SYNTHETIC FISCHER-TROPSCH (FT) JP-5/JP-8 AVIATION TURBINE FUEL ELASTOMER COMPATIBILITY

FINAL REPORT

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14. ABSTRACT
When some elastomer (rubber) compounds, and specifically those used for seals in fuel-wetted components of vehicles and equipment, are suddenly 'switch-loaded' from one kind of fuel to another, swell/shrink issues relating to seal performance may arise, possibly leading to fuel leakage. The key objective of this study was to compare and contrast the material compatibility of nitrile coupons and O-rings with selected petroleum-derived fuels, Fisher-Tropsch (FT) synthetic JP-5/JP-8 fuel, and blends of FT JP-5/JP-8 with various amounts of aromatic blend stock. This study provided a baseline for predicting the effects of static elastomer swell to the potential degree of swell/shrink that can be expected when fuels are "switch-loaded" and a comparison of effects on coupons as well as O-rings which indicated similar overall trends and were in agreement with prior work. The use of an aromatic concentrate as a surrogate source of aromatics did not reveal any significant bias when compared to petroleum derived JP-5 and diesel fuel, although it was shown to have a reduced effect on elastomer change as compared to the petroleum fuels.

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EXECUTIVE SUMMARY

Problems and Objectives

When some elastomer (rubber) compounds, and specifically those used for seals in fuel-wetted components of vehicles and equipment, are suddenly 'switch-loaded' from one kind of fuel to another, swell/shrink issues relating to seal performance may arise, possibly leading to fuel leakage. Studies conducted in 2003 indicated that nitrile elastomers were particularly sensitive to switching between various fuels, and that the magnitude and direction of these physical changes (swell/shrink) were dependent on the fuel composition, in particular aromatic content.

The key objective of this study was to compare and contrast the material compatibility of nitrile coupons and O-rings with selected petroleum-derived fuels, Fischer-Tropsch (FT) synthetic JP-5/JP-8 fuel, and blends of FT JP-5/JP-8 with various amounts of aromatic blend stock. Nitrile elastomer is typically found in the fuel systems of Army tactical and combat vehicles and varies in composition giving a large range of compatibility with fuel composition.

Importance of Project

This project was completed under a joint DoD-DoE Memorandum of Agreement (MOA) to conduct collaborative research and development in the assessment of alternative fuels, particularly synthetic fuel produced from gas-to-liquid (GTL)/FT technology. This project is one of several second year efforts under this MOA to address the potential use of FT fuels by the military.

Technical Approach

To assess the compatibility of the selected elastomer in various fuels, coupons and O-rings were immersed in each fuel and held there, at elevated temperature of 40°C, for a period of up to 43 days. Prior to immersion, and then at several intervals of 3, 9 and 43 days, measurements were made on a significant sampling of coupons and O-rings to determine net changes in coupon dimensions of mass, volume, and hardness properties.

Accomplishments

The matrix of fuels tested, of varying aromatic content, provided a baseline for predicting the effects of static elastomer swell to the potential degree of swell/shrink that can be expected when these fuels are "switch-loaded." The data set also provided a comparison of effects on coupons as well as O-rings which indicated similar overall trends and were in agreement with prior work. The use of an aromatic concentrate as a surrogate source of aromatics for blending in the paraffinic FT JP-5/JP-8 did not reveal any significant bias when compared to petroleum derived JP-5 and diesel fuel, although it was shown to have a reduced effect on elastomer change as compared to the petroleum fuels.

Military Impact

The possibility for the use of synthetic fuels by the U.S. Military opens up a whole new dimension in considering sources of supply and, most notably as a result, the associated potential for enhancing security of supply. Development of military specifications for fuel made from petroleum, as well as synthetic hydrocarbons, relies on military material evaluation data such as the elastomeric materials evaluations provided in this report.

FOREWARD/ACKNOWLEDGMENTS

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I. OBJECTIVE

The overall goal of this study was to compare and contrast the material compatibility of a nitrile elastomer (typical of what might be found in the fuel systems of Army tactical and combat vehicles) with petroleum-derived diesel fuel and JP-5 (as reference fuels) and, synthetic GTL/FT JP-5 fuel of varing aromatic content (0%, 10% and 25% by volume). Underlying goals of this study were to: (1) evaluate and compare elastomer compatibility and swelling behavior of both coupons and O-rings in the selected fuels based on aromatic content (by volume) , (2) evaluate Aromatic A150 as a potential aromatic additive for neat FT fuels, and (3) evaluate reproducibility and repeatability of coupon results by comparison to prior coupon data.

II. BACKGROUND

As the U.S. Military considers fuel sources around the world and into the future, it is very likely that fuels produced via non-conventional means become increasingly available and of growing importance. One such type of fuel, a synthetic fuel, can today be produced from a synthesis process first developed in the 1920's known as Fischer-Tropsch. As a matter of fact, some limited production of coal-derived synthetic fuel has been a reality since the early 1970's in South Africa, and starting in the early 1990's synthetic fuel derived from natural gas has been produced in Bintulu, Indonesia. The possibility for the use of synthetic fuels by the U.S. Military opens up a whole new dimension in considering sources of supply. In turn, various scenarios for the production of synthetic fuel can be envisioned which could significantly contribute to increased energy security and enhanced mobility for the U.S. Military.

With the developments now evolving in Qatar for construction of world-scale plants to produce fuels derived from natural gas via low temperature GTL/FT synthesis technologies, and the likelihood for these fuels to become increasingly available around the world, the potential use of these FT fuels by the U.S. Military needs to be considered. With this in mind, a joint-agency Memorandum of Agreement (MOA) to study the potential use of these fuels by the military was initiated in late 2002. This MOA, involving Department of Defense (DoD) fuels labs of the Army, Air Force, and Navy, along with the National Energy Technology Laboratory (NETL) of the Department of Energy (DoE), allows for "…cooperative research, development, testing, and evaluation (RDT&E) activities for innovative, alternative, and best-in-kind development and assessment of alternative fuels for the DoD and DoE programs. The principal technology of interest is synthetic JP-8/JP-5 fuel." A synthetic JP-5 like fuel, produced by Syntroleum Corporation using their GTL process, was provided as the baseline synthetic fuel for investigation under a FY03 testing program agreed to by DoD and DoE labs.

Elastomeric, or rubber-like, materials are used throughout the fuel distribution systems of air and ground vehicles and equipment as seals, coatings, for hoses and other various applications. These compounds have varying degrees of resistance and sensitivity to the fuels which they may encounter. Depending on the particular compound, some change in dimensions may result as the elastomer is exposed to the fuel. These changes in dimensions do not necessarily result in application performance issues, but may, for instance, when a dramatic change in the type of fuel being used in

the vehicle or equipment occurs. It is generally known that aromatic species in hydrocarbon fuels are primary contributors to elastomer swelling of Buna-N. In the case of a seal, aromatic constituents in the fuel will cause seals made from affected elastomers to increase in volume as absorption of the aromatic solute takes place. In likewise fashion, if that seal is then subjected to a fuel containing a much reduced level of aromatic solvents, the process may reverse itself and the seal may then decrease in size. Such a reduction in the size or volume of the seal at that point in time may result in poor sealing performance and possibly even leakage of fuel.

III. APPROACH

A.   *Summary of Technical Approach*

To assess the compatibility of the selected elastomeric compound in various fuels, a very fundamental approach was employed in this investigation. Coupons and O-rings of the selected elastomer material were immersed in each fuel, at elevated temperature (40°C), for a period of up to 43 days. Prior to immersion, and then at several intervals thereafter, measurements were made to determine net changes in mass, volume, and hardness properties. For the O-rings only, dimensional measurements were also made (inner diameter and cross-section) using an optical technique, and net changes in volume were also determined from this data. Measurements were made on a larger number of coupons and O-rings than required by the ASTM methods for determining changes in mass, volume and hardness to enhance the data sets for net changes in these properties.

B.   *Fuels*

The five fuels used in this study are indicated in Table 1. The first fuel listed, designated as 'S-5' is a high flash-point synthetic FT jet fuel meeting the physical/chemical properties of JP-5 and JP-8, but not containing additives required for JP-5 and JP-8. [1, 2, 3][1] JP-8 is the single battlefield fuel designated for use in all military aviation turbine engines and diesel engines, except for those used aboard ships where JP-5 is designated. JP-5 is essentially the same as JP-8, with one major difference being a higher flash point that provides added safety for shipboard use. The S-5 fuel was produced by Syntroleum Corporation using their gas-to-liquids FT technology to convert natural gas into liquid hydrocarbon fuel. The processes they employ include Fischer-Tropsch synthesis and synthetic crude upgrade to obtain the low freeze point temperature and other properties of JP-5/JP-8. [4] The fuel properties for the S-5 fuel are shown in Appendix A, Table A-1.

A petroleum-based aromatic hyrdrocarbon fluid manufactured by ExxonMobil, Aromatic A150, was added to neat S-5 to produce the two other synthetic fuel blends used in this study, S-5 + 10% A150 and S-5 + 25% A150, with aromatic contents of 10% vol. and 25% vol., respectively. A link to the datasheet for Aromatic A150 is included in Appendix B.

The two petroleum fuels used in the study are a Navy-provided JP-5 fuel, and Emission Control Diesel-1 (ECD-1) from the former Arco Refinery, near Los Angeles, now owned by BP. ECD-1 is

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[1] Numbers between brackets refer to References found at the end of the document.

a CARB-equivalent ultra-low sulfur fuel equivalent[2] No. 2 Diesel, with sulfur < 15 ppm and approximately 19% vol. aromatics. [5] Laboratory tests indicate that JP-5 is approximately 18% vol. aromatics. The fuel properties for the JP-5 fuel are shown in Appendix C, Table C-1, along with data for the ECD-1 fuel.

As shown in Table 1, the synthetic fuel, S-5, contains no aromatics. This is representative of synthetic fuels that are produced from FT synthesis utilizing low reactor temperatures and cobalt or iron based catalyst. ECD-1 is representative of diesel fuel derived from conventional sources, such as petroleum crude oil, in that they contain aromatics. The current specification for low sulfur diesel fuels [4] in the U.S. allows up to 35% vol. aromatics. Likewise, the current specifications for JP-8 and JP-5 allows up to 25% vol. aromatics. [2, 3]

Table 1. List of Fuels

Fuel Name	Fuel Description	Sample ID Number
S-5	0% aromatics	FL-11741-03
S-5 + 10% A150	10% vol. aromatics	FL-11741-03 + 10% FL-11755-03
JP-5	18% vol. aromatics	FL-11891-04
ECD-1	19% vol. aromatics, ultra-low sulfur	FL-11749-03
S-5 + 25% A150	25% vol. aromatics	FL-11741-03 + 25% FL-11755-03
A150	aromatic additive	FL-11755-03

C.   Elastomers

Elastomer N0674-70, a general purpose 70-durometer nitrile elastomer, was chosen for this study. Properties of this material, a compound of the Parker O-Ring Division, are shown in Appendix D. Elastomer N0674-70 is a nitrile elastomer typically found in some fuel systems of Army tactical and combat vehicles. Studies conducted in 2003 indicated that this elastomer was particularly sensitive to swelling (related to aromatic hydrocarbons in test fuels) compared to the fuel resistant chlorinated carbon polymers. [7, 8]

D.   Test Procedure

Elastomer coupons (25 × 50 × 2.0 ± 0.1 mm), cut from sheets of the elastomer, and elastomer O-rings (9.12-9.37 mm inner diameter × 1.70-1.85 mm cross-section diameter) were stored in glass vessels containing each of the test fuels. The samples were stored at 40°C (104°F) and measurements were made at 0, 3, 9, and 43 days.

