Compatibility of Single Hydraulic Fluid with Military Specification Fluids, Seals and Metallurgy

March 1995

By Ellen M. Purdy
Donna M. Rutkowski
USA Tank Automotive Command
Mobility Technology Center Belvoir

U.S. Army Tank-Automotive Command
Research, Development and Engineering Center
Warren, Michigan 48397-5000
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Contents

Section 1  Introduction and Background .................................................................1

Section 2  Technical Approach ..............................................................................3

Section 3  Results ................................................................................................4

Section 4  Conclusions .........................................................................................8

References ...........................................................................................................9

Tables

1. Requirements for Desirable Military Hydraulic Fluids.................................1
2. Baseline Elastomer Compatibility .....................................................................4
3. Sequential Elastomer Swell ..............................................................................5
4. Elastomer Swell of SHF Contaminated with FRH ..........................................6
5. Elastomer Swell of SHF Contaminated with OHT ........................................6
6. Elastomer/Metallurgy Compatibility .................................................................7
Section 1  Introduction and Background

The Army currently uses three military specification hydraulic fluids for its ground equipment; MIL-H-6083 (OHT); MIL-H-46170 (FRH); and MIL-H-5606 (OHA). In The US Army currently relies on three different hydraulic fluids for its ground equipment. MIL-H-5606 (OHA) and MIL-H-6083 (OHT) are both petroleum base fluids with excellent low temperature operability, but poor fire resistance. MIL-H-46170 (FRH) is a synthetic hydrocarbon based hydraulic fluid with excellent fire resistance but poor low temperature performance. Since none of the three fluids provide all desired characteristics for military purposes, the US Army Mobility Technology Center - Belvoir developed a modified fire resistant hydraulic fluid, designated Single Hydraulic Fluid (SHF), which exhibits satisfactory low temperature operability. This fluid has met all target performance requirements in the laboratory (see Table 1) and offers every indication of replacing the three currently used fluids.

Table 1. Requirements for Desirable Military Hydraulic Fluid

<table>
<thead>
<tr>
<th>PERFORMANCE TEST</th>
<th>MIL-L-46170</th>
<th>SHF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidation/Corrosion</td>
<td>168 hrs @ 121°C vis. &lt; 10%</td>
<td>168 hrs @ 135°C vis. &lt; 10%</td>
</tr>
<tr>
<td>ASTM D4636, #3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrosion Inhibition</td>
<td>100 hrs min</td>
<td>100 hrs min</td>
</tr>
<tr>
<td>ASTM D1748</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galvanic Corrosion</td>
<td>10 days min</td>
<td>10 days min</td>
</tr>
<tr>
<td>FTM 5322</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Temp Stability</td>
<td>72 hrs @ -54°C</td>
<td>72 hrs @ -54°C</td>
</tr>
<tr>
<td>FTM 3458</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pour Point</td>
<td>-60°C min</td>
<td>-60°C min</td>
</tr>
<tr>
<td>ASTM D97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viscosity @ 40°C</td>
<td>19.5 cSt max</td>
<td>19.5 cSt max</td>
</tr>
<tr>
<td>ASTM D445</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viscosity @ 100°C</td>
<td>3.4 cSt min</td>
<td>2.5 cSt min</td>
</tr>
<tr>
<td>ASTM D445</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viscosity @ -40°C</td>
<td>2600 cSt max</td>
<td>800 cSt max</td>
</tr>
<tr>
<td>ASTM D445</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viscosity @ -54°C</td>
<td>report</td>
<td>3500 cSt max</td>
</tr>
<tr>
<td>ASTM D445</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid particle Count</td>
<td>10,000 max @ 5-25 micrometers</td>
<td>10,000 max @ 5-15 micrometers</td>
</tr>
<tr>
<td>MIL-H-46170</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid Particle Count</td>
<td>250 max @ 26-50 micrometers</td>
<td>1,000 max @ 16-25 micrometers</td>
</tr>
<tr>
<td>MIL-H-46170</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid Particle Count</td>
<td>50 max @ 51-100 micrometers</td>
<td>150 max @ 26-50 micrometers</td>
</tr>
<tr>
<td>MIL-H-46170</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid Particle Count</td>
<td>10 max @ over 100 micrometers</td>
<td>20 max @ 51-100 micrometers</td>
</tr>
<tr>
<td>MIL-H-46170</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 1. Requirements for Desirable Military Hydraulic Fluid (continued)

