AFRL-RZ-WP-TR-2011-2020

PROPULSION AND POWER RAPID RESPONSE RESEARCH AND DEVELOPMENT (R&D) SUPPORT

Delivery Order 0011: Production Demonstration and Laboratory Evaluation of R-8 and R-8X Hydroprocessed Renewable Jet (HRJ) Fuel for the DOD Alternative Fuels Program

James K. Klein

Klein Consulting LLC

For:

Universal Technology Corporation

MAY 2010
Interim Report

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14. ABSTRACT

The objective of this research project was to determine whether a suitable jet fuel could be made from animal fat and other bio feed stocks. A pilot production of 610 gallons of renewable synthetic fuel (termed R-8 and R-8X for renewable and JP-8 like) was successfully accomplished. In 2008, a nomenclature of hydroprocessed renewable for jet (HRJ) was determined for these classes of fuels. Numerous fuel property tests, engine, combustor and pump demonstrations, and risk assessments were performed for the R-8 HRJ fuel. The R-8 HRJ appears suitable as an aviation fuel blending stock up to 50 vol%. It is also concluded that the unblended and unadditized R-8 HRJ has poor lubricity.

15. SUBJECT TERMS

alternative fuels; synthetic fuel, Fischer-Tropsch fuel, aircraft certification, airworthiness certification, fuel certification, MIL-HDBK-510, hydroprocessed renewable jet (HRJ)

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PREFACE

This report was prepared by the Klein Consulting LLC for the Universal Technology Corporation (UTC), 1270 North Fairfield Road, Dayton, Ohio, 45432-2600 under Contract Number FA8650-08-D-2806 for the Air Force Research Laboratory's Propulsion Directorate (AFRL/RZ). Mrs. Michele Puterbaugh (Contractor, Universal Technology Corporation) was the project manager for this effort. Mr. James K. Klein, (Contractor, Klein Consulting LLC) was the Principal Investigator in support of Dr. James T. Edwards of the Fuels Branch (AFRL/RZPF), Energy, Power and Thermal Division, Propulsion Directorate, Air Force Research Laboratory, Wright-Patterson Air Force Base, Ohio. The research reported herein covers the period of June 2007 thru January 2010. This effort was funded by the Air Force Research Laboratory. Portions of this report are excerpted from AFRL-RZ-WP-TR-2009-2040 for public release.

The report is a collection of production reports, laboratory evaluations and technical risk analysis performed by the Air Force Research Laboratory, University of Dayton Research Institute, Southwest Research Institute, Beta Analytic Inc., and Klein Consulting LLC. Combustion sector evaluations were performed by the Liberty Works Rolls-Royce Corporation with details reported separately.

The report is organized by summarized activity with laboratory reports/analysis provided as appendices.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of a number of individuals who made it possible to obtain the data and results described in this report:

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Ms. Pam Kearney, (UTC)

1.0 EXECUTIVE SUMMARY

The rising cost of aviation fuel and the real potential of supply shortages have been recognized as strategic issues for the United States Air Force. In April of 2006, the Secretary of the Air Force directed that a Fischer-Tropsch (F-T) derived synthetic paraffinic kerosene (SPK) fuel blend be demonstrated in a manned aircraft by the end of FY 2006, and a flight demonstration in a B-52 aircraft was successfully accomplished. In March 2007, the USAF expanded its interest to other SPK fuels. Studies showed that the United States produces in excess of 8 billion pounds of animal fat each year, and with a conversion of approximately 55% to SPK, a potential market of 15 million barrels (750 million gallons) of renewable jet fuel per year might be realized. Hence a research project was begun to determine whether renewable synthetic alternative fuels using animal fat and other bio feed stocks (often termed bio-SPK or hydroprocessed renewable jet/HRJ) could be made into suitable jet fuel.

A pilot production of 600 gallons of renewable IPK alternative fuel (termed R-8 for renewable and JP-8 like) was successfully completed by the Syntroleum Corporation. The feedstock utilized for this research was animal fat and greases. Numerous tests, demonstrations and assessments were performed for the R-8 fuel. These evaluations included specification, fuel characteristic, compositional and property studies, fit-for-purpose studies, relative oxidative stability characteristics, material swell and material compatibility, gaseous and particulate emission characteristics using the T63-A-700 turbo shaft engine located at the USAF/AFRL, fuel injection pump wear testing using the Stanadyne model DB2831-5209 rotary fuel injection pump, AE3007 combustor sector evaluations, technology development and aircraft performance impact assessments.

A quantity of approximately 8 gallons of renewable IPK alternative fuel from halophyte (Salicornia oil from sea plants) was also produced by the Syntroleum Corporation and termed R-8X. Syntroleum processed these bio-oils without catalyst change-out or processing optimization. Only a portion of the fit for purpose and characterization testing was accomplished due to the limited quantities available for test.

