	114.92	76.97	*152.23	6.00	-3.00
8F-9	76.74	80.98	100.26	-1.00	5.48
8F-10	77.39	73.15	*91.98	-14.00	20.11
8F-12	89.85	80.15	105.22	-10.00	15.22
8F-13	117.22	90.00	*127.23	-4.00	1.77
8F-14	103.26	73.24	*132.59	1.00	1.63
8F-16	105.09	82.19	—	-2.00	3.49
8F-19	91.86	114.22	83.35	-4.00	2.59
8F-22	103.41	114.59	86.98	-5.00	1.96
8F-23	84.94	138.55	*77.35	4.00	2.23
8F-26	105.00	58.40	*171.96	-4.00	8.70
8F-27	89.73	77.50	—	3.00	.71
8F-29	102.14	115.12	—	.00	2.91
8F-31	76.38	74.38	*101.13	-7.00	16.55
8F-32	84.29	90.50	108.06	-3.00	10.80

* = 100% Mod.

Table 9. Retention of Properties—Fluid MF-13

Compound	Tensile Ret. %	Elong. Ret. %	200% Mod. Ret. - %	Hard. Chge. pts.	Vol. Chge. %
8F-1	123.60	79.15	*171.38	13.00	-11.00
8F-2	103.95	76.35	133.18	.00	3.64
8F-3	92.24	75.00	*121.07	-2.00	4.08
8F-4	111.05	76.97	*148.51	4.00	.22
8F-5	120.99	78.65	*158.80	6.00	-2.28
8F-9	85.53	80.60	115.06	-3.00	6.44
8F-10	78.09	64.43	—	-12.00	20.52
8F-12	85.85	71.32	*119.46	-9.00	15.30
8F-13	118.31	88.24	*131.63	-1.00	2.14
8F-14	105.74	70.42	*142.60	3.00	2.65
8F-16	108.97	76.71	—	-1.00	3.52
8F-19	94.94	117.16	86.03	-3.00	2.67
8F-22	98.07	104.98	92.93	-3.00	2.17
8F-23	84.94	141.57	*76.13	-2.00	2.64
8F-26	92.28	140.00	69.02	-7.00	10.02
8F-27	100.00	67.50	—	4.00	1.32
8F-29	95.77	97.67	—	.00	3.50
8F-31	72.91	64.05	*117.55	-10.00	16.95
8F-32	78.65	84.50	113.54	-4.00	15.04

* = 100% Mod.

Table 10. Retention of Properties—Fluid MF-14

Compound	Tensile Ret. %	Elong. Ret. %	200% Mod. Ret. - %	Hard. Chge. pts.	Vol. Chge. %
8F-1	123.05	85.31	*161.31	13.00	-11.10
8F-2	105.33	79.18	129.87	2.00	3.92
8F-3	93.60	77.86	*121.73	2.00	4.68
8F-4	111.09	84.27	*134.78	3.00	1.13
8F-5	111.51	80.34	*137.66	3.00	-1.55
8F-9	88.28	84.75	107.53	-4.00	5.83
8F-10	79.34	79.87	*89.65	-11.00	22.65
8F-12	87.71	79.78	102.97	-9.00	16.86
8F-13	124.07	99.41	*124.76	-7.00	3.86
8F-14	95.60	71.13	*132.03	3.00	3.26
8F-16	83.42	68.49	—	-2.00	4.52
8F-19	67.94	114.71	66.24	-4.00	3.10
8F-22	116.21	120.28	87.78	3.00	2.38
8F-23	83.03	148.80	*76.17	-4.00	2.56
8F-26	81.66	201.60	91.70	-8.00	11.36
8F-27	82.53	59.17	—	-10.00	2.47
8F-29	94.39	104.65	—	-2.00	4.64
8F-31	72.34	73.97	*95.69	-12.00	18.35
8F-32	88.01	93.80	102.52	-4.00	11.76

* = 100% Mod.