<table>
<thead>
<tr>
<th>PERFORMANCE TEST</th>
<th>MIL-L-46170</th>
<th>SHF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Particle Count</td>
<td>5 max @ over 100 micrometers</td>
<td></td>
</tr>
<tr>
<td>MIL-H-46170</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acid Number ASTM D664</td>
<td>0.2 gm KOH/gm max</td>
<td>0.3 gm KOH/gm max</td>
</tr>
<tr>
<td>Elastomer Swell FTM 3603</td>
<td>15% - 25%</td>
<td>19% - 28%</td>
</tr>
<tr>
<td>Evaporation Loss ASTM D972</td>
<td>5% max</td>
<td>35% max</td>
</tr>
<tr>
<td>Steel on Steel Wear ASTM D4172</td>
<td>0.3 mm max @ 10 kg load</td>
<td>0.3 mm max @ 10 kg load</td>
</tr>
<tr>
<td>Steel on Steel Wear ASTM D4172</td>
<td>0.65 mm max @ 40 kg load</td>
<td>0.65 mm max @ 40 kg load</td>
</tr>
<tr>
<td>Foam Characteristics ASTM D892</td>
<td>65 ml max</td>
<td>65 ml max</td>
</tr>
<tr>
<td>Water Content ASTM D1744</td>
<td>500 ppm max</td>
<td>100 ppm max</td>
</tr>
<tr>
<td>Flash Point ASTM D92</td>
<td>219°C min</td>
<td>180°C min</td>
</tr>
<tr>
<td>Fire Point ASTM D92</td>
<td>246°C min</td>
<td>190°C min</td>
</tr>
<tr>
<td>Autoignition Temp ASTM E659</td>
<td>343°C min</td>
<td>325°C min</td>
</tr>
<tr>
<td>Hi Temp/Hi Press Ignt FTM 6052</td>
<td>no continuation of burning when ignition source is removed</td>
<td>no continuation of burning when ignition source is removed</td>
</tr>
<tr>
<td>Flame Propagation MIL-H-83282</td>
<td>0.3 cm/sec max</td>
<td>0.3 cm/sec max</td>
</tr>
<tr>
<td>Storage Stability FTM 3465</td>
<td>12 months</td>
<td>12 months</td>
</tr>
</tbody>
</table>

To insure that the developmental SHF can successfully be fielded in Army ground equipment, compatibility with existing systems must be assured. Because SHF is intended as a one-to-one replacement for currently used fluids, it must be compatible not only with the metallurgy and elastomeric seals in the hydraulic systems but also with any residual hydraulic fluid that remains after conversion. To demonstrate this compatibility, SHF was subjected to varying amounts of fluid “contamination” with OHT and FRH, and tested in the presence of elastomeric materials and metals commonly used in hydraulic system components. OHA was not used as a test fluid as it is chemically identical to OHT except that it does not contain a corrosion inhibitor. IF SHF demonstrates compatibility with OHT it will be compatible with OHA.
Section 2  Technical Approach

To demonstrate compatibility with existing fluids and seals, the investigation was conducted in three parts. First, all three fluids were subjected to elastomer swell testing with the elastomer samples of fluorosilicone (FVMC), polyurethane (AU), nitrile (NBR), polyacrylate (ACM), and fluorocarbon (CFM). The elastomers were tested for volume swell and hardness before and after a 168 hour soak in the test fluid at 70°C. This established an initial baseline of performance for each fluid in the presence of the elastomers (see Table 2, page 4).