For the determination of swelling response, volume change due to swell was determined based on a water displacement technique and according to ASTM D 471 procedures. [9] Mass change was also determined according to ASTM D 471. Measurements were made on 4 unique coupons and 4 unique O-rings, respectively, for each data point.

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[2] The term 'fuel equivalent' refers to fuels that meet emission requirements without meeting fuel property requirements.

In addition, physical measurements were made on each O-ring and averaged to calculate the % change in dimensions according to ASTM D 471 (section 17.3). This physical measurement data was deemed unreliable and not included in this report.

For measuring hardness, the ASTM D 2240 test method was followed. [9] All data points were generated in triplicate.

IV. RESULTS

Results are presented covering the effects of the five fuels on elastomer N0674-70 coupons and O-rings as evidenced by changes in mass, volume (for swelling behavior) and by changes in hardness.

One aspect of this investigation related to fuel additives should be noted at this point. The synthetic fuel, S-5, was evaluated as a neat fuel and therefore it did not contain any antioxidants or other military JP-8/JP-5 additives. The S-5 fuel, being very iso-paraffinic in nature, would likely be susceptible to oxidation and in practice would contain antioxidant similar to the practice used for highly hydrotreated fuels. However, during the course of this investigation, no attempts were made to determine whether oxidation of this fuel had or was occurring. These results, then, are presented without any such knowledge regarding oxidation of the S-5 fuel or therefore, how such oxidation, if present, might impact the effects of the fuel on the elastomers. ECD-1 fuel, being commercially produced, may have contained antioxidants. Fuels made from regular petroleum crude would be less prone to oxidation than the S-5 fuel, unless they were highly hydrotreated and in such case the use of antioxidants is required.

A.   Effects on Swelling Behavior

The average coupon mass and volume change found after 43 days of immersion in the various fuels at 40°C is shown in Figures 1 and 2, respectively. Likewise, for the O-rings, the average mass and volume changes after 43 days of immersion are shown in Figures 3 and 4, respectively. This data is based on average values from measurements on four (4) coupons or O-rings. A tabular summary of this data, including standard deviations, is provided in Appendix E, Table E-1 and E-2. Also included in Appendix E are charts in Figures E-1 through E-4, showing changes in mass and volume at days 3, 9 and 43 days and Figures E-5 through E-8 showing changes in mass and volume over time.

For both coupons and O-rings, the changes in volume as presented in the Figures 1-4, and Appendix E, were determined based on the water displacement method per ASTM D 471. The results determined for changes in volume of the O-rings, only, were also determined based on dimensional measurements. These results are presented in the Discussion Section of this report.

Figure 1. Average Mass Change (%) After 43 Days for Nitrile Elastomer N0674-70 Coupons
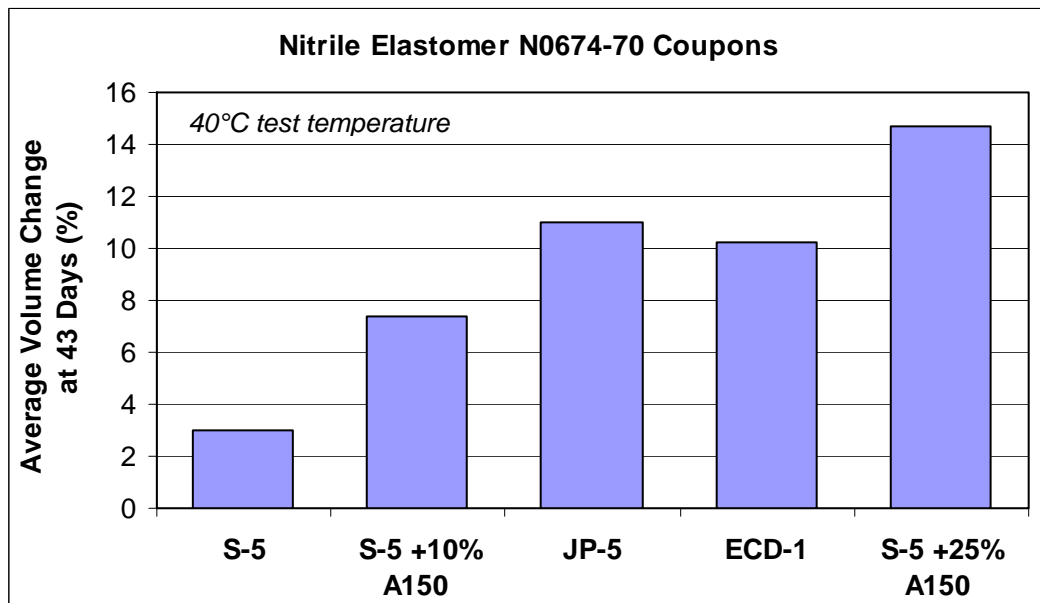
Figure 2. Average Volume Change (%) After 43 Days for Nitrile Elastomer N0674-70 Coupons

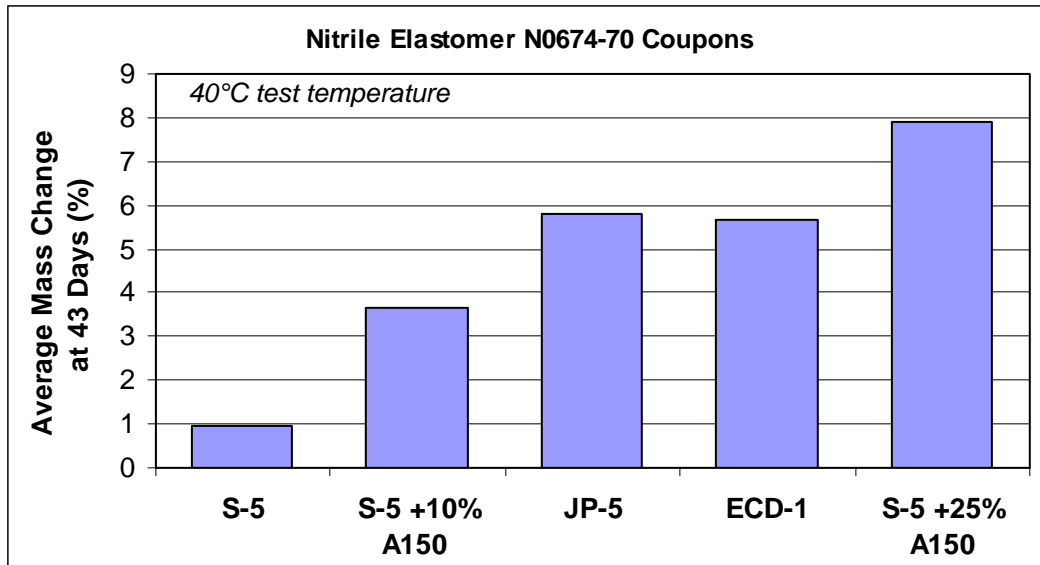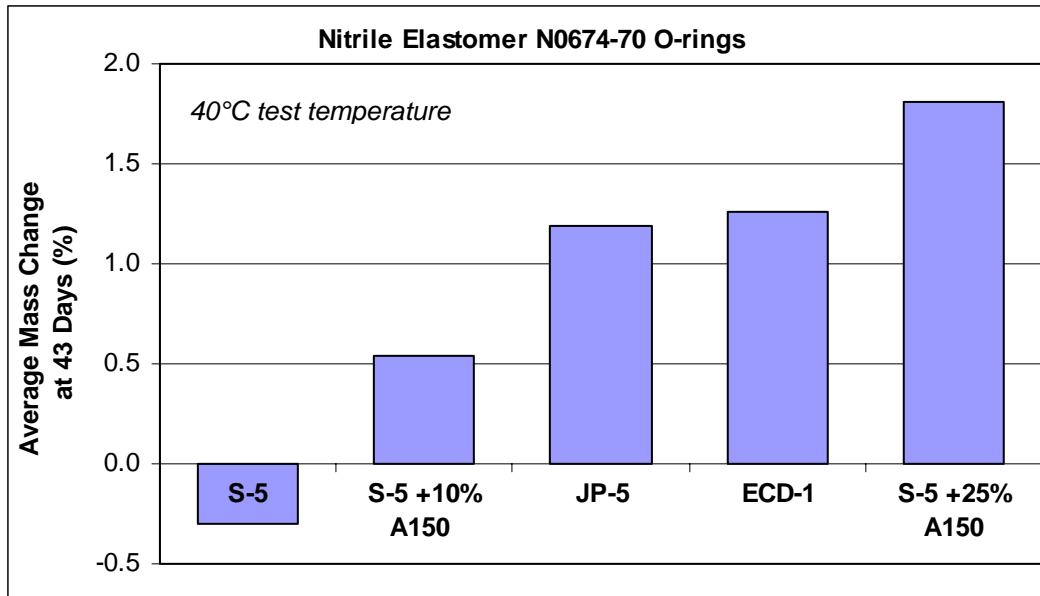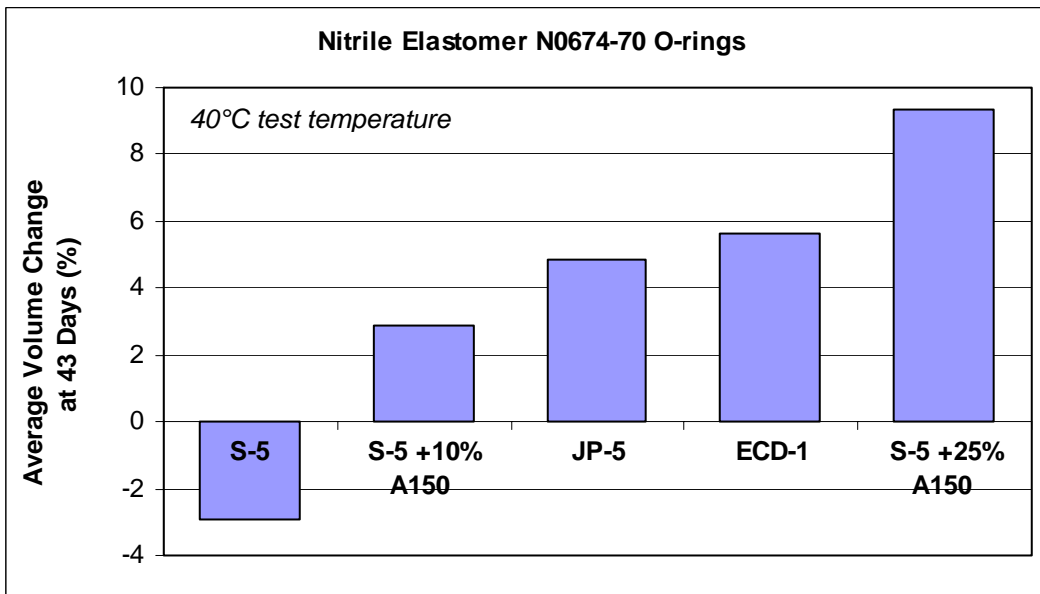**Figure 3. Average Mass Change (%) After 43 Days for Nitrile Elastomer N0674-74 O-rings**

Figure 4. Average Volume Change (%) After 43 Days for Nitrile Elastomer N0674-70 O-rings