Table 11. Effect of Fluids on Physical Properties

ID	MIL-H-6083 Fluids				MIL-H-46170 Fluids				
	H-6000	H-6001	H-6002	H-6004	HF-4	HF-12	HF-15	MF-13	MF-14
8F-1	2, 3, 5, 7	2, 3, 5, 7	3, 5	3, 5	2, 3, 5, 7	2, 3, 5, 7	2, 3, 5	2, 3, 5, 7	3, 5, 7
8F-2	2, 3	1, 2	3	3	2, 3	2, 3	3	2, 3	2, 3
8F-3	2	1, 2	1, 2	2	2	2	2	2, 3	2, 3
8F-4	3				2, 3	2, 3	3, 5	2, 3	3
8F-5	3		3		2, 3, 5	2, 3, 5	2, 3, 5	2, 3, 5	3, 5
8F-9	2	1	1, 2	1	2	2	1		
8F-10	1, 2, 4, 6, 8	1, 2, 6, 8	1, 2, 6, 8	1, 2, 6, 8	1, 2, 6, 8	1, 2, 6, 8	1, 2, 6, 8	1, 2, 6, 8	1, 2, 6, 8
8F-12	1, 2, 6, 8	1, 2, 6, 8	1, 2, 6, 8	1, 2, 6	2, 3, 6, 8	2, 3, 6, 8	8	2	2, 6
8F-13					3	3	3	3	3
8F-14	2, 3		2		2, 3	2, 3	2, 3	2, 3	2, 3
8F-16			2		2	2		2	2
8F-19	1, 2	1		1, 4	4	4			4
8F-22	1, 4	4		1, 4					
8F-23	1, 4	1, 4		1, 4	4	4	4	4	4
8F-26	2, 3	1, 4, 8	1, 4, 8	1, 4	4, 8	4, 8	2, 3	4	
8F-27	1, 2	2	2	1	2	2	2	2	2
8F-29			1						
8F-31	1, 2, 6, 8	1, 2, 6, 8	1, 2, 6, 8	1, 2, 6, 8	1, 2, 6, 8	1, 2, 6, 8	1, 2, 6	1, 2, 6	1, 2, 6, 8
8F-32	1	1	1, 6	1, 8					

1 = excessive tensile loss

2 = excessive elongation loss

3 = excessive modulus increase

4 = excessive modulus decrease

5 = shrinkage

6 = excessive swelling

7 = excessive hardness increase

8 = excessive hardness decrease

Table 12. Seal/Fluid Compatibility—Tensile Product

Comp.	MIL-H-6083 Fluids				MIL-H-46170 Fluids				
	H-6000	H-6001	H-6002	H-6004	HF-4	HF-12	HF-15	MF-13	MF-14
8F-1	7.34	7.56	10.47	8.76	8.67	9.33	8.17	9.78	10.50
8F-2	7.31	7.76	6.78	8.23	7.35	8.23	8.55	7.94	8.34
8F-3	4.53	5.29	5.58	6.93	6.53	6.48	6.31	6.92	7.29
8F-4	9.03	9.06	8.71	8.85	8.06	10.21	10.05	8.55	9.36
8F-5	8.47	8.81	8.27	8.88	9.55	9.64	8.85	9.52	8.96
8F-9	6.02	6.46	6.06	6.20	6.94	7.84	6.21	6.89	7.48
8F-10	3.24	2.26	1.75	2.32	5.00	4.87	5.66	5.03	6.34
8F-12	4.23	5.59	4.62	5.19	5.81	7.16	7.20	6.12	7.00
8F-13	9.65	9.79	9.68	9.76	9.26	10.32	10.55	10.44	12.33
8F-14	6.63	8.45	5.48	8.71	7.25	7.49	7.56	7.45	6.80
8F-16	7.95	9.13	7.51	6.89	7.37	9.23	8.64	8.36	5.71
8F-19	5.13	7.27	10.26	4.99	8.92	12.25	10.49	11.12	7.79
8F-22	7.28	9.58	10.08	8.08	12.33	13.20	11.85	10.30	13.98
8F-23	8.45	10.52	9.57	8.95	11.57	12.68	11.77	12.02	12.35
8F-26	4.02	11.60	10.86	10.67	10.36	7.45	6.13	12.92	16.46
8F-27	4.95	5.83	6.96	6.12	5.74	6.92	6.95	6.75	4.88
8F-29	8.84	9.39	5.51	9.38	9.32	10.92	11.76	9.35	9.88
8F-31	3.62	4.27	3.14	3.14	5.54	5.58	5.68	4.67	5.35
8F-32	7.08	6.84	6.75	6.93	6.95	7.66	7.63	6.65	8.26
Avg.	6.51	7.66	7.26	7.32	8.03	8.81	8.42	8.46	8.90
	Row Avg.	H Fluid Avg.	HF/MF Avg.	Diff.					
8F-1	8.96	8.54	9.29	.76					
8F-2	7.83	7.52	8.08	.56					
8F-3	6.21	5.58	6.71	1.13					
8F-4	9.10	8.91	9.25	.34					
8F-5	8.99	8.61	9.30	.70					
8F-9	6.68	6.19	7.07	.89					
8F-10	4.05	2.39	5.38	2.99					
8F-12	5.88	4.91	6.66	1.75					
8F-13	10.20	9.72	10.58	.86					
8F-14	7.31	7.32	7.31	-.01					
8F-16	7.87	7.87	7.86	-.01					
8F-19	8.69	6.91	10.11	3.20					
8F-22	10.74	8.76	12.33	3.58					
8F-23	10.88	9.37	12.08	2.71					
8F-26	10.05	9.29	10.66	1.38					
8F-27	6.12	5.96	6.25	.28					
8F-29	9.37	8.28	10.25	1.97					
8F-31	4.55	3.54	5.36	1.82					
8F-32	7.19	6.90	7.43	.53					