For the next phase, the elastomer samples from the FRH and OHT fluids were subjected to an additional 168 hour soak in SHF. Testing the elastomers in SHF after they have already been subjected to FRH or OHT provides an indication of how the seals in hydraulic systems will be affected after they have been changed over from FRH or OHT to SHF. This investigation is intended to determine if any excessive swelling, loss of volume swell, or deterioration occurs in the elastomers after they have experienced subsequent exposure to SHF. If no major changes in the elastomers occur upon exposure to SHF after previous exposure to OHT or FRH, fluid/elastomer compatibility will be partly established.

A final demonstration of fluid/elastomer compatibility involves treating SHF with varying concentrations of FRH and OHT. Samples of SHF were prepared that contained 1%, 3%, 5%, 10% and 15% FRH and OHT, thus a total of ten test fluids were subjected to the elastomer materials. Contaminating SHF with FRH and OHT simulates the conditions expected after a flush and fill conversion of a vehicle using FRH or OHT. If no excessive swelling, loss of volume swell, or deterioration of the elastomers occurs upon exposure to these mixed fluid samples, SHF will have truly demonstrated fluid and seal compatibility.

To demonstrate full compatibility with Army hydraulic systems, SHF was tested in the presence of both the elastomer materials and component metals. The metals used in testing were steel, cadmium, copper, magnesium, and aluminum. These metals are specified in FTM-791-5308, Corrosiveness and Oxidation Stability of Light Oils (Metal Squares).
Section 3  Results

Baseline testing was accomplished by following FTM-791 Method #3603, Swelling of Synthetic Rubbers, for each of the test fluids. Table 2 summarizes the volume swell and seal hardness for each fluid and elastomer.

Table 2. Baseline Elastomer Compatibility

<table>
<thead>
<tr>
<th>Seal</th>
<th>SHF</th>
<th>OHT</th>
<th>FRH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>V%</td>
<td>HD1</td>
<td>HDf</td>
</tr>
<tr>
<td>FVMC</td>
<td>3.0</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>AU</td>
<td>1.0</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>NBR</td>
<td>3.0</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>ACM</td>
<td>3.3</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>CFM</td>
<td>0.7</td>
<td>26</td>
<td>25</td>
</tr>
</tbody>
</table>

Key:  V% = Volume Swell  
      HD1 = Initial Hardness  
      HDf = Final Hardness

As can be seen from the above data, OHT causes the seal materials to swell significantly more than FRH except for the fluorocarbon samples. OHT is also more proficient at seal swell than SHF for the test materials, although SHF provides more seal swell than FRH. For the fluorosilicone, polyurethane, and fluorocarbon materials, SHF provides sufficient seal swell to be comparable to OHT in performance even though SHF is slightly on the low side. The nitrile and polyacrylate materials, however, indicate a wider discrepancy between the OHT performance and SHF performance. It is not known if this discrepancy is significant enough to cause a difference in performance of the seals in actual vehicles. Table 2 also indicates the different effects the fluids have on seal hardness.

While the above baseline data allows some direct comparisons to be drawn from the fluids’ effect on the elastomers, it does not give an indication of how SHF will perform in a vehicle that has been previously exposed to FRH or OHT. To pursue this question, sequential rubber swell tests were conducted. The same elastomer samples that yielded the above data were re-tested in SHF for an additional 168 hours. This type of sequential testing does not follow a standard test methodology in that submerging an elastomer previously subjected to an initial fluid in a second fluid has never been previously reported in literature. The same procedure for determining elastomer swell (FTM-791 Method #3603) was used on the already swelled elastomer sample, thus a logical methodology was utilized in obtaining this data. Table 3 provides the results of these subsequent exposures.
Table 3. Sequential Elastomer Swell