The following conclusions and recommendations were determined from these evaluations:

a) Test data and analyses show the R-8 HRJ to be comparable to the Syntroleum S-8 FT SPK and support the proposal for use of R-8 HRJ as a blending stock for jet fuel, up to 50 volume %, just as F-T SPK is allowed to be used in MIL-DTL-83133F.

b) The R-8 feedstock of fats, oils, and grease (FOG) was successfully converted into a satisfactory aviation fuel product. This may represent a “worst case” starting material for HRJ fuel alternates,

c) Evaluations suggest that there is no difference in filtration performance between the baseline fuels and R-8 HRJ.

d) The JP-8/R-8 blend generally appears to have a very similar affect on materials based on comparison with the JP-8 baseline and JP-8/F-T blend results. Additionally, as with the 100 percent F-T blend, it does not appear the 100 percent R-8 fuel would be suitable for use from a materials compatibility perspective.

e) The R-8 blends, (50 vol %) respond to the addition of MIL-DTL-25017 corrosion inhibitor / lubricity improver additive in a normal fashion, providing adequate pump performance.

f) The technology development risk assessment model for the JP-8/R-8 blend with military additives shows no unexplained high risk. It is noted that neither the hot section materials compatibility test nor nozzle coking evaluation were conducted, (sufficient fuel quantities for these tests were not produced).

g) The aircraft fuels performance model shows some negative impact to range for both R-8 unblended and blended fuels when compared to the average JP-8. However, neither the unblended nor blended fuels show impact when compared to a minimum specification JP-8.

h) It is concluded that the unblended and unadditized R-8 HRJ has poor lubricity. Use of neat (100%) R-8 HRJ without lubricity additive fuel in rotary fuel injection equipment is not recommended.

i) Based on the technology development risk assessment, aircraft performance impact and materials compatibility test results, the neat (100%) R-8 HRJ is not recommended for use.

2.0 INTRODUCTION

In March 2007, the USAF expanded its interest to fuels other than Fischer-Tropsch synthetic paraffinic kerosene (SPK) fuels. Studies showed that the United States produces in excess of 8 billion pounds of animal fat each year, and with a conversion of approximately 55% to SPK, a potential market of 15 million barrels (750 million gallons) of renewable jet fuel per year might be realized. A research project was begun to determine whether renewable SPK alternative fuels using animal fat and other bio feed stocks could be made into a suitable jet fuel.

UTC placed a subcontract with the Syntroleum Corporation to accomplish a pilot production of 600 gallons of renewable SPK alternative fuel (termed R-8 for renewable and JP-8 like) to a draft R-8 specification. The feedstock utilized for this research was animal fat and greases.

In March 2008, NASA became interested in upgrading other feedstocks (bio-oils) using the Syntroleum Bio-Synfining™ process. The Global Seawater Inc. furnished approximately 20 gallons of halophyte Salicornia oil from sea plants to Syntroleum. Syntroleum processed these bio-oils without catalyst change-out and delivered 5-10 gallons of R-8X (R-8 Experimental) to the Government (AFRL/RZPF) and UDRI for evaluation.

In October 2008, ASTM adopted the official nomenclature of hydroprocessed renewable jet (HRJ) for these classes of fuels; hence the Syntroleum fuels were named R-8 HRJ and R-8X HRJ. The terms R-8 and R-8 HRJ, and R-8X and R-8X HRJ are used interchangeably within this report. HRJ has also been termed “bio-SPK”.

The various R-8 and R-8X HRJ suitability evaluations are presented in this report.

3.0 METHODS, ASSUMPTIONS, AND PROCEDURES

UTC accomplished this work effort using on-site and off-site contractors and subcontractors possessing expert qualifications in the various technical areas to be explored. Extensive use was made of widely available project management and systems engineering standards, tools and methodologies. Progress towards completing the study objectives was carefully tracked through the use of monthly reports. Close coordination with Government Program Managers and suppliers was maintained throughout the period of performance to ensure delivery schedules were met.

A project management plan was finalized, approved, and implemented by UTC to produce and evaluate the R-8 HRJ research fuels for the USAF Assured Fuels Initiative. The plan included transportation and delivery of the R-8 HRJ research fuels, fuel product integrity, laboratory evaluation and system suitability. Technical leadership was provided by UTC and Klein Consulting LLC.

A Program Introduction Document (PID) was prepared in September 2007 to define the evaluation of the R-8 HRJ fuel. The strategy included AFRL and UDRI baseline property and materials compatibility studies, SwRI fit-for-purpose evaluations and AE3007 sector evaluations. The PID is documented in AFRL-RZ-WP-TR-2009-2040, (limited distribution).

The risk analyses are performed using the James Gregory Associates, Inc. licensed Dynamic Insight software. Dynamic Insight was originally developed to support Integrated Product and Process Development within the context of AFRL's Science and Technology programs.

4.0 RESEARCH FUEL PRODUCTION

4.1 Syntroleum HRJ Bio-Fuels

The Syntroleum Corporation, Tulsa OK, has entered into a venture with Tyson Foods to produce renewable synthetic fuels utilizing Syntroleum's proprietary biorefining technology and Tyson supplied feedstock. The Government became very interested in this alternate fuels technology in February 2007 and funded a study to answer two questions: (1) Can a material be produced from animal fats using the Syntroleum Bio-Synfining™ process that will make a satisfactory blend stock for jet fuel, and (2) Is that product equivalent to and interchangeable with the Syntroleum Fischer-Tropsch S-8 research fuel?