Table 13. Seal/Fluid Compatibility—Volume Change

Comp.	MIL-H-6083 Fluids				MIL-H-46170 Fluids				
	H-6000	H-6001	H-6002	H-6004	HF-4	HF-12	HF-15	MF-13	MF-14
8F-1	-9.56	-8.72	-12.39	-8.97	-10.93	-11.37	-11.15	-11.00	-11.10
8F-2	7.78	8.42	7.92	7.62	3.71	3.64	3.49	3.64	3.92
8F-3	8.14	7.90	10.36	8.73	4.52	4.62	3.50	4.08	4.68
8F-4	5.31	6.69	7.26	5.36	.78	-.06	-.61	.22	1.13
8F-5	3.03	4.06	4.33	2.97	-2.26	-2.04	-3.00	-2.28	-1.55
8F-9	9.02	9.04	8.90	9.34	5.27	5.38	5.48	6.44	5.83
8F-10	63.06	65.25	65.45	65.17	20.71	21.61	20.11	20.52	22.65
8F-12	24.77	27.08	27.91	23.94	17.00	14.91	15.22	15.30	16.86
8F-13	7.67	8.93	8.94	7.29	3.16	3.90	1.77	2.14	3.86
8F-14	8.63	10.06	10.51	8.17	3.66	2.27	1.63	2.65	3.26
8F-16	9.46	9.26	9.62	8.26	3.94	3.70	3.49	3.52	4.52
8F-19	9.73	3.46	1.79	4.24	2.97	2.34	2.59	2.67	3.10
8F-22	7.21	4.87	2.36	5.40	3.01	2.36	1.96	2.17	2.38
8F-23	4.44	3.99	1.49	4.55	2.87	2.44	2.23	2.64	2.56
8F-26	14.50	15.64	15.21	13.44	11.90	9.11	8.70	10.02	11.36
8F-27	6.45	8.67	7.71	5.48	2.48	.86	.71	1.32	2.47
8F-29	10.82	12.35	12.61	10.10	6.03	3.32	2.91	3.50	4.64
8F-31	20.87	25.42	25.74	23.55	17.97	15.91	16.55	16.95	18.35
8F-32	14.63	16.11	16.50	14.87	11.30	11.45	10.80	11.76	11.76
Avg.	11.89	12.55	12.22	11.55	5.69	4.97	4.55	5.07	5.83

Row	Avg.	H Fluid	HF/MF	Diff.	NBR-L (8F-31) Comparison		
					Fluid	Mfr. R & CF	
		Avg.	Avg.			70°C	100°C
8F-1	-10.58	-9.91	-11.11	1.20			
8F-2	5.57	7.94	3.68	4.26			
8F-3	6.28	8.78	4.28	4.50			
8F-4	2.90	6.16	.29	5.86	H-6000	25.0	20.0
8F-5	.36	3.60	-2.23	5.82	H-6001	26.0	25.4
8F-9	7.19	9.07	5.68	3.39	H-6002	26.5	25.7
8F-10	40.50	64.73	21.12	43.61	H-6004	—	23.6
8F-12	20.33	25.93	15.86	10.07	HF-4	21.4	18.0
8F-13	5.30	8.21	2.97	5.24	HF-12	19.9	15.9
8F-14	5.65	9.34	2.69	6.65	HF-15	19.5	16.6
8F-16	6.20	9.15	3.83	5.32	MF-13	20.0	17.0
8F-19	3.65	4.81	2.73	2.07	MF-14	23.2	18.4
8F-22	3.52	4.96	2.38	2.58			
8F-23	3.02	3.62	2.55	1.07			
8F-26	12.21	14.70	10.22	4.48			
8F-27	4.02	7.08	1.57	5.51			
8F-29	7.36	11.47	4.08	7.39			
8F-31	20.15	23.90	17.15	6.75			
8F-32	13.24	15.53	11.41	4.11			