<table>
<thead>
<tr>
<th>SEAL</th>
<th>SHF</th>
<th>OHT</th>
<th>OHT/SHF</th>
<th>FRH</th>
<th>FRH/SHF</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVMC</td>
<td>3.0%</td>
<td>4.5%</td>
<td>-16.8%</td>
<td>1.2%</td>
<td>-19.2%</td>
</tr>
<tr>
<td>AU</td>
<td>1.0%</td>
<td>1.2%</td>
<td>1.1%</td>
<td>0.6%</td>
<td>1.1%</td>
</tr>
<tr>
<td>NBR</td>
<td>3.0%</td>
<td>6.1%</td>
<td>3.9%</td>
<td>1.5%</td>
<td>3.9%</td>
</tr>
<tr>
<td>ACM</td>
<td>3.3%</td>
<td>5.8%</td>
<td>4.6%</td>
<td>1.7%</td>
<td>3.3%</td>
</tr>
<tr>
<td>CFM</td>
<td>0.7%</td>
<td>0.7%</td>
<td>0.9%</td>
<td>0.6%</td>
<td>1.1%</td>
</tr>
</tbody>
</table>

**Key:**
- OHT/SHF = Final volume swell of elastomer sample after exposure to OHT then sequential exposure to SHF
- FRH/SHF = Final volume swell of elastomer sample after exposure to FRH then sequential exposure to SHF

The data in Table 3 indicates the final state of the elastomer samples. By comparing columns 2, 3, and 4, it can be seen that except for the two fluoro elastomers, the subsequent immersion of the samples into SHF yielded a final swell which is greater than that achieved by SHF alone, yet less than what was originally exhibited after immersion in OHT. A comparison of columns 2, 5, and 6 indicates the situation is slightly different for the FRH/SHF samples. Except for the fluoro silicone, each elastomer sample exhibited seal swell equivalent to or greater than the swell achieved with SHF alone. The fluorocarbon samples exhibited a slight increase in swell for both OHT and FRH, but since the numbers are so close, it cannot actually be concluded that fluorocarbon increases in swell after subsequent exposure to SHF. The change in seal swell is not significant enough to be outside the “noise” of the test methodology. The results of the fluoro silicone test, however, are an anomaly. The test was repeated after the results indicated severe loss of seal swell, but the numbers were verified in the second test. This investigation has not pursued an explanation as to the chemistry between the fluids and fluoro silicone. At this time it can only be concluded that SHF is not compatible with a fluoro silicone seal that has previously been exposed to either FRH or OHT. If the fluoro silicone seal is brand new, it can be used with SHF with no risk of incompatibility or deterioration.

The next investigation into fluid/elastomer compatibility involved testing the SHF contaminated with varying concentrations of FRH and OHT. Tables 4 and 5 give the results of these tests. In addition to determining the volume swell of the elastomers, the mixed fluid viscosities, and flash and fire points were also determined.
Table 4. Elastomer Swell of SHF Contaminated with FRH

<table>
<thead>
<tr>
<th>SEAL</th>
<th>SHF</th>
<th>1%FRH</th>
<th>3%FRH</th>
<th>5%FRH</th>
<th>10%FRH</th>
<th>15%FRH</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVMC</td>
<td>3.0%</td>
<td>2.6%</td>
<td>3.1%</td>
<td>2.6%</td>
<td>2.1%</td>
<td>2.2%</td>
</tr>
<tr>
<td>AU</td>
<td>1.0%</td>
<td>2.6%</td>
<td>1.4%</td>
<td>1.4%</td>
<td>1.0%</td>
<td>1.5%</td>
</tr>
<tr>
<td>NBR</td>
<td>3.0%</td>
<td>3.5%</td>
<td>3.6%</td>
<td>3.7%</td>
<td>3.1%</td>
<td>4.1%</td>
</tr>
<tr>
<td>ACM</td>
<td>3.3%</td>
<td>1.2%</td>
<td>3.1%</td>
<td>2.4%</td>
<td>2.2%</td>
<td>3.7%</td>
</tr>
<tr>
<td>CFM</td>
<td>0.7%</td>
<td>0.6%</td>
<td>0.2%</td>
<td>0.9%</td>
<td>0.3%</td>
<td>0.2%</td>
</tr>
<tr>
<td>VIS @ 40°C</td>
<td>10.2cSt</td>
<td>10.2cSt</td>
<td>10.4cSt</td>
<td>10.8cSt</td>
<td>10.9cSt</td>
<td>11.6cSt</td>
</tr>
<tr>
<td>VIS @ 100°C</td>
<td>2.8cSt</td>
<td>3.1cSt</td>
<td>3.0cSt</td>
<td>3.2cSt</td>
<td>3.2cSt</td>
<td>3.0cSt</td>
</tr>
<tr>
<td>Flash Point</td>
<td>184°C</td>
<td>186°C</td>
<td>186°C</td>
<td>188°C</td>
<td>188°C</td>
<td>190°C</td>
</tr>
<tr>
<td>Fire Point</td>
<td>202°C</td>
<td>196°C</td>
<td>196°C</td>
<td>204°C</td>
<td>204°C</td>
<td>206°C</td>
</tr>
</tbody>
</table>