The Syntroleum process, called Bio-Synfining™, uses a renewable feedstock. Syntroleum has demonstrated its capability to take a triglyceride feedstock, the primary component of fats and oils, and convert that renewable feedstock using the following process, converting the oils and fats into a normal paraffinic hydrocarbon then into an iso-paraffinic hydrocarbon by isomerization.

Syntroleum Bio-Synfining™ Process:

Fats → Pretreatment → Hydrotreating → Isomerization → Distillation → Jet fuel

A pilot production of 600 gallons of renewable HRJ alternative fuel (termed R-8 for renewable and JP-8 like) was accomplished to a draft R-8 specification. The feedstock utilized for this research was solely animal fat and greases. During the course of the project, a portion of the pilot production (350 gallons) was provided to the Government (AFRL/RZPF) and the University of Dayton Research Institute (UDRI) for in-house protocol and simulator testing and 250 gallons was provided to Southwest Research Institute for other fit-for-purpose evaluations. The Klein Consulting LLC was tasked to provide overall project technical management and to conduct risk and suitability analyses. The Syntroleum R-8 production report is provided as Appendix A with Syntroleum's specification analysis provided as Appendix B.

In March 2008, NASA became interested in upgrading other feedstocks (bio-oils) using the Syntroleum Bio-Synfining™ process. Global Seawater Inc. furnished approximately 20 gallons of Salicornia oil from sea plants to Syntroleum. Syntroleum processed these bio-oils without catalyst change and delivered 5-10 gallons of R-8X HRJ (R-8 Experimental) to the Government (AFRL/RZPF) and UDRI for evaluation. The Syntroleum R-8X production report is provided as Appendix C.

In October 2008, ASTM adopted the official nomenclature of hydroprocessed renewable for jet (HRJ) for these classes of fuels; hence the Syntroleum fuels were named R-8 and R-8X HRJ. The terms R-8 and R-8 HRJ, and R-8X and R-8X HRJ are used interchangeably throughout this report. HRJ has also been termed "bio-SPK".

4.1.1 R-8 HRJ Research Fluid

The Syntroleum Corporation conducted a pilot production of the R-8 HRJ to the draft specification shown below.

Table 1. R-8 Draft Specification

Specification Properties of R-8 Research Fluid			
Physical Properties	**Test Method**	**Units**	**Specification Value**
Density	ASTM D-4052	kg/L	Report
API Gravity	ASTM D-4052	°	Report
Ash, max	ASTM D-482	wt%	Report
Flash Point, min	ASTM D-93	°C	38
Freeze Point, max	ASTM D-5972	°C	-47
Color	ASTM D-156	Saybolt	Report
Kinematic Viscosity, , @ 40°C	ASTM D-445	cSt	Report
Distillation, % recovered	ASTM D-86 (D2887)	°C	Report
IBP		°C	Report
10% Recovered, max		°C	Report
20% Recovered		°C	Report
50% Recovered		°C	Report
90% Recovered		°C	Report
FBP, max		°C	Report
Cetane Index	ASTM D-976		Report

Specific attention was given to low temperature and high temperature characteristics, with key parameters to investigate being freeze point, flash point and thermal stability. Syntroleum obtained 1,500 gallons of feedstock for pre-treatment. The feed was prepared by blending animal fats, including poultry fat, prepared foods grease, floatation grease, brown grease, and yellow grease, (refer to Figure 1). The feed was filtered to remove insolubles and then washed with water in order to reduce the metal chloride content, ("desalting").

After desalting, the feedstock was sent to the Alternative Fuels Pilot Plant at the Southwest Research Institute (SwRI), San Antonio Texas for the hydrodeoxygenation process. The first product from SwRI was found to be a highly pure n-paraffin composition, confirming the desired deoxygenation performance. The intermediate products produced at SwRI were then sent to a private research and development laboratory in Pennsylvania owned by Caleb Brett USA Inc., Intertek PARC, Pittsburgh, Pennsylvania for final processing. A one liter sample of the final product was drawn from the start of production and also sent to the Fuels Branch for evaluation. This initial production sample was received on May 22, 2008 and assigned the internal identification number POSF-5439. A shipment of 250 gallons was made to SwRI on June 20, 2008, and a second shipment of 350 gallons was made to AFRL/UDRI on July 31st. The AFRL identification number for the larger scale production run (lot 2) is POSF-5469. UDRI compared the R-8 samples received from the beginning and end of the large-scale production run and concluded that there was reasonable consistency in the R-8 HRJ production run, with only slight differences in the two R-8 fuels from the beginning and the end of the run.