B.   Effects on Hardness

The average hardness changes found for each elastomer after 43 days of immersion in the various fuels at 40°C is shown in Figure 5. This data is based on the average values from measurements on

three (3) coupons. A tabular summary of this data, including standard deviations, is shown in Appendix F, Table F-1. Also included in Appendix F are charts in Figures F-1 through F-7 showing changes in hardness versus time.
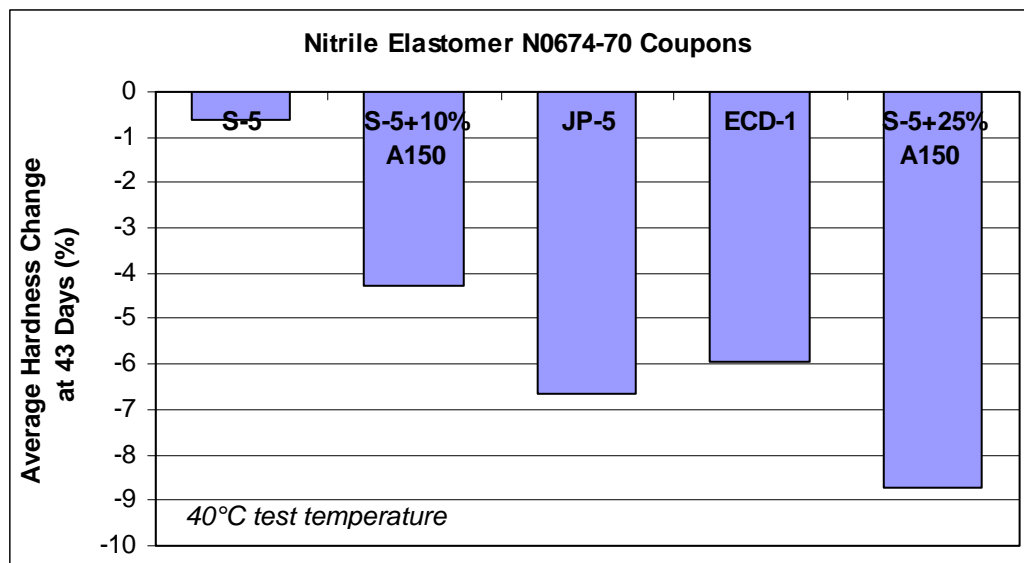

Figure 5. Average Hardness Change (%) After 43 Days for Nitrile Elastomer N0674-70 Coupons

V. DISCUSSION

Based on prior work, it was determined that elastomer N0674-70 is particularly sensitive to swell in the presence of aromatic hydrocarbons. The approach in this investigation, therefore, was to determine the effects of petroleum-based fuels (JP-5 and ECD-1) on this elastomer and to compare these results with results of the same determinations for synthetic fuel containing 0% aromatics (S-5), and synthetic fuel (S-5) blended with Aromatic A150 to achieve levels of 10% vol. aromatics and 25% vol. aromatics, respectively. The fuels tested had aromatic contents in increasing amounts as follows: S-5 (**0%** vol.), S-5 + 10% A150 (**10%** vol.), JP-5 (**18%** vol.), ECD-1 (**19%** vol.), and S-5 + 25% A150 (**25**% vol.).

Nitrile N0674-70 coupons experienced swelling when immersed in each test fuel. The overall trend was that the amount of swelling increased as the fuel aromatic content increased; i.e., the greatest amount of swell was measured for immersion in S-5 + 25% A150. By day 43, Nitrile N0674-70 coupons exposed to S-5 + 25% A150 had increased in volume by 14.7%. Some interesting observations can be made, however, in studying responses in more detail, particularly for coupons exposed to the petroleum-based fuels (JP-5 and ECD-1) versus the S-5 + 25% A150. Coupons exposed to JP-5 reached a change in volume approaching that of the coupons exposed to S-5 + 25% A150 (+11.0% and +14.7% respectively), even though significantly less aromatics are present in the JP-5 fuel versus the S-5 + 25% A150 (+18% vol. and 25% vol. respectively). On the other hand, coupons exposed to ECD-1 experienced slightly less change in volume to that of coupons exposed to JP-5 (+10.2% vol. and +11.0% vol. respectively), even though the aromatic content of ECD-1 is similar to that of JP-5 (19% vol. and 18% vol. respectively). These non-linear responses of swell for nitrile in these three fuels (S-5 + 25% A150, JP-5, and ECD-1) can be attributed to differences in

fuel composition as indicated by more than just aromatic "content" (concentration); i.e., not only is the concentration of aromatics present a factor in the degree of swell, but so too is the specific type of aromatics eg., degree of alkyl substitution.

In research being conducted by the the University of Dayton Research Institute (UDRI) in conjunction with the Air Force Research Laboratory (AFRL), under the same MOA as the research performed by TARDEC documented herein, it has been shown that nitrile exhibits preferential absorption of the fuel components in the order aliphatics<aromatics<di-aromatics<di-EGME. [10] Note that the latter component in this hierarchy, di-EGME, is not a naturally-occurring component in JP (Jet Propulsion) fuels, but rather a required additive in JP-8/JP-5 fuels as a fuel system icing inhibitor. [1, 2, 11] The di-EGME, along with other components such as methyl phenols and methyl esters which do occur naturally in JP fuels, are polar in nature. As shown in the work by AFRL-UDRI, polar components in fuels, even at very low concentrations, *particularly di-EGME*, may significantly influence the swelling behavior of nitrile in such fashion as to make it "more easily swollen by the less polar components of the fuel such as the aromatics." With this background, we have some plausible explanation for the non-linear response in nitrile swell found in the study herein. Table 2 lists selected fuel components and indicates their presence in the test fuels. As shown in Table 2, the JP-5 fuel used in this study does contain di-EGME (see Appendix C), in addition to aromatics and would be expected to also contain other polar components. ECD-1 would also be expected to contain polar components; neither ECD-1 nor S-5 + 25% A150 contain di-EGME (as deliberately added or as anticipated otherwise). Therefore, we would anticipate that the effectiveness of these fuels in swelling nitrile would be in the order JP-5>ECD-1>S-5+ 25% A150, and the data generated in this study supports this conclusion. There may be other factors relating to differences in aromatic composition, such as the degree of alkylation on the aromatic ring and the molecular weight of the alkyl-substituted monoaromatic rings, which would also explain the relative swelling effectiveness of these fuels.

Table 2. Presence[*] of Selected Fuel Components in Test Fuels

Fuel Component	JP-5	ECD-1	S-5 + 25% A150
di-EGME	+		
Polars (in addition to di-EGME)	+	+	
Diaromatics	+	+	+
Monoaromatics	+	+	+

[*] As detected in testing or as anticipated.

The results for equilibrium swell, expressed as % vol. change at day 7 and day 43, between the UDRI study and this study (TARDEC) respectively, are compared in Table 3. The tests were conducted with different nitrile compounds, and the duration of immersion and fuel temperature during immersion were different, so it is difficult to draw any strong conclusions regarding similarities or differences between the results. In the TARDEC study, the size of the O-rings used were specifed per SAE AS568-012, with as manufactured dimensions called out for inner diameters of 9.12-9.37 mm and cross sections of 1.70-1.85 mm, resulting in a range for O-ring volume (calculated), as manufactured, of 77.16-94.75 mm^3 ; the O-ring size used in the UDRI study was not reported. In the TARDEC study the net swell of the nitrile O-ring immersed in S-5 was negative (-2.9%), where as in the UDRI study a +1.7% change occurred; note, however, that in this study the

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change was +3.0% for the nitrile coupon. A notable difference is seen for the O-ring swell values in JP-5 fuel. In the UDRI study a +15.0% change was found, where as in the TARDEC study a change of only 4.9% was measured; note, however, that in this study a change of +11.0% was measured for the coupons.

Table 3. Equilibrium Swell Results of Nitrile Specimens in Test Fuels
Results reported as % vol. change per water displacement method
in ASTM D 471 unless otherwise noted.

Fuel (vol. aromatics)	UDRI Study Nitrile N-602, 7 days at 21°C	TARDEC Study Nitrile N0674-70, 43 days at 40°C		
	O-Rings	O-Rings	O-Rings[1]	Coupons
S-5 (0%)	1.7%	-2.9%	-4.0%	3.0%
S-5 + A150 (10%)	2.0%[2]	2.9%	5.0%	7.4%
JP-5/S-5 (10%)	7.5%[2]	–		–
JP-5 (18%)[3]	15.0%	4.9%	8.7%	11.0%
ECD-1 (19%)	–	5.6%	4.4%	10.2%
S-5 + A150 (25%)	10.5%	9.4%	13.4%	14.7%

[1]Results shown are calculated from O-ring inner diameter (ID) and O-ring cross-section (CS) dimensions determined via a video microscope (Photovolt Microwatcher VS-35H) at ×10 magnification where volume (V) is $V = \frac{1}{4}\pi^2 \times CS^2 \times (ID + CS)$.
[2]These values were interpreted from plots.
[3]The JP-5 aromatics level of 20% reported in the UDRI study is slightly different than the 18% determined by PWBA Lab, even though the samples are reported to be of the same sample lot held by Navy.

In the TARDEC study, Nitrile N0674-70 O-rings experienced swelling when immersed in each test fuel, with the exception of neat S-5. Unlike the nitrile coupons tested, the O-rings exposed to S-5 actually decreased slightly in volume (shrank) by 2.9% with a slight corresponding decrease in mass (0.3%). Differences in the TARDEC study between the volume changes for the coupons versus the O-rings might relate to the composition of the nitrile and the nitrile test specimen itself. Although both the O-rings and coupons are identified as being made of Nitrile N0674-70, they almost certainly were not produced from the same lot/batch of material (they were purchased from different suppliers), so there are may be some variations in composition. The nitrile's properties, and thus response to its environment, may also be affected by the manufacturing processes employed. The coupon test specimens were fabricated (cut) from nitrile sheet material, which most likely was extruded, while the O-rings were molded. Still, the overall trend in the amount of nitrile swelling for the O-rings was similar to that found for the coupons, i.e., the greatest amount of swell was measured with S-5 + 25% A150 (+9.4% and +13.4% for O-rings and 14.7% for coupons).

According to the coupon data, the most effective fuel in swelling, relative to aromatic content, occurred with JP-5 fuel (11.0% swell), then ECD-1 (10.2% swell), then S-5 + 25% A150 (14.7% swell). This overall trend did not hold as true for the O-ring data. For the O-ring data as derived by the water displacement method, the swell in JP-5 was only 4.9% and in ECD-1 only 5.6%, as compared to the swell in S-5 + 25% A150 of 9.4%. For the O-ring data as derived from dimensional measurements, the swell in JP-5 was 8.7%, as compared to the swell in ECD-1 of only 4.6% and in S-5 + 25% A150 of 13.4%. In this case, the O-ring data does support the JP-5 as being more effective in swelling than the ECD-1, but not more so than the S-5 + 25% A150.

For the TARDEC coupon and o-ring swelling results only, charts showing changes versus time can be found in Appendix G.

Changes in durometer points were observed for all coupons after exposure to the fuels. At the end of 43 days, Nitrile N0674-70 coupons had decreases in durometer points in all fuels; i.e., the elastomer material softened. The trend was that the degree of softness measured increased with increasing aromatic content of the fuel. The largest change was measured in coupons exposed to the S-5 + 25% A150 with a change in durometer points of -8.7% at 43 days. In addition, the trend identified from the coupon data for swelling effectiveness of the fuels, JP-5>ECD-1>S-5+ 25% A150, also held for softening effectiveness as indicated by data for coupons (note: hardness data was not determined for O-rings since specimen geometry cannot accommodate such a measurement).