Contamination of SHF with FRH from 1% to 15% results in little significant change in the elastomer swell. The addition of 15% FRH yields a change of only 1% increase in swell for the nitrile elastomer and a 1% decrease in swell for the fluorosilicone elastomer samples. This amount of FRH in SHF does have a some impact, however, on the fluid properties. Note from Table 4 that the flash point has increased to 190°C and the fire point has increased to 206°C. The viscosities remain relatively unaffected.

Addition of OHT to SHF also produced some minor effects. Volume swell for the nitrile sample showed a slight increase with the addition of OHT while the fluorocarbon exhibited a slight decrease. The most significant change occurred in the loss of fire and flash point. Addition of 15% OHT dropped the flash point to 156°C and the fire point to 170°C. Again, the viscosities remain relatively unchanged.

Table 5. Elastomer Swell of SHF Contaminated with OHT

<table>
<thead>
<tr>
<th>SEAL</th>
<th>SHF</th>
<th>1%OHT</th>
<th>3%OHT</th>
<th>5%OHT</th>
<th>10%OHT</th>
<th>15%OHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVMC</td>
<td>3.0%</td>
<td>2.9%</td>
<td>2.6%</td>
<td>2.7%</td>
<td>2.8%</td>
<td>2.8%</td>
</tr>
<tr>
<td>AU</td>
<td>1.0%</td>
<td>1.4%</td>
<td>1.6%</td>
<td>1.4%</td>
<td>1.4%</td>
<td>1.4%</td>
</tr>
<tr>
<td>NBR</td>
<td>3.0%</td>
<td>4.3%</td>
<td>3.7%</td>
<td>3.8%</td>
<td>4.2%</td>
<td>3.6%</td>
</tr>
<tr>
<td>ACM</td>
<td>3.3%</td>
<td>2.9%</td>
<td>2.9%</td>
<td>3.3%</td>
<td>3.2%</td>
<td>3.3%</td>
</tr>
<tr>
<td>CFM</td>
<td>0.7%</td>
<td>0.8%</td>
<td>0.5%</td>
<td>0.5%</td>
<td>0.5%</td>
<td>0.5%</td>
</tr>
<tr>
<td>VIS @ 40°C</td>
<td>10.2cSt</td>
<td>10.5cSt</td>
<td>10.6cSt</td>
<td>10.6cSt</td>
<td>10.7cSt</td>
<td>11.2cSt</td>
</tr>
<tr>
<td>VIS @ 100°C</td>
<td>2.8cSt</td>
<td>3.4cSt</td>
<td>3.4cSt</td>
<td>3.5cSt</td>
<td>3.5cSt</td>
<td>3.8cSt</td>
</tr>
<tr>
<td>Flash Point</td>
<td>184°C</td>
<td>182°C</td>
<td>172°C</td>
<td>168°C</td>
<td>162°C</td>
<td>156°C</td>
</tr>
<tr>
<td>Fire Point</td>
<td>202°C</td>
<td>196°C</td>
<td>186°C</td>
<td>180°C</td>
<td>168°C</td>
<td>170°C</td>
</tr>
</tbody>
</table>