Feedstock

Syntroleum

Test	Result
Fatty Acid Profile, % Relative	Area Percent
C08:0 Octanoic (Caprylic)	< 0.10 %
C10:0 Decanoic (Capric)	< 0.10 %
C11:0 Undecanoic (Hendecanoic)	< 0.10 %
C12:0 Dodecanoic (Lauric)	0.10 %
C13:0 Tridecanoic	< 0.10 %
C14:0 Tetradecanoic (Myristic)	1.03 %
C14:1 Tetradecenoic (Myristoleic)	0.17 %
C15:0 Pentadecanoic	0.13 %
C15:1 Pentadecenoic	< 0.10 %
C16:0 Hexadecanoic (Palmitic)	20.50 %
C16:1 Hexadecenoic (Palmitoleic)	3.86 %
C16:2 Hexadecadienoic	< 0.10 %
C16:3 Hexadecatrienoic	< 0.10 %
C16:4 Hexadecatetraenoic	< 0.10 %
C17:0 Heptadecanoic (Margaric)	0.35 %
C17:1 Heptadecenoic Margaroleic	0.22 %
C18:0 Octadecanoic (Stearic)	8.56 %
C18:1 Octadecenoic (Oleic)	40.87 %
C18:2 Octadecadienoic (Linoleic)	19.49 %
C18:3 Octadecatrienoic (Linolenic)	1.61 %
C18:4 Octadecatetraenoic	0.28 %
C20:0 Eicosanoic (Arachidic)	0.22 %
C20:1 Eicosenoic (Gadoleic)	1.08 %
C20:2 Eicosadienoic	0.17 %
C20:3 Eicosatrienoic	< 0.10 %
C20:4 Eicosatetraenoic (Arachidonic)	0.23 %
C20:5 Eicosapentaenoic	< 0.10 %
C21:5 Heneicosapentaenoic	< 0.10 %
C22:0 Docosanoic (Behenic)	0.14 %
C22:1 Docosenoic (Erucic)	< 0.10 %
C22:2 Docosadienoic	< 0.10 %

- Thirty drums (1500 gal total)
- Blend of various low cost feedstocks
  - Brown grease
  - Yellow grease
  - Poultry fat
  - Floatation grease
  - Waste streams from industrial food processing
- 40 ppm total metals and phosphorus – ***987 ppm before pre-treat***
- Total acid number 129 mg/g KOH (65% FFA) – ***acid number 61 when received***

1

Figure 1. R-8 HRJ Feedstock Details (Courtesy of Syntroleum Corporation)

Ultra-Clean Fuels from Waste Fats and Greases

Syntroleum

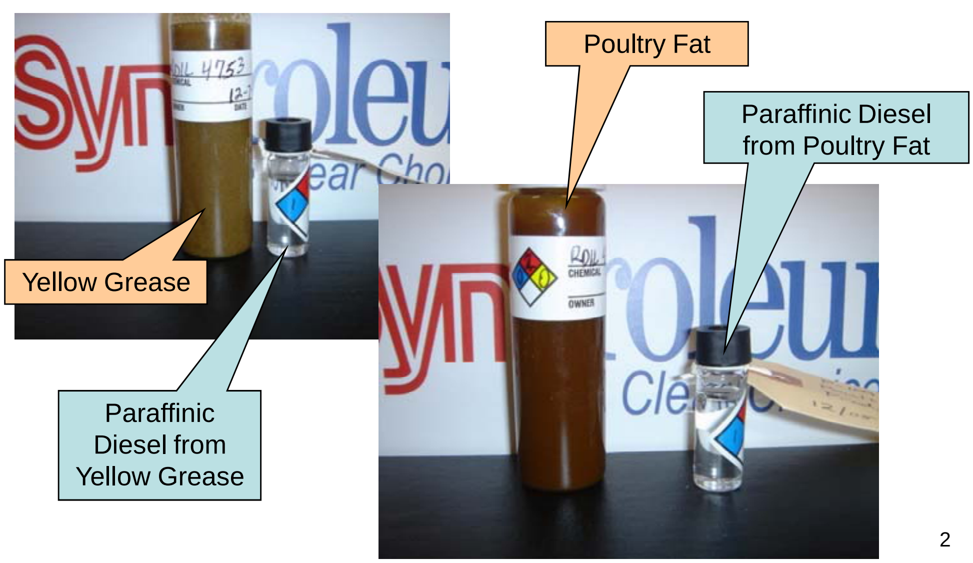

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Figure 2. Feedstock Picture (Courtesy of Syntroleum Corporation)

4.1.2 R-8X HRJ Research Fluid

At the completion of the R-8 pilot production, Syntroleum converted 20 gallons of salicornia oil to HRJ. To differentiate from the R-8, this fuel was termed R-8X, (R-8 fuel from sea plant feedstock). Approximately 9 gallons of the R-8X was produced with no change in catalyst or process parameters. The Syntroleum R-8X production report is provided as Appendix C. The AFRL identification number for R-8X is POSF-5470. This fuel contains between 23 and 29 mg/l phenolic antioxidant to improve storage stability. Due to the small quantity of fuel produced, not all of the evaluations were performed.

4.2 Biobase Content

A biobased content determination using ASTM-D6866-08[1] was performed by the Beta Analytic Inc, Miami, Florida. Table 2 presents the results of this testing.