A similar investigation, that included the same or similar fuels and the same elastomer as selected for this investigation, Nitrile N0674-70 coupons, was reported by TARDEC in November 2003 [8]. Comparisons of the average mass, volume and hardness results between the similar fuels used in both studies are shown in Figures 6 and 7, respectively. Both studies evaluated S-5 with 0% vol. aromatics, S-5 + 10% vol. aromatics, ECD-1 with 19% vol. aromatics, and S-5 + 25% vol. aromatics. Results are generally consistent between the two studies, although some changes, particularly for the measurements with S-5 and S-5 + 25% A150, are somewhat higher for the 2004 data than for the 2003 data. Since the S-5 fuel used in this study was produced in late 2002 and stored since without any antioxidant, some peroxide formation may have occurred. Peroxide attack of the nitrile might, then, be a possible explanation for the higher values seen with some of the S-5 data in 2004 versus 2003. Significant peroxide formation during 40°C storage is more likely than in sealed drum storage, in terms of magnitude.
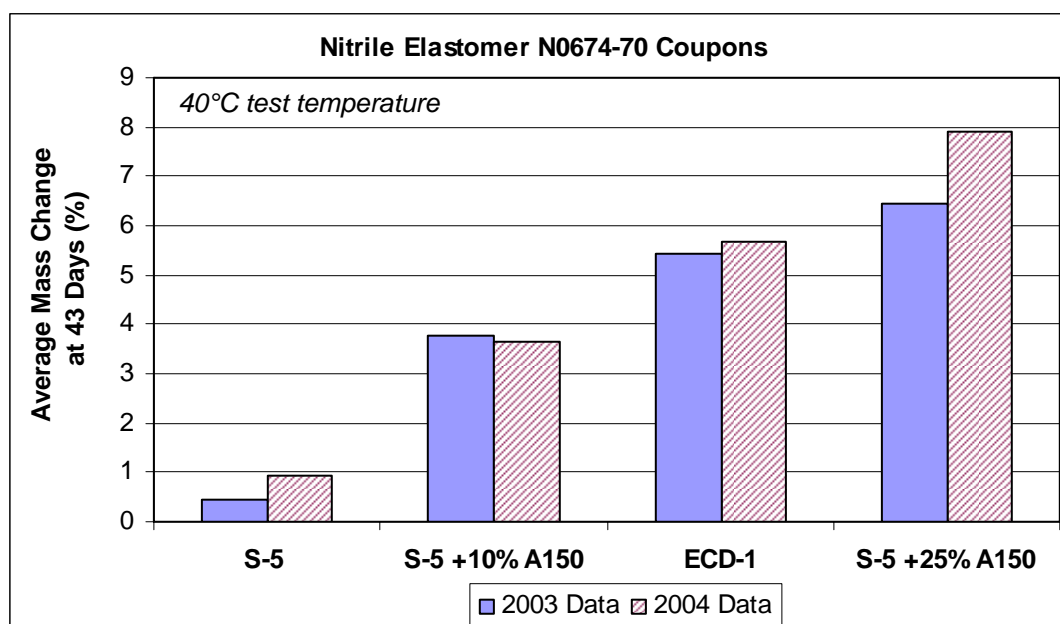

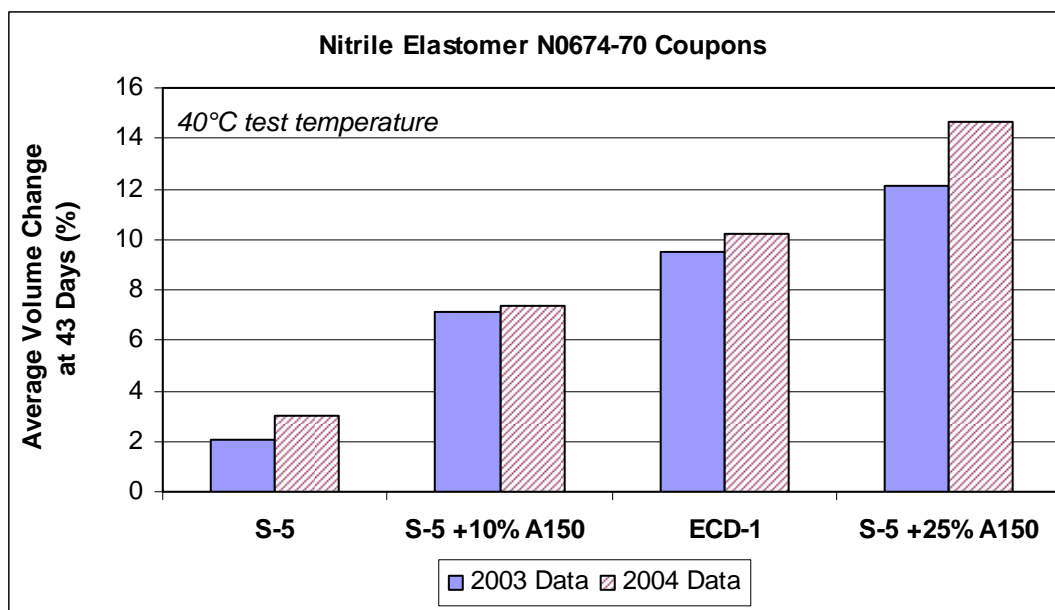**Figure 6. Comparison of Avg. Mass Changes (%) Between 2003 and 2004 Studies**

Figure 7. Comparison of Avg. Volume Changes (%) Between 2003 and 2004 Studies

VI. CONCLUSIONS & RECOMMENDATIONS

In this investigation, the effects of the synthetic S-5 fuel, derived from low temperature GTL/FT synthetic crude upgraded by hydrocracking and hydrotreating, on nitrile type elastomer N0674-70 is contrasted with two fuels produced from petroleum crude oil and two blends containing 10% and 25% of an aromatic concentrate (Aromatic A150) in the S-5. The conventional petroleum JP-5 was provided by the Navy and the ECD-1 was a commercially available diesel fuel of ultra-low sulfur content (<15 ppm).

All five fuels caused a significant change in nitrile elastomer N0674-70 for both coupons and O-rings. The trend in the amount of change generally increased with increasing aromatic content, however aromatic content (concentration) alone is not sufficient to explain the differences in response found between the petroleum fuels, JP-5 and ECD-1, and the fuel blends of S-5 with 25% by volume of the aromatic concentrate (Aromatic A150). The use of an aromatic concentrate as a surrogate source of aromatics for blending in the paraffinic FT JP-5/JP-8 did not reveal any significant bias when compared to petroleum derived JP-5 and diesel fuel, although it was shown to have a reduced effect on elastomer change as compared to the petroleum fuels. A more pronounced response was determined for the JP-5 and ECD-1 fuels (in case of coupon data and some of the O-ring data) than for the S-5 blends and this can be attributed to other compositional differences such as the presence of polar components in the petroleum fuels, especially the di-EGME in the JP-5 fuel.

One of the key objectives of the DoD-DoE Team working together in assessing the potential use of FT fuel by the military is to determine a FT fuel formulation that is fully synthetic and is also freely interchangeable in the existing DoD fleet. With the type of FT fuel studied herein, one that is produced via a low temperature Fischer-Tropsch reaction, the resultant FT jet fuel will be free of aromatic and polar components. As supported by the work of the DoD-DoE Team, such a FT fuel

formulation is indicated to be short of the objective of being a freely interchangeable fuel due to the differences in some elastomer's response to such a FT fuel and, as a result, the possibility for performance degradation, namely fuel leakage, in some equipment. One possible solution to developing a freely interchangeable FT fuel formulation is to develop an additive that can mitigate these differences in elastomer response. Such an approach is being investigated by the team, led by the research previously referenced being done at UDRI. [10] Once candidate additives are identified, those should be evaluated in the same fashion as done in the study herein, to determine elastomer response and to compare to the baseline work established from this study and the prior 2003 study. Note that the volume swell of the nitrile coupons were significantly larger than that of the O-rings.

In order to further understand the possible implications of switch-loading fuels of significantly different aromatic compositions in the existing fleet of Army tactical and combat vehicles, elastomer material evaluations should be conducted with an expanded population of elastomer compounds, drawing elastomer components from rebuild kits across a representative array of the vehicles in the fleet. The elastomer compounds used for these components, then, would be the most reflective of what is currently being used in the fleet.

VII. REFERENCES

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5. Walls, M.; Montemayor, A.; Stavinoha, L.; Dobbs, H.; Williams, J. "Fuel Cell Introduction into a Class 8 Truck" SAE Paper No. 2003-01-3410, October 2003.

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10. Graham, J.; Striebich, R.; Minus, D.; Harrison III, W. "The Swelling of Selected O-Ring Materials in Jet Propulsion and Fischer-Tropsch Fuels" *Preprint Paper–American Chemical Society, Division of Petroleum Chemistry* 2004, 49(3&4).

11. Military Specification, MIL-DTL-85470B, "Detail Specification, Inhibitor, Icing, Fuel System, High Flash NATO Code Number S-1745" 15 June 1999.

APPENDICES

APPENDIX A

Properties of S-5 Fuel

Table A-1 • Properties of S-5 Fuel

Property, Units	Test Method	Analysis by USARMY S-5 X-03-001 Unadditized Batch 0001, Lot 0002
Flash point, °C	ASTM D 56	62
Freezing point, °C:	ASTM D 5972	-50
Saybolt Color	ASTM D 156	+ 30
Total Sulfur, wt %	ASTM D 5185	<1 ppm
Distillation temperature, °C:	ASTM D 86	
Initial boiling point		183
10% recovered		194
20% recovered		201
50% recovered		219
90% recovered		254
Final boiling point (end point)		267
residue, % vol.		1.3
loss, %		0
Density at 15°C, kg/m^3	ASTM D 1298	0.764
Calculated Cetane Index	ASTM D 976 (ASTM D 4737)	69.5/67.3*(74.0)
Aromatics, % vol.	Internal method**	<1
Kinematic Viscosity, mm^2/s @ -20°C	ASTM D 445	6.0
Total Acid Number, mg KOH/g	ASTM D 664	0.0014
Total Water Content, %	ASTM D 6304	0.0019
Conductivity, pS/m	ASTM D 2624	1

Notes:
* Results shown for Equation 1/Equation 2 calculations
** Internal Method

APPENDIX B

Link to Data Sheet for Aromatic Surrogate A150

http://www.exxonmobilchemical.com/Public_Products/Fluids/Aromatics_HeavyAromatics/Worldwide/Grades_and_DataSheets/Aro_HeavyAromatics_Solvesso_Grades_WW.asp

APPENDIX C

Properties of
JP-5 and ECD-1 Fuels

Table C-1 • Properties of JP-5 and ECD-1 Fuels

Property, Units	ASTM Test Method	JP-5 Fuel Data		ECD-1 Data
		Analysis by Army FL-11981-04	Analysis by Navy [1] FF-03-033	Analysis by SwRI FL-11749-03
Appearance	D 156			
Flash point, °C	D 56 (D 93)	N.A.[2]	(62)	(48)
Freezing point, °C:	D 5972 (D 2386)	-47	(-50)	(-8)
Saybolt Color	D 156	22	26	N.A.
Total Sulfur, wt %	D 2622 (D 4294)	0.11	(0.12)	<0.001
Distillation temperature, °C:	D 86			
Initial boiling point		181	176	180
10% recovered		190	188	204
20% recovered		193	193	213
50% recovered		207	206	247
90% recovered		236	235	314
Final boiling point (end point)		251	252	343
residue, % vol.		1.3	N.A.	1.4
loss, %		0.9	N.A.	N.A.
Density at 15°C, kg/m^3	D 1298 (D 4052)	0.803	(0.803)	0.821
Calculated Cetane Index	D 976 (ASTM D 4737)	46.0/46.0 (47.7)	N.A.	52.6/N.A. (53.6)
Aromatics, % vol. (% wt.)	D 1319 (D 5186)	18.4	19.8	-19.3
Kinematic Viscosity, mm^2/s	D 445			
at -20°C		4.7	4.8	N.A.
at 40°C		1.4	N.A.	2.18
Total Acid Number, mg KOH/g	D 664 (D 3242)	<0.001	(0.003)	<0.01
Total Water Content, %	D 6304	0.005	N.A.	0.0125
Conductivity, pS/m	D 2624	5	N.A.	N.A.