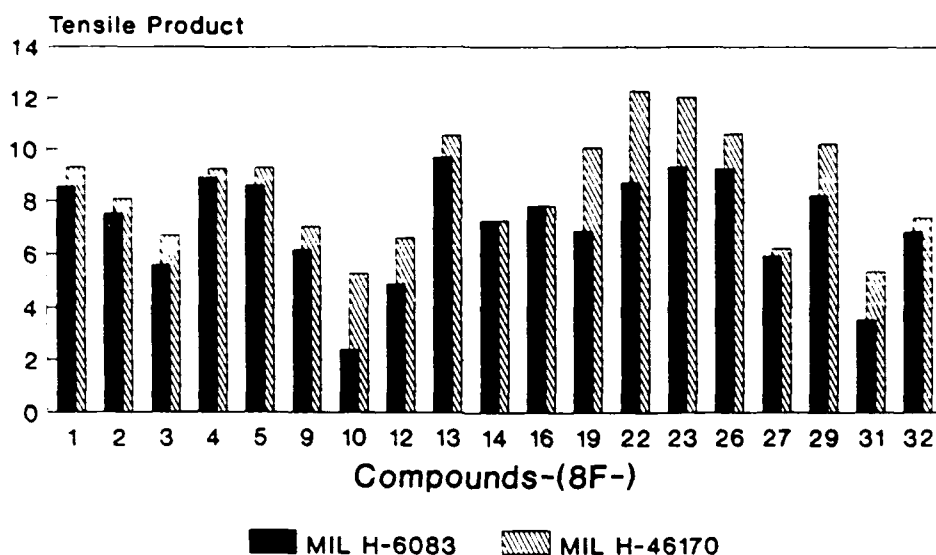
Table 14. Retention of Properties—Mixed Fluid Immersion

Compound	Tensile Ret. %	Elong. Ret. %	200% Mod. Ret. - %	Hard. Chge. pts.	Vol. Chge. %
8F-5					
H-6002	103	80	*127	-1	4.3
HF-15	115	77	*152	6	-3.0
Mixed	115	78	*138	1	-1.4
8F-12					
H-6002	70	66	*114	-14	27.9
HF-15	90	80	105	-10	15.2
Mixed	84	82	95	-8	16.6

* = 100% Mod.