Table 2. Mean Biobased Results

Fuel	JP-8	R-8	R-8X	R-8/JP-8 Blend	S-8
POSF	4751	5469	5646	5536	4820
Bio Content	0%	96%	100%	49%	0%

[1] ASTM-D6866 cites precision on The Mean Biobased Result as +/- 3% (absolute). The accuracy of the result as it applies to the analyzed product, fuel, or flue gas relies upon all the carbon in the analyzed material originating from either recently respired atmospheric carbon dioxide (within the last decade) or fossil carbon (more than 50,000 years old). "Percent biobased" specifically relates % renewable (or fossil) carbon to total carbon, not to total mass or molecular weight. Mean Biobased estimates greater than 100% are assigned a value of 100% for simplification.

5.0 R-8 AND R-8X HRJ SUITABILITY EVALUATIONS

5.1 AFRL/UDRI Small-Scale Protocol Testing

The Air Force Research Laboratory (AFRL) Fuels Branch along with the Air Force Petroleum Agency (AFPET) and the University of Dayton Research Institute (UDRI) has developed a series of screening evaluations for proposed bio-jet fuel candidates to determine if those samples possess the minimum requirements to be considered for aviation fuels. The purpose of the screening tests is to eliminate/disqualify low quality ("bad") fuel candidates in a timely and cost effective manner. Upon successful completion of the screening tests, more extensive evaluations are outlined in the protocol. These include ASTM tests under the JP-8 Specification conformance tests and several thermal stability, low temperature and limited material compatibility and combustion tests. In addition, emissions tests on a research combustor and a T63 engine fueled with the bio-jet fuel (neat or blended with JP-8) are to be conducted. AFRL and UDRI completed the small-scale protocol testing with reports provided in Appendix D, E, F and G. Summaries, (following sub-paragraphs) are extracted from these laboratory evaluations.

a) When comparing the results for the R-8 and R-8X samples to the JP-8 fuel specification and a representative JP-8 sample, the only considered properties which did not satisfy current requirements were specific gravity/density, conductivity, FSII, and lubricity. Of those four properties, all but density could be made to fall within the specification limits with the addition of JP-8 additives. However even with JP-8 additives, the total aromatic contents of the R-8 and R-8X fuels are significantly below the level typically found in petroleum-derived aviation fuels, which may result in the inability of the neat fuel to directly satisfy required "Fit-For-Use" properties without blending with a JP-8 fuel.

b) From the testing that was performed, there appeared to be reasonable consistency in the R-8 production run. There were only slight differences in the two R-8 fuels from the beginning and the end of the run, with the largest difference being in the total aromatic content of the two fuels. (1.6 vol. % to 0.0 vol. %) In addition, the R-8X fuel is very similar to the R-8 fuel for most of the properties tested. An exception to this is that the R-8X exhibits superior low-temperature behavior to the R-8 fuel.

c) The ECAT Flow Reactor System was used to preliminarily evaluate the relative oxidative stability characteristics of the R-8 HRJ, in a flowing environment. The R-8 fuel demonstrated excellent oxidative stability characteristics during testing resulting in minimal surface deposition on the reaction tube. In addition, the bulk deposits collected on the downstream filter were reduced by over an order of magnitude (approximately 200 μg versus 4,000 μg for JP-8). The stability of R-8 is better than that typically observed on the ECAT for a JP-8 fuel with the use of the currently qualified JP-8+100 thermal stability additive package.

d) The volume swell of selected polymeric materials in POSF 4751 (JP-8), 4909 (F-T), 5480 (R-8 + JP-8 additives), and 5646 (R-8X + JP-8 additives?) was determined to estimate the degree to which the acute material compatibility of R-8 and R-8X compares with that of the FT fuel. Based on the analysis of the volume swell, mass fraction of fuel absorbed, and analysis of the fuel absorbed the overall compatibility of R-8 and R-8X with polymeric fuel system materials should be comparable to that of F-T. Overall, it is anticipated that the volume swell character of fuel blends based on R-8 will be similar to those based on F-T, while fuel blends based on R-8X may show volume swell that is slightly less than fuel blends involving F-T fuels.

e) The gaseous and particulate emission characteristics of the research fuel received from Syntroleum (designated R-8 and assigned internal code 5469) was compared to a specification JP-8 (assigned 3773) using the T63-A-700 turbo shaft engine located at the USAF/AFRL WPAFB Propulsion Directorate. Testing with neat R-8 and a 50/50 volume percent R-8/JP-8 fuel blend showed a significant reduction in aerosol and PM emissions; these trends were similar to previous testing with an F-T derived SPK produced by Syntroleum (S-8). Gaseous emissions were minimally impacted, with only slight reductions in carbon monoxide observed.

5.2 R-8 Fit-for-Purpose (FFP) Evaluations

The initial FFP testing was accomplished by SWRI and the initial report is provided as Appendix H-1. Test results indicate that the R-8 thermal stability is excellent, that there are no detectable free fatty acids, that there are no adverse effect to water separation characteristics, and that there are no physical compatibility concerns with any of the standard JP-8 fuel additives. Additional analysis and testing of these HRJ fuels was requested and these additional test results are provided in Appendix H-2. Plots of selected data are provided below in Figures 3 through 14.