Compatibility of Single Hydraulic Fluid with Military Specification Fluids, Seals and Metallurgy
The final phase of this investigation involved testing the elastomer samples in the presence of metal coupons which are indicative of the metallurgy commonly used in Army hydraulic systems (see Table 6). The elastomers were tested for change in hardness (IRHD points) and volume swell, while the metal coupons were monitored for changes in weight (mg/cm²) and visual signs of corrosion. Weight changes of up to 0.2mg/cm² are acceptable for magnesium (Mg), aluminum (Al), iron (Fe), and cadmium (Cd), and up to 0.6 mg/cm² for copper (Cu). A change in hardness of +10 to -15 IRHD points is acceptable.

Table 6. Elastomer/Metallurgy Compatibility

<table>
<thead>
<tr>
<th>Seal</th>
<th>ΔVOL%</th>
<th>ΔHARD</th>
<th>ΔWt Cu</th>
<th>ΔWT Mg</th>
<th>ΔWT Al</th>
<th>ΔWT Fe</th>
<th>ΔWT Cd</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVMC</td>
<td>2.8%</td>
<td>-1</td>
<td>0.009</td>
<td>0.014</td>
<td>0.007</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>AU</td>
<td>0.1%</td>
<td>-2</td>
<td>0.014</td>
<td>0.011</td>
<td>0.008</td>
<td>0.020</td>
<td>0.006</td>
</tr>
<tr>
<td>NBR</td>
<td>2.4%</td>
<td>+9</td>
<td>0.001</td>
<td>0.012</td>
<td>0.022</td>
<td>0.012</td>
<td>0.018</td>
</tr>
<tr>
<td>ACM</td>
<td>2.5%</td>
<td>-1</td>
<td>0.006</td>
<td>0.015</td>
<td>0.027</td>
<td>0.005</td>
<td>0.046</td>
</tr>
<tr>
<td>CFM</td>
<td>1.9%</td>
<td>-1</td>
<td>0.001</td>
<td>0.007</td>
<td>0.002</td>
<td>0.001</td>
<td>0.003</td>
</tr>
</tbody>
</table>

As can be seen from Table 6, all coupon weight changes are well within acceptable limits, indicating no incompatibility of SHF with the metallurgy in the presence of different elastomers. The elastomer samples themselves exhibited no significant difference in volume swell in the presence of the metal coupons when compared to results obtained without the presence of coupons. Except for the nitrile, each elastomer sample only exhibited a change in hardness of 1 or 2 points. Referring back to Table 2, it can be seen that these changes in hardness are acceptable in that the baseline results for OHT and FRH are almost identical.
Section 4  Conclusions

From this rather extensive compatibility study, it can be concluded that SHF is entirely compatible in all aspects with current Army hydraulic systems. SHF is completely miscible in OHT and FRH and remains stable in all temperature conditions.\textsuperscript{5} Because no appreciable change in corrosion protection or elastomer swell occurs when SHF is combined with OHT or FRH in varying concentrations, hydraulic systems which contain SHF mixed with FRH or OHT can be expected to perform in a satisfactory manner.

Although no incompatibilities have been detected in this study, it is clear that for the sample elastomers investigated, SHF usually provides more seal swell than FRH and less seal swell than OHT. It cannot be determined conclusively that the amount of seal swell delivered by SHF is adequate for all seal materials in all Army vehicles. There still remains the possibility that SHF will cause seals designed for vehicles using FRH to swell too much and seals designed for vehicles using OHT to swell too little. This likelihood is remote, however, based on vehicles currently fielded. Both the M109 Self Propelled Howitzer and the M1A1 Battle Tank make extensive use of nitrile and fluorocarbon seals in their hydraulic systems.\textsuperscript{6,7} The M109 utilizes OHT while the M1A1 uses FRH.\textsuperscript{8,9} Neither vehicle exhibits problems with either seal leakage or sticking due to too much swell. Since FRH provides sufficient seal swell to prevent leakage and OHT does not cause seals to stick from excessive swelling, it can be concluded that SHF provides adequate seal swell which is neither too excessive or minimal.
References