Notes:

[1] The analysis provided by the Navy showed presence of Fuel System Icing Inhibitor, di-EGME, at 0.16% vol. as determined by ASTM D 5006.

[2] Pending repair of equipment.

APPENDIX D

Data Sheet for Nitrile N0674-70 Elastomer

Compound Data Sheet
O-Ring Division United States

_____

MATERIAL REPORT

REPORT NUMBER: KK2046
DATE: 2/06/90

TITLE: Evaluation of Parker Compound N0674-70 to ASTM D2000 2BG 720 EA 14 E014 E034.

PURPOSE: To document conformance to periodic test.

CONCLUSION: Parker Compound N0674-70 meets the requirements of ASTM D2000 2 BG 720 EA14 E014 E034.

Recommended Temperature Range: -30 to 250F

Recommended for: petroleum oils, water (up to 212F),
    Salt & Alkali solutions, weak acids

Not Recommended for: aromatic fuels, strong acids,
    glycols, ozone, polar solvents

Parker O-Ring Division
2360 Palumbo Drive
Lexington, Kentucky 40509
(859) 269-2351

REPORT DATA
Report Number: KK2046

BASIC PROPERTIES	2BG720 EA14 E014 E034	N0674-70 ATM D2000 RESULTS	PLATEN
Hardness, Shore A, pts.	70 ± 5	71	
Tensile Strength, psi. min.	2000	2546	
Elongation, % min.	250	331	

HEAT RESISTANCE
70 HRS. @ 212°F

Hardness chg. pts.	±15	+6	
Tensile Strength chg, %	±30	+6.3	
Elongation chg, % max.	-50	-30.2	

COMPRESSION SET,
22 HRS. @ 212°F

% of original deflection, max.	50	12.6	

EA14 WATER RESISTANCE,
70 HRS. @ 212°F

Hardness chg. pts.	±10	+1	
Volume chg, % max.	±15	+1.1	

EO14 ASTM #1 OIL,
70 HRS. @ 212°F

Hardness chg. pts.	-5 to +10	+3	
Tensile Strength chg, % max	-25	+5.5	
Elongation chg, % max	-45	-15.1	
Volume chg, %	-10 to +5	-2.3	

EO34 ASTM #3 OIL,
70 HRS. @ 212°F

Hardness chg. pts.	-10 to +5	-7	
Tensile Strength chg, % max	-45	+2.9	
Elongation chg, % max	-45	-7.9	
Volume chg, %	0 to +25	+13.5	

APPENDIX E

Swelling Results, Changes in Mass and Volume

Table E-1 • Summary of Average Percent Change in Mass and Volume

Nitrile Elastomer N0674-70 Coupons – Average % Change in Mass and Volume					
Fuel Type	Time (Days)	Average Mass (%)	Standard Deviation	Average Volume (%)	Standard Deviation
S-5	3	0.72	0.02	1.79	0.08
S-5	9	1.12	0.02	3.00	0.02
S-5	43	0.94	0.03	2.98	0.05
S-5 +10% A150	3	3.62	0.13	6.73	0.33
S-5 +10% A150	9	4.22	0.18	8.22	0.32
S-5 +10% A150	43	3.65	0.20	7.37	0.32
JP-5	3	6.39	0.06	11.58	0.12
JP-5	9	7.03	0.08	13.32	0.15
JP-5	43	5.79	0.08	10.98	0.15
ECD-1	3	4.54	0.04	7.77	0.09
ECD-1	9	6.01	0.03	10.73	0.08
ECD-1	43	5.67	0.03	10.22	0.06
S-5 +25% A150	3	8.85	0.12	16.22	0.14
S-5 +25% A150	9	8.47	0.19	15.80	0.19
S-5 +25% A150	43	7.90	0.12	14.67	0.30

Table E-2 • Summary of Average Percent Change in Mass and Volume

Nitrile Elastomer N0674-70 O-rings - Average % Change in Mass and Volume					
Fuel Type	Time (Days)	Average Mass (%)	Standard Deviation	Average Volume (%)	Standard Deviation
S-5	3	0.11	0.03	1.24	0.47
S-5	9	-0.11	0.03	1.14	0.94
S-5	43	-0.30	0.06	-2.92	0.45
S-5 +10% A150	3	1.05	0.07	6.65	0.99
S-5 +10% A150	9	0.69	0.09	5.36	1.19
S-5 +10% A150	43	0.54	0.09	2.87	1.25
JP-5	3	1.67	0.06	9.00	1.26
JP-5	9	1.28	0.06	7.45	0.95
JP-5	43	1.19	0.05	4.87	0.44
ECD-1	3	1.53	0.02	7.45	0.88
ECD-1	9	1.34	0.03	7.45	0.99
ECD-1	43	1.26	0.03	5.61	0.90
S-5 + 25% A150	3	2.28	0.07	13.16	1.16
S-5 + 25% A150	9	1.86	0.11	10.93	1.38
S-5 + 25% A150	43	1.81	0.09	9.37	1.04
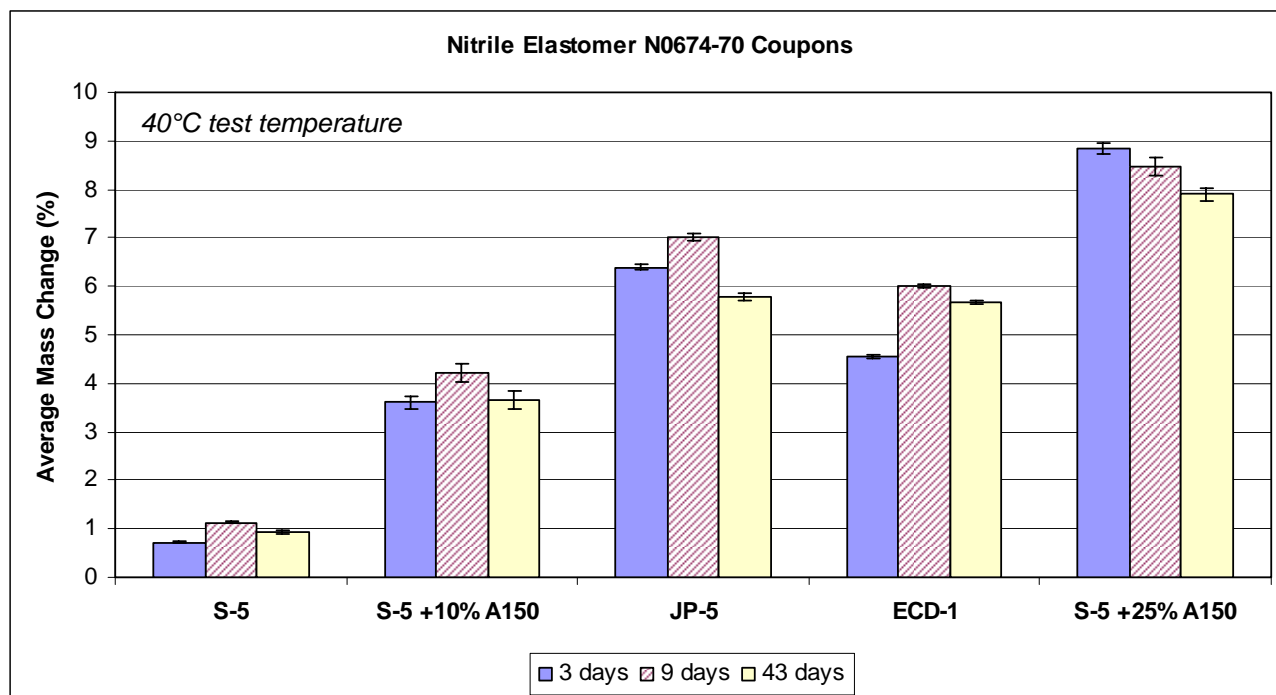
Figure E-1. Average Mass Change (%) at 3, 9 and 43 Days for Nitrile Elastomer N0674-70 Coupons
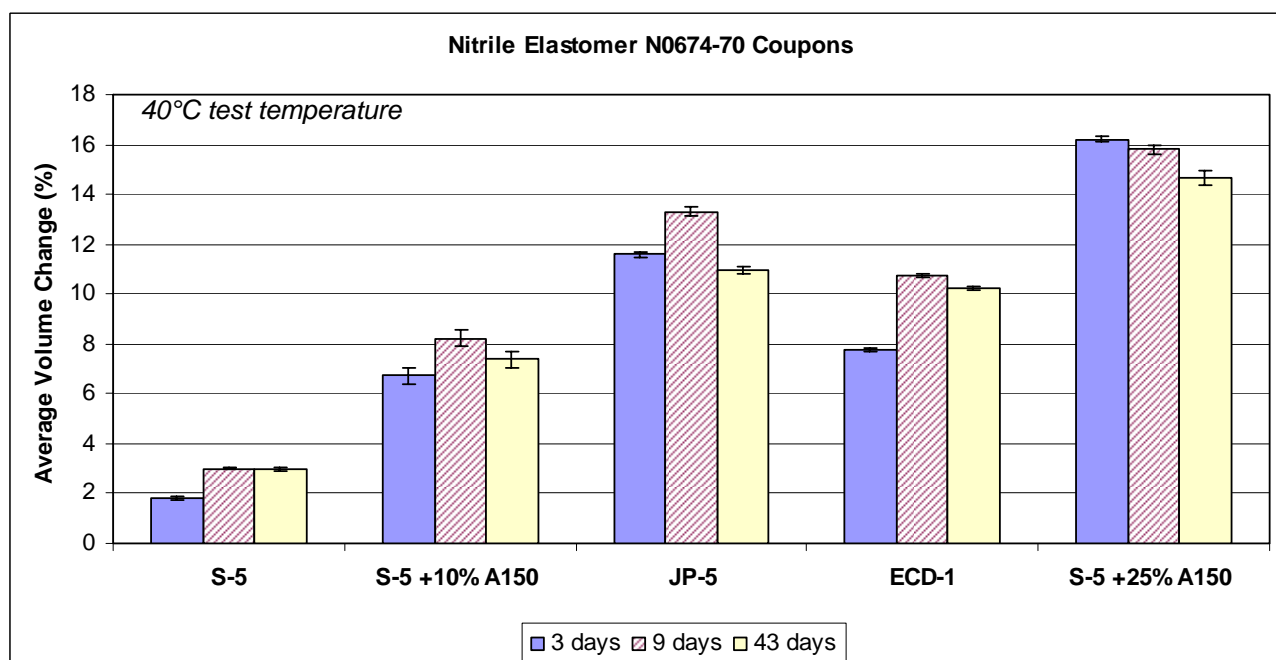
Figure E-2. Average Volume Change (%) at 3, 9 and 43 Days for Nitrile Elastomer N0674-70 Coupons
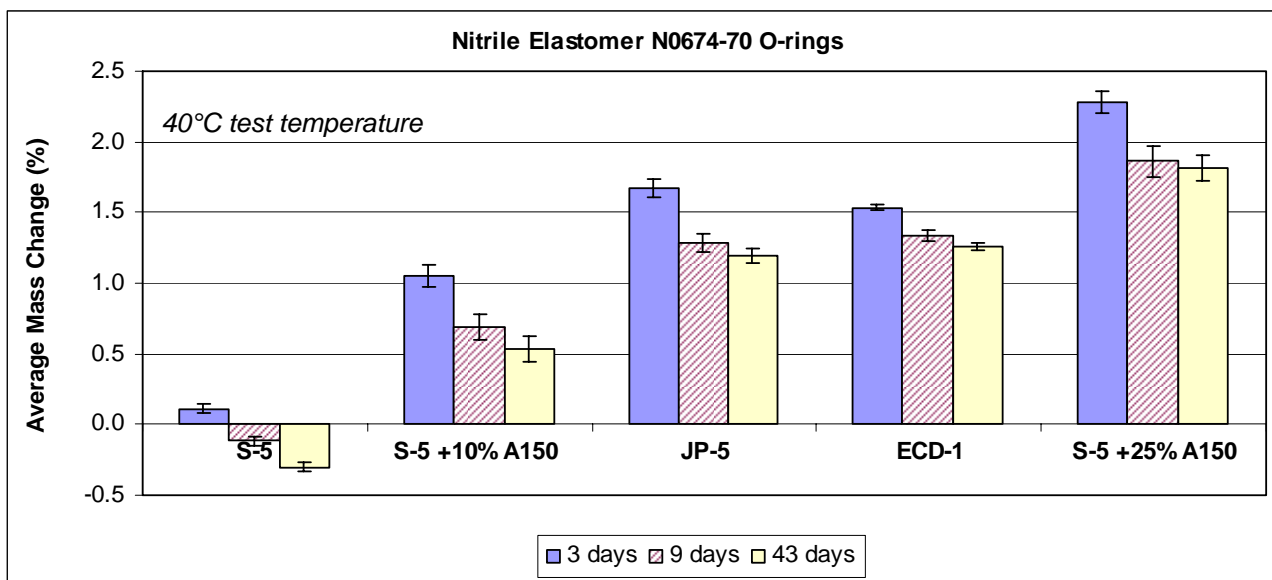
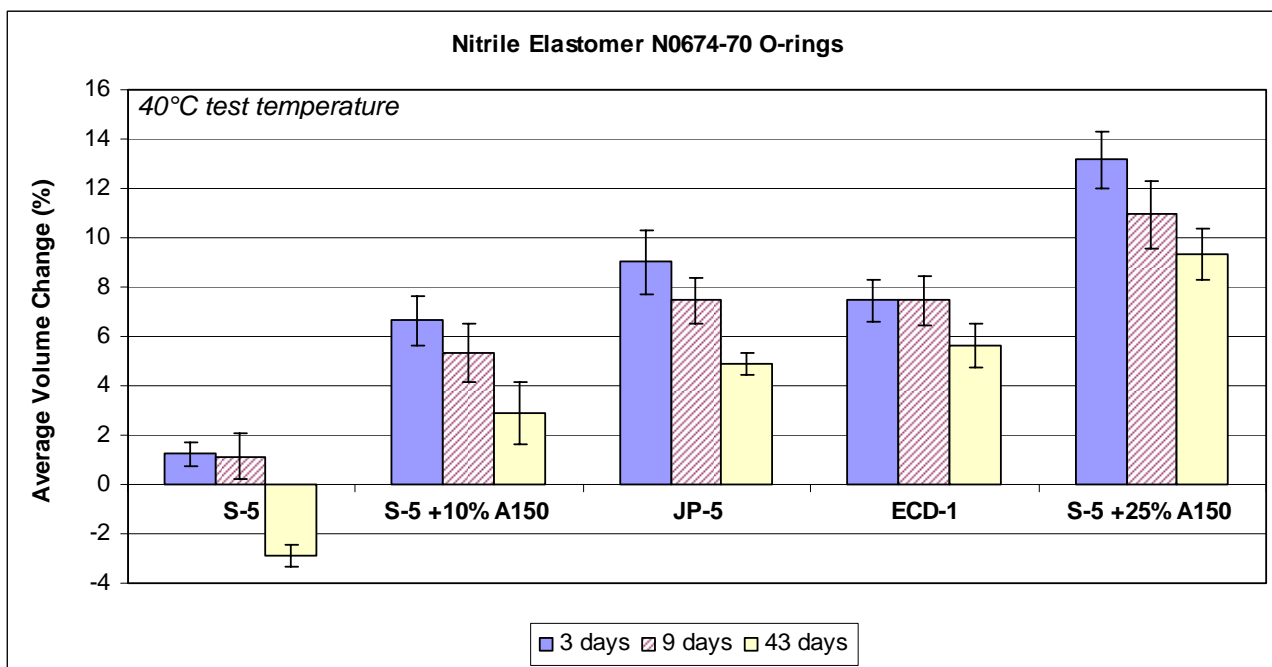**Figure E-3. Average Mass Change (%) at 3, 9 and 43 Days for Nitrile Elastomer N0674-70 O-rings**