	Tensile Product		
	H-6002	HF-15	Mixed
8F-5	8.27	8.85	8.94
8F-12	4.62	7.20	6.86

Tensile Product Averages MIL H-6083 vs. MIL H-46170



Volume Change Averages MIL H-6083 vs. MIL H-46170

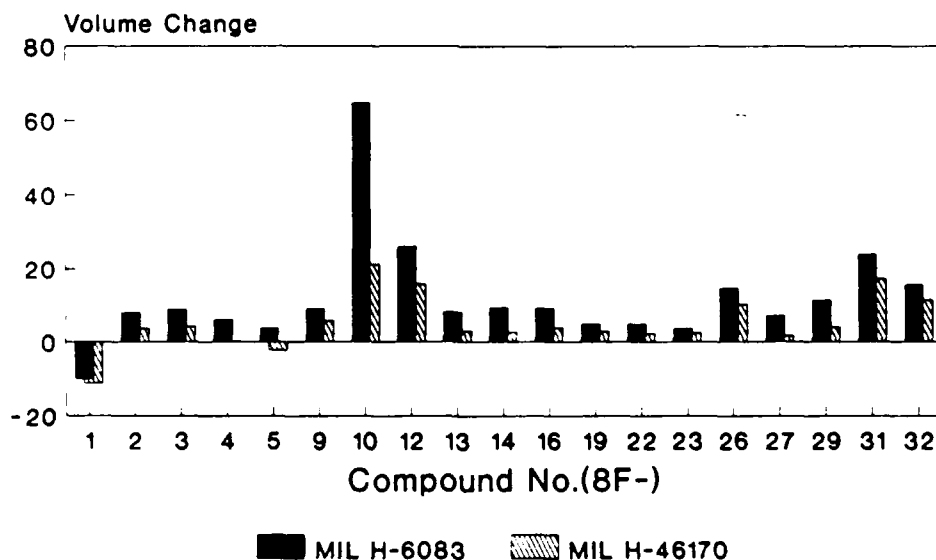
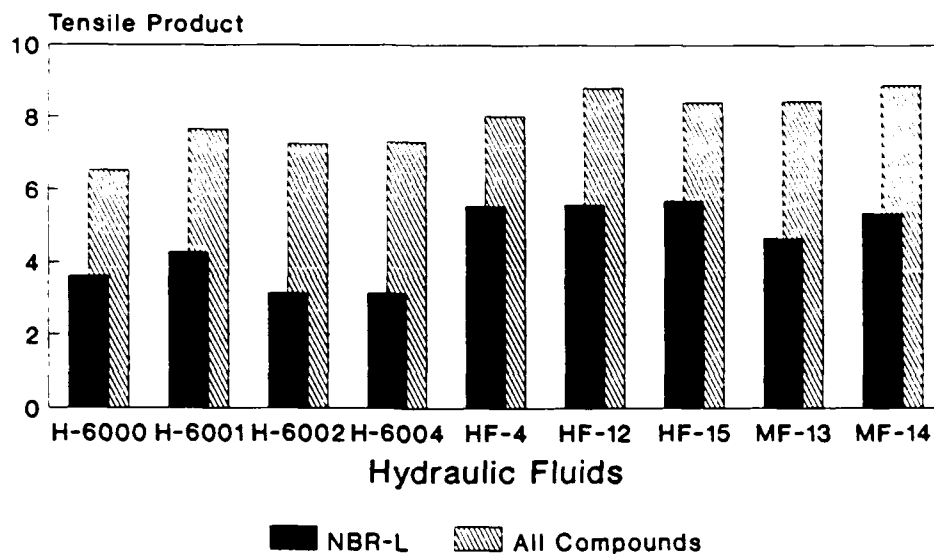


Figure 1. Tensile Product and Volume Change Averages, MIL-H-6083 vs. MIL-H-46170

Tensile Product NBR-L vs. Group Average



Volume Change NBR-L vs. Group Average

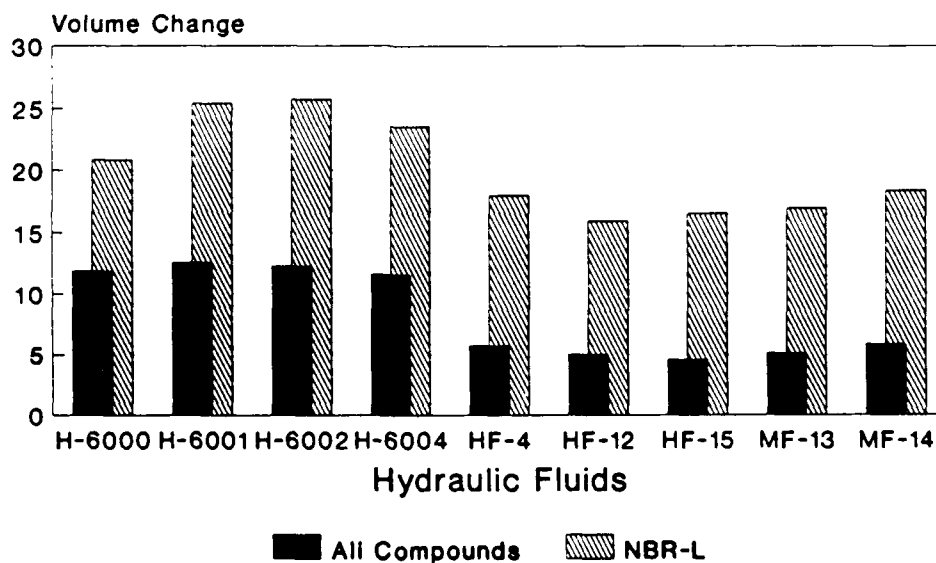


Figure 2. Tensile Product and Volume Change, NBR-L vs. Group Average

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