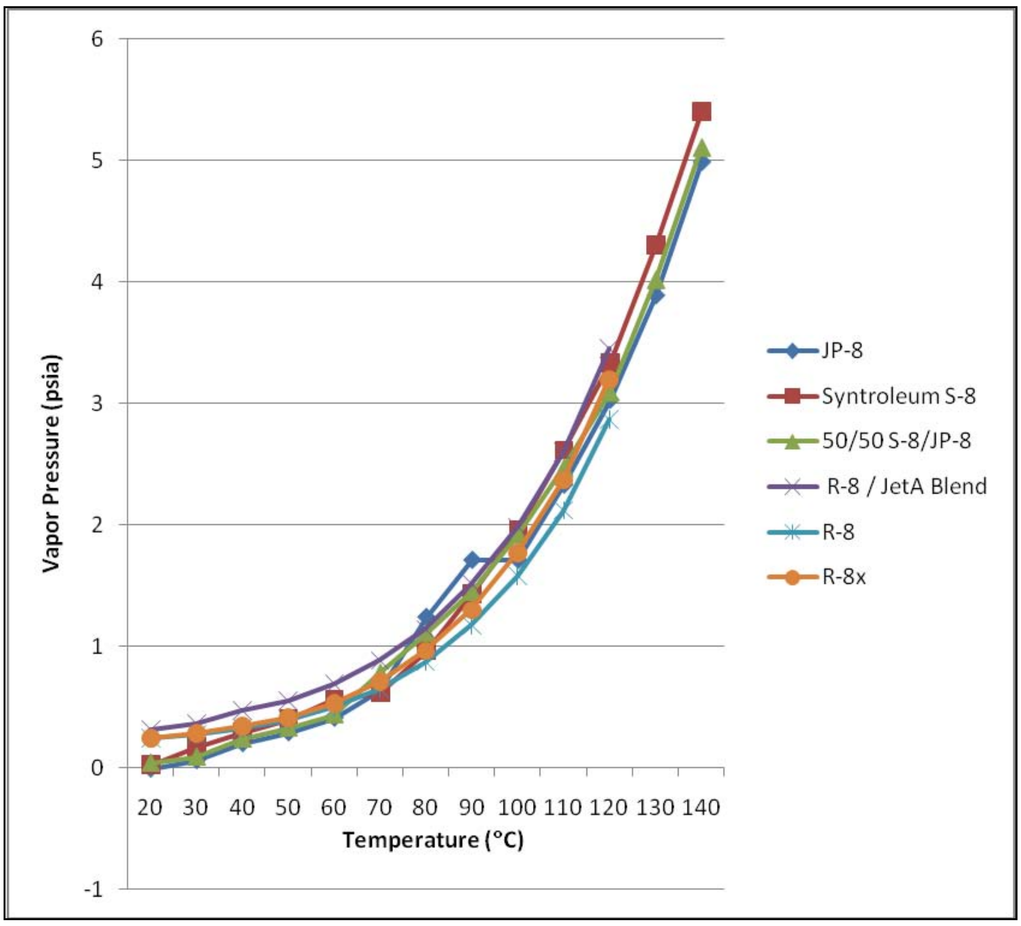


Figure 3. Vapor Pressure (psia) vs. Temperature (°C)