Figure E-4. Average Volume Change (%) at 3, 9 and 43 Days for Nitrile Elastomer N0674-70 O-rings
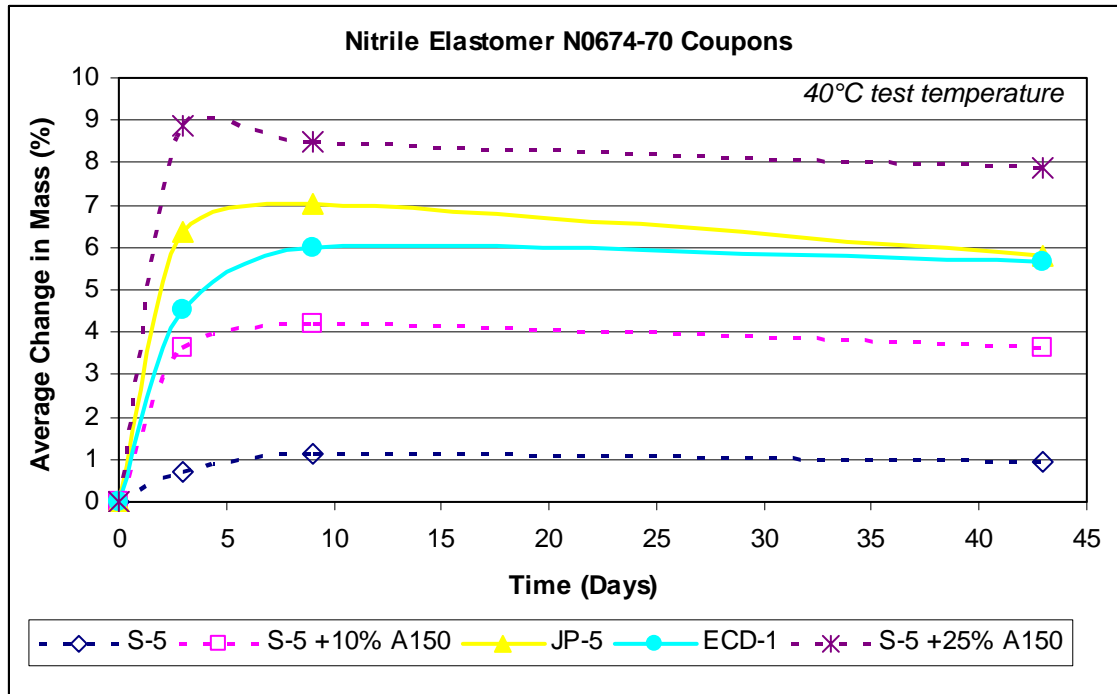
Figure E-5. Average Mass Change (%) Over Time for Nitrile Elastomer N0674-70 Coupons
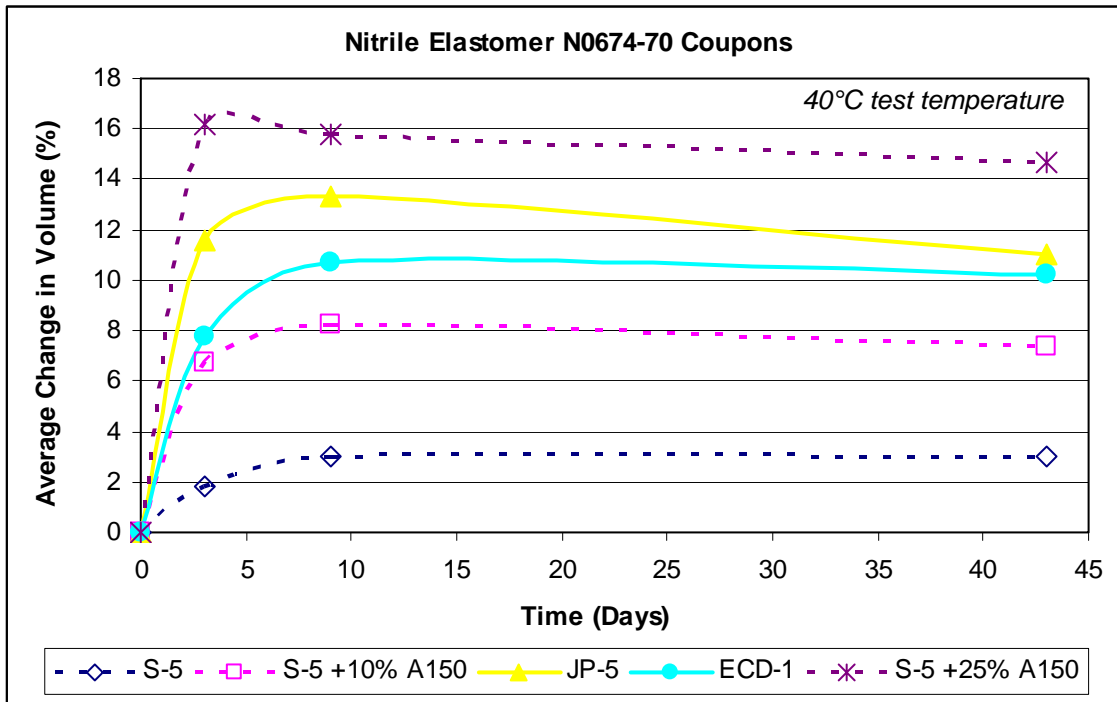
Figure E-6. Average Volume (%) Change Over Time for Nitrile Elastomer N0674-70 Coupons
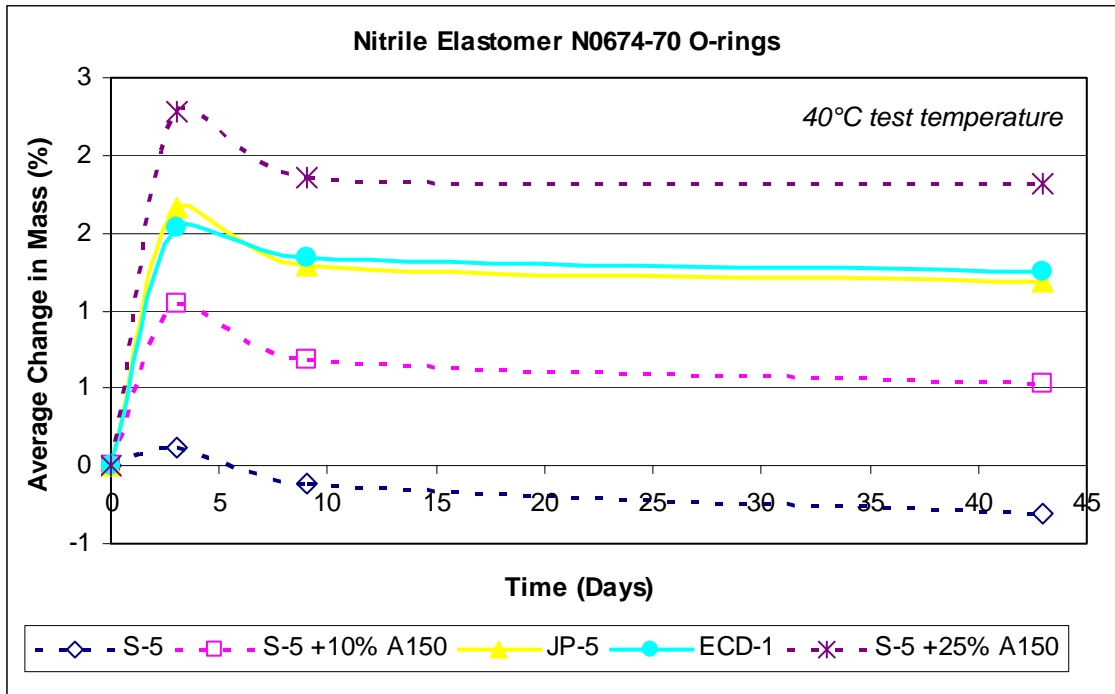
Figure E-7. Average Mass Change (%) Over Time for Nitrile Elastomer N0674-70 O-rings
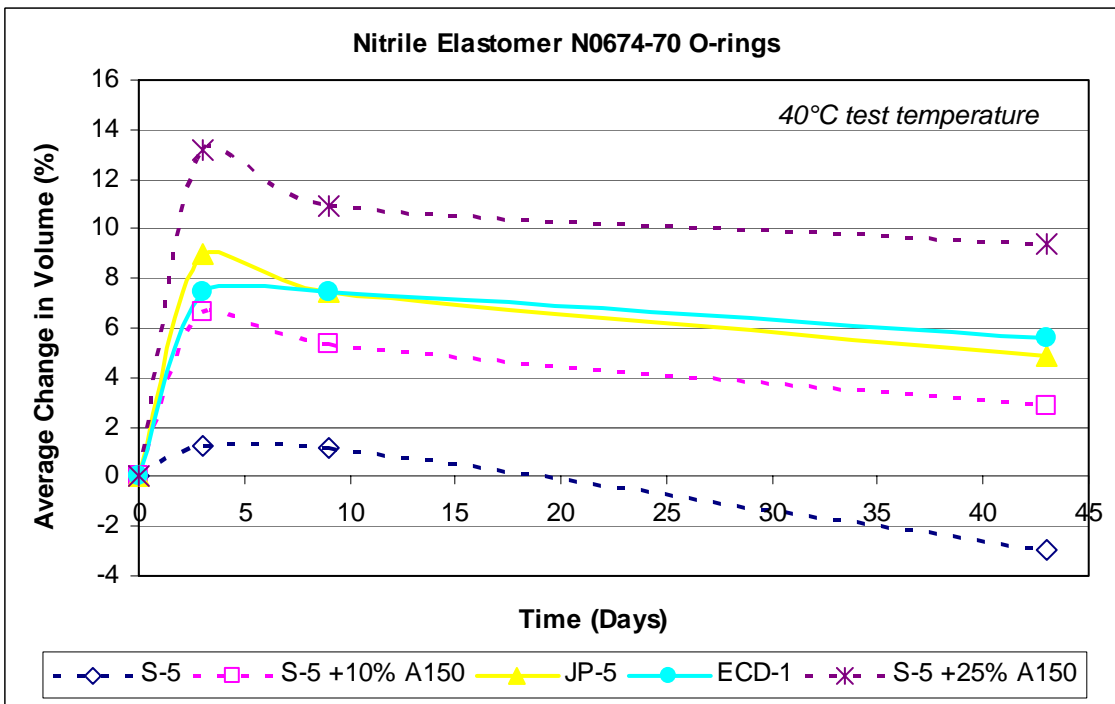
Figure E-8. Average Volume Change(%) Over Time for Nitrile Elastomer N0674-70 O-rings