CDR ARO
1. ATTN AMXRO EN (D MANN)
   RSCH TRIANGLE PK
   NC 27709-2211

DIR
1. ATTN SDSTO TE S
   TOBYHANNA PA 18466-5097

CDR AEC
1. ATTN SFIM AEC ECC (T ECCLES)
   APG MD 21010-5401

CDR ARMY ATCOM
1. ATTN AMSAT I ME (L HEPLER)
1. ATTN AMSAT I LA (V SALISBURY)
1. ATTN AMSAT R EP (V EDWARD)
   4300 GOODFELLOW BLVD
   ST LOUIS MO 63120-1798

CDR AVIA APPL TECH DIR
1. ATTN AMSAT R TP (H MORROW)
   FT EUSTIS VA 23604-5577

CDR ARMY NRDEC
1. ATTN SATNC US (SIEGEL)
1. ATTN SATNC UC
   NATICK MA 01760-5018

CDR ARMY ARDEC
1. ATTN SMCCAR CC
1. ATTN SMCCAR ESC S
   PICATINNY ARSENAL
   NJ 07808-5000

CDR ARMY CRDEC
1. ATTN SMCCCR RS
   APG MD 21010-5423

CDR ARMY DESCOM
1. ATTN AMSDS MN
1. ATTN AMSDS EN
   CHAMBERSBURG PA 17201-4170

CDR ARMY AMCOM
1. ATTN AMSMC MA
   ROCK ISLAND IL 61299-6000

CDR ARMY WATERTVIET ARSN
1. ATTN SARWY RDD
   WATERTVIET NY 12189

DIR AMC LOG SPT ACT
1. ATTN AMXLS LA
   REDSTONE ARSENAL
   AL 35890-7466

CDR APC
1. ATTN SATPC Q
1. ATTN SATPC QE (BLDG 85 3)
   NEW CUMBERLAND
   PA 17070-5005

1. PETROL TEST FAC WEST
   BLDG 247 TRACEY LOC
   DDRW
   P O BOX 96001
   STOCKTON CA 95296-960
   CDR ARMY LEA
1. ATTN LOEA PL
   NEW CUMBERLAND
   PA 17070-5007