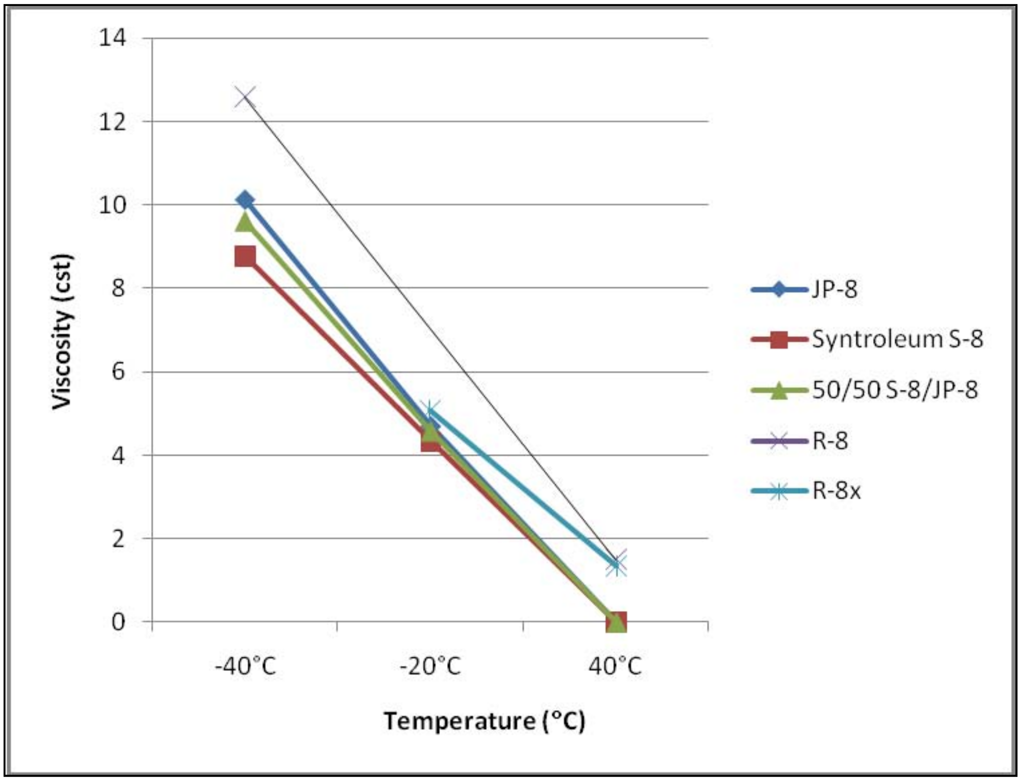


Figure 4. Viscosity (cst) vs. Temperature (°C)

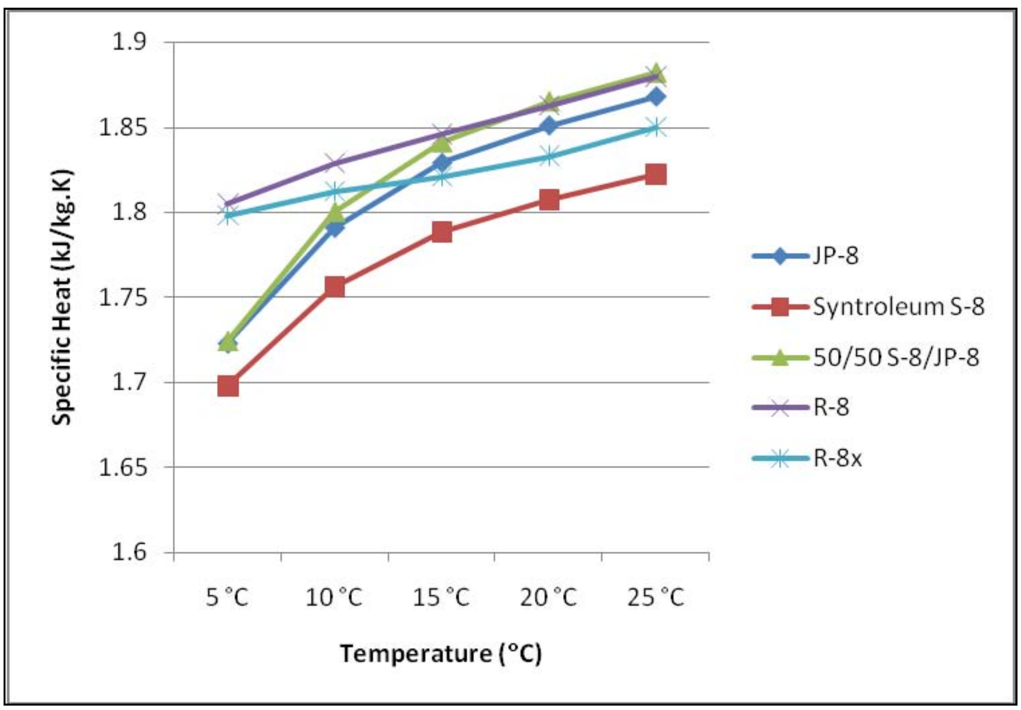


Figure 5. Specific Heat (kJ/kg.K) vs. Temperature (°C)