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APPENDIX F

Fuel Effects on Hardness

Table F-1 • Summary of Average Percent Change in Hardness

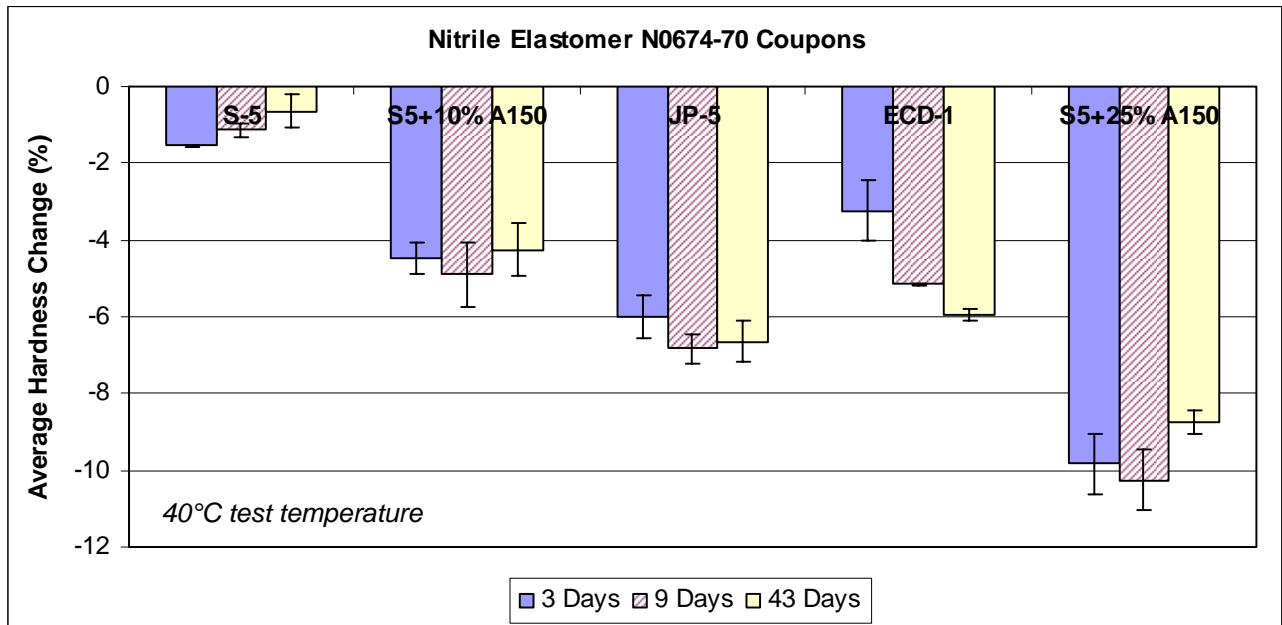| Elastomer N0674-70 Coupons - Change in Hardness					
Fuel Type	Time (Days)	Average Hardness	Standard Deviation	Average Hardness (%)	Standard Deviation
S-5	0	73.33	0.23		
S-5	3	72.20	0.28	-1.55	0.01
S-5	9	72.50	0.14	-1.14	0.19
S-5	43	72.87	0.12	-0.64	0.41
S-5 + 10% A150	0	72.87	0.37		
S-5 + 10% A150	3	69.60	0.49	-4.48	0.41
S-5 + 10% A150	9	69.30	0.35	-4.89	0.83
S-5 + 10% A150	43	69.77	0.15	-4.25	0.67
JP-5	0	73.20	0.35		
JP-5	3	68.80	0.00	-6.01	0.55
JP-5	9	68.20	0.28	-6.83	0.39
JP-5	43	68.33	0.12	-6.65	0.54
ECD-1	0	73.07	0.12		
ECD-1	3	70.70	0.71	-3.24	0.78
ECD-1	9	69.30	0.14	-5.16	0.01
ECD-1	43	68.73	0.12	-5.93	0.15
S-5+25% A150	0	73.20	0.28		
S-5+25% A150	3	66.00	0.43	-9.84	0.79
S-5+25% A150	9	65.70	0.50	-10.25	0.80
S-5+25% A150	43	66.80	0.18	-8.74	0.32

Figure F-1. Average Hardness Change (%) at 3, 9 and 43 Days for Nitrile Elastomer N0674-70 Coupons
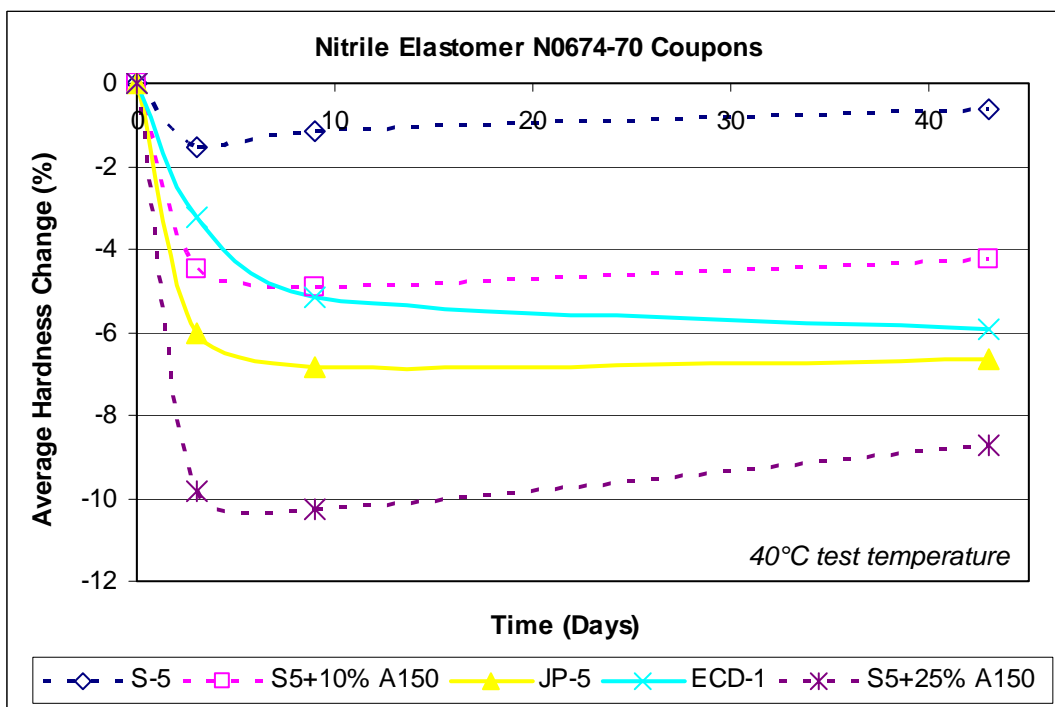

Figure F-2. Average Hardness Change (%) Over Time for Nitrile Elastomer N0674-70 Coupons

APPENDIX G

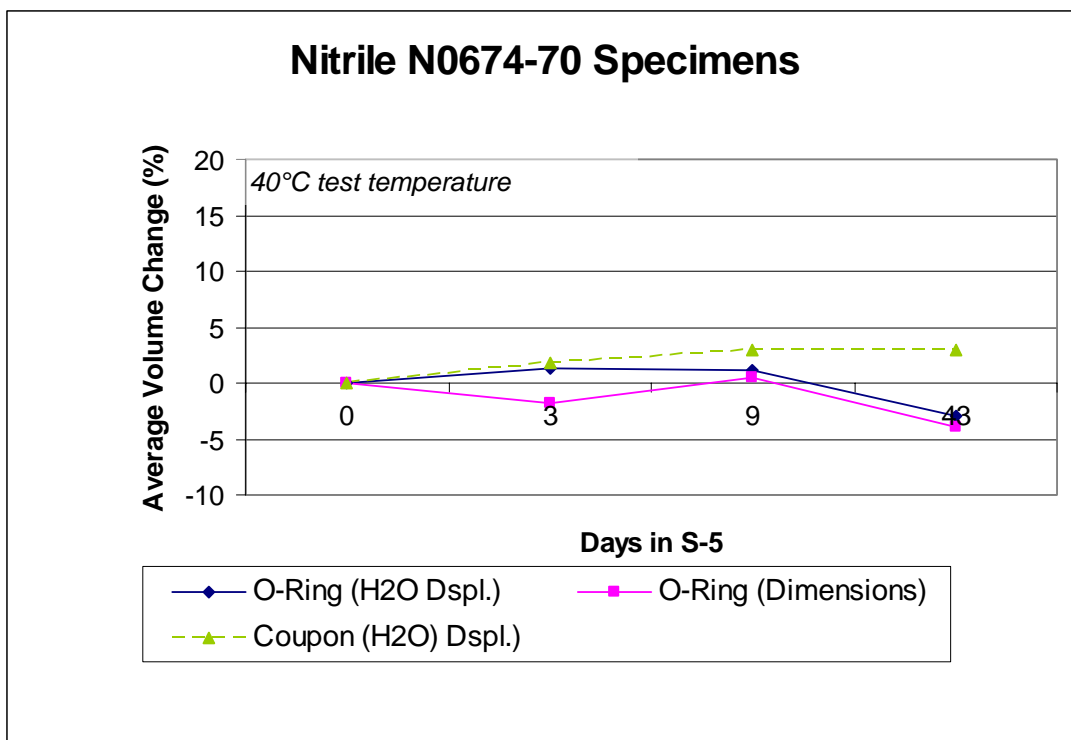# Comparison of Swelling Results for Coupons and O-Rings