CDR ARMY TECOM
1. ATTN AMSTE TA R
1. ATTN AMSTE TC D
1. ATTN AMSTE EQ
   APG MD 21005-5006

PROJ MGR PETROL WATER LOG
1. ATTN AMCIN PNW
   4300 GOODFELLOW BLVD
   ST LOUIS MO 63120-1798

PROJ GMG MOBILE ELEC PWR
1. ATTN AMCPM MEP
   7798 CISSNA RD STE 200
   SPRINGFIELD VA 22150-3199

CDR
ARMY COLD REGION TEST CTR
1. ATTN STECR TM
1. ATTN STECR LG
   APO AP 96508-7850

CDR
ARMY BIOMED RSCH DEV LAB
1. ATTN SQRD UBZ A
   FT DETRICK MD 21702-5010

CDR FORSCOM
1. ATTN AFLG TRS
   FT MCPHERSON GA 30330-6000

CDR TRADOC
1. ATTN ATCD SL S
   INGALLS RD BLDG 163
   FT MONROE VA 23651-5194

CDR ARMY ARMOR CTR
1. ATTN ATSB CD ML
1. ATTN ATSB TSM T
   FT KNOX KY 40121-5000

CDR ARMY QM SCHOOL
1. ATTN ATSM CD
1. ATTN ATSM PWD
   FT LEE VA 23001-5000

CDR
ARMY COMBINED ARMS SPT CMD
1. ATTN ATCL CD
1. ATTN ATCL MS
   FT LEE VA 23801-6000

Distribution-2
CDR ARMY FIELD ARTY SCH
ATTN ATSF CD
FT SILL OK 73503

CDR ARMY TRANS SCHOOL
ATTN ATSP CD MS
FT EUSTIS VA 23604-5000

CDR ARMY INF SCHOOL
ATTN ATSH CD
ATTN ATSH AT
FT BENNING GA 31905-5000

CDR ARMY AVIA CTR
ATTN ATZQ DOL M
ATTN ATZQ DI
FT RUCKER AL 36362-5115

CDR ARMY CACDA
ATTN ATZL CD
FT LEAVENWORTH KA 66027-5300

CDR ARMY ENGR SCHOOL
ATTN ATSE CD
FT LEONARD WOOD
MO 65473-5000

CDR ARMY ORDN CTR
ATTN ATSL CD CS
APG MD 21005

CDR ARMY SAFETY CTR
ATTN CSSC PMG
ATTN CSSD SPS
FT RUCKER AL 36362-5363

CDR ARMY CSTA
ATTN STECS EN
ATTN STECS LI
ATTN STECS AE
ATTN STECS AA
APG MD 21005-5059

CDR ARMY YPG
ATTN STEYP MT TL M
YUMA AZ 85365-9130

CDR ARMY CERL
ATTN CECER EN
PO BOX 9005
CHAMPAIGN IL 61826-9005

DIR
AMC FAST PROGRAM
10101 GRIDLEY RD STE 104
FT BELVOIR VA 22060-5818

CDR I CORPS AND FT LEWIS
ATTN AFZH CSS
FT LEWIS WA 98433-5000

CDR
RED RIVER ARMY DEPOT
ATTN SDSRR M
ATTN SDSRR Q
TEXARKANA TX 75501-5000

PS MAGAZINE DIV
ATTN AMXLS PS
DIR LOGSA
REDSTONE ARSENAL
AL 35898-7466

CDR 6TH ID (L)
ATTN APUR LG M
1060 GAFFNEY RD
FT WAINWRIGHT
AK 99703

DEPARTMENT OF THE NAVY
OFC OF NAVAL RSCH
ATTN ONR 464
800 N QUINCY ST
ARLINGTON VA 22217-5660

CDR
NAVAL SEA SYSTEMS CMD
ATTN SEA 03M3
2531 JEFFERSON DAVIS HWY
ARLINGTON VA 22242-5160

CDR
NAVAL SURFACE WARFARE CTR
ATTN CODE 632
ATTN CODE 859
3A LEGGETT CIRCLE
ANNAPOlis MD 21401-5067

CDR
NAVAL RSCH LABORATORY
ATTN CODE 6181
WASHINGTON DC 20375-5342

CDR
NAVAL AIR WARFARE CTR
ATTN CODE PE33 AJD
PO BOX 7176
TRENTON NJ 08628-0176

CDR
NAVAL PETROLEUM OFFICE
CAMERON STA T 40
5010 DUKE STREET
ALEXANDRIA VA 22304-6180

OFC ASST SEC NAVY (I 7 E)
CRYSTAL PLAZA 5
2211 JEFFERSON DAVIS HWY
ARLINGTON VA 22244-5110
HQ USAF/LGT
1
ATTN VEH EQUIP/FACILITY
1030 AIR FORCE PENTAGON
WASHINGTON DC  20330-1030

AIR FORCE WRIGHT LAB
1
ATTN WL/POS
1
ATTN WL/POSF
1
ATTN WL/POS L
1790 LOOP RD N
WRIGHT PATTERSON AFB
OH  45433-7103

AIR FORCE WRIGHT LAB
1
ATTN WL/MLBT
2941 P ST STE 1
WRIGHT PATTERSON AFB
OH  45433-7750
AIR FORCE WRIGHT LAB
1
ATTN WL/MLSE
2179 12TH ST STE 1
WRIGHT PATTERSON AFB
OH  45433-7718

1
AIR FORCE MEEP MGMT OFC
615 SMSQ/LGTV MEEP
201 BISCAYNE DR STE 2
ENGLIN AFB FL  32542-5303

1
SA ALC/SFT
1014 ANDREWS RD STE 1
KELLY AFB TX  78241-5603

1
WR ALC/LVRS
225 OCMULGEE CT
ROBINS AFB
GA  31098-1647