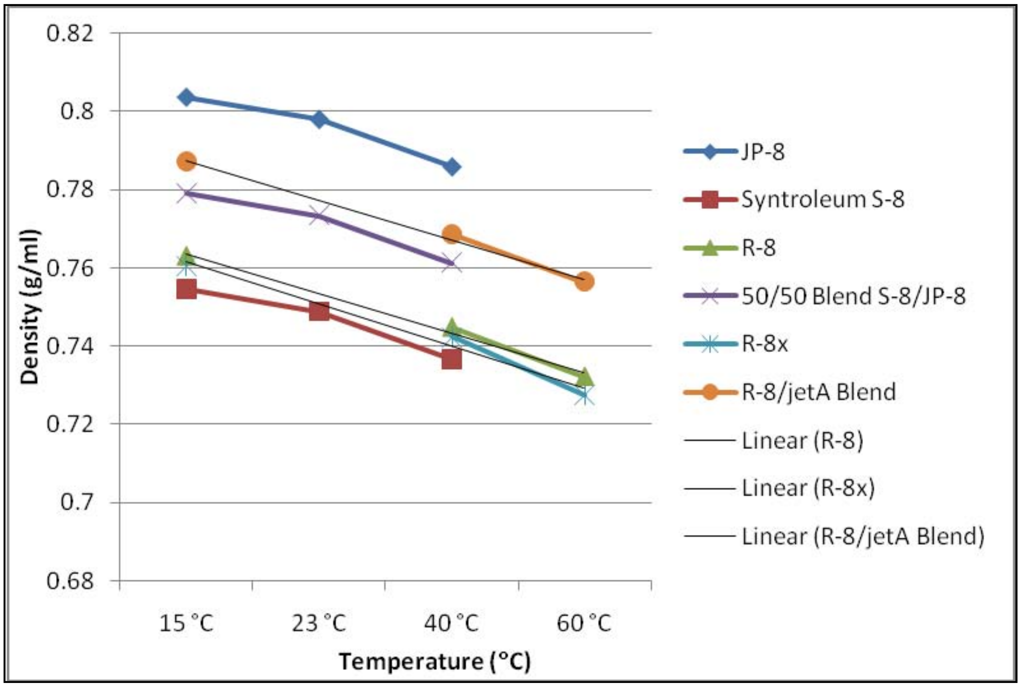


Figure 6. Density (g/ml) vs. Temperature (°C)

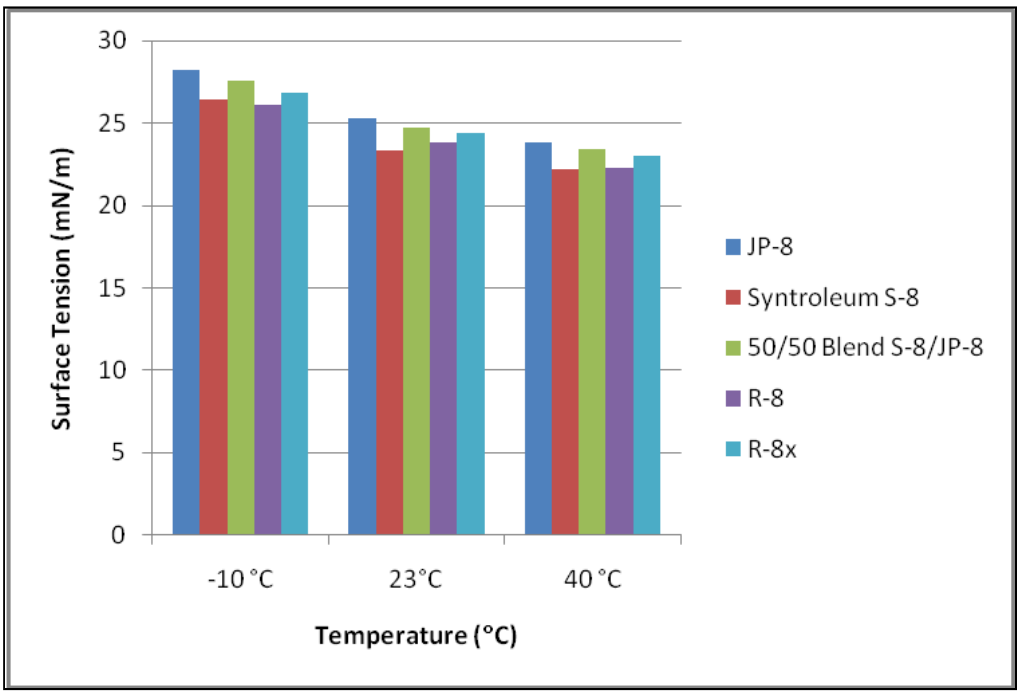


Figure 7. Surface Tension (mN/m)

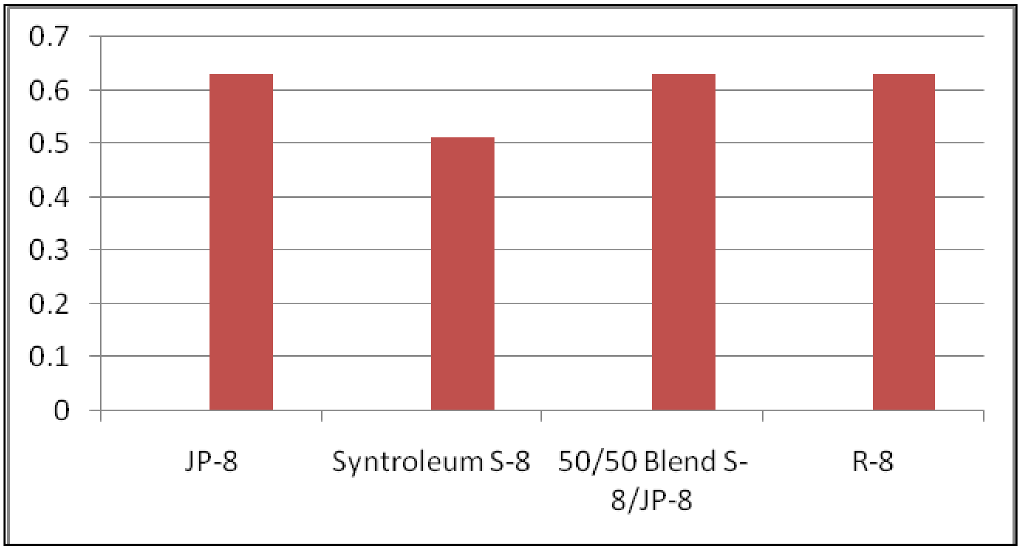


Figure 8. Minimum Ignition Energy (mJ)