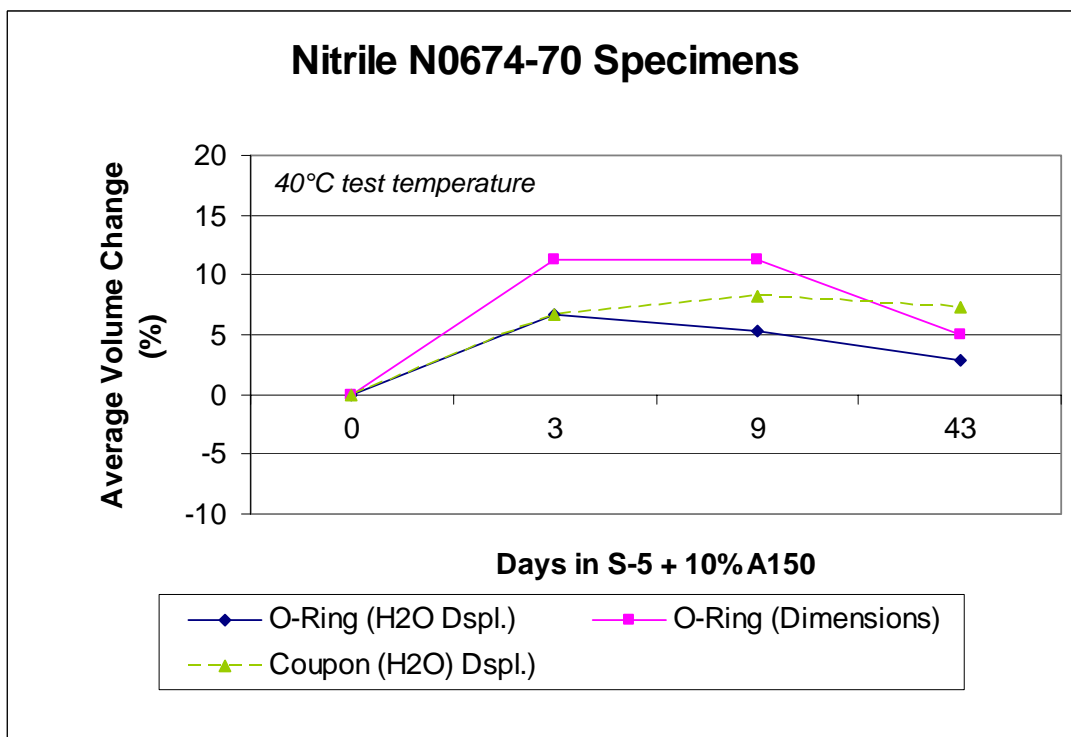**Figure G-1. Avg. Volume Change (%) Over Time for Nitrile N0674-70Specimens in S-5**

Figure G-2. Avg. Volume Change (%) Over Time for Nitrile N0674-70 Specimens in S-5 +10%A150
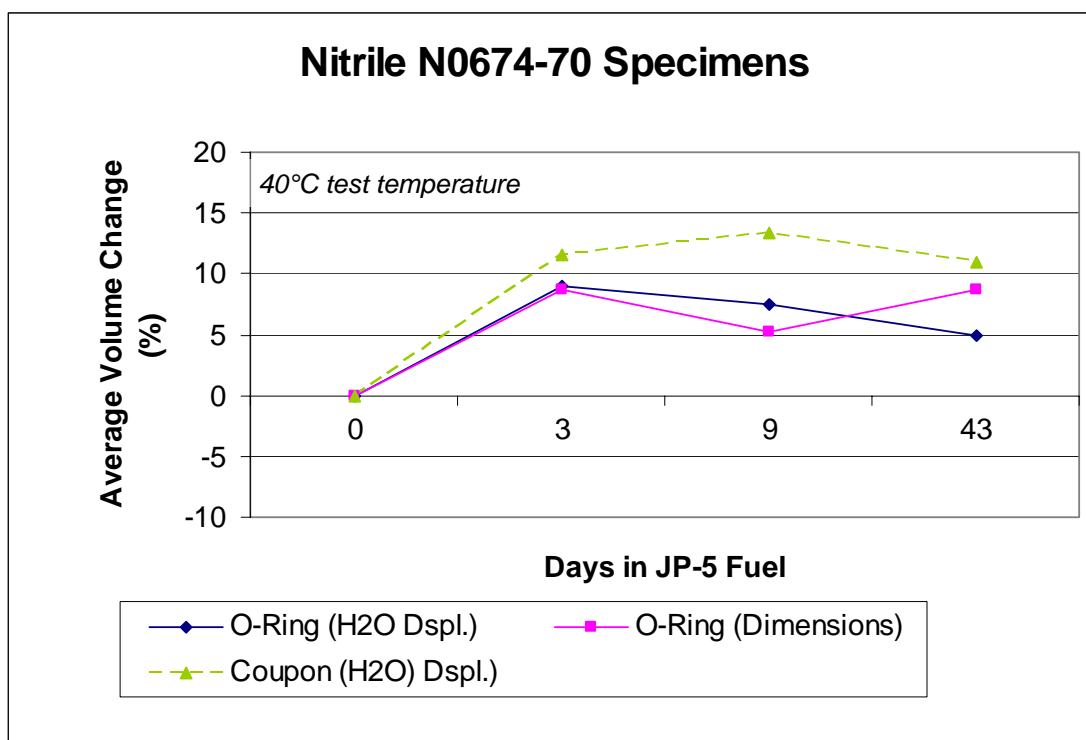
Figure G-3. Avg. Volume Change (%) Over Time for Nitrile N0674-70 Specimens in JP-5
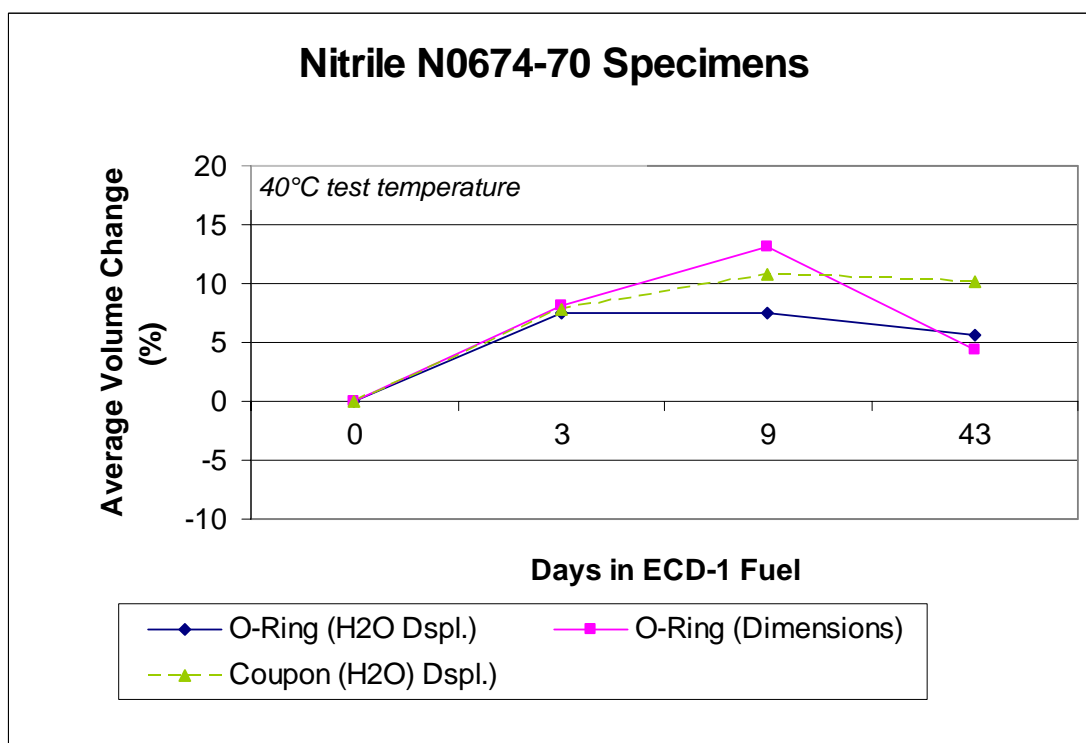

Figure G-4. Avg. Volume Change (%) Over Time for Nitrile N0674-70 Specimens in ECD-1
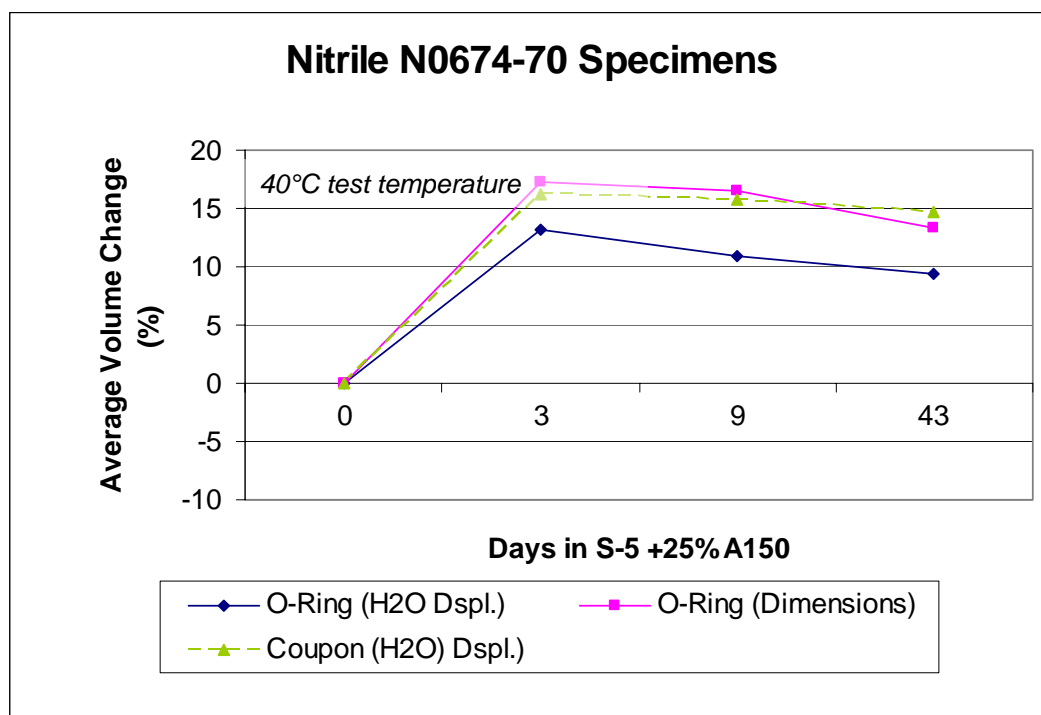
Figure G-5. Avg. Volume Change (%) Over Time for Nitrile N0674-70 Specimens in S-5 +25%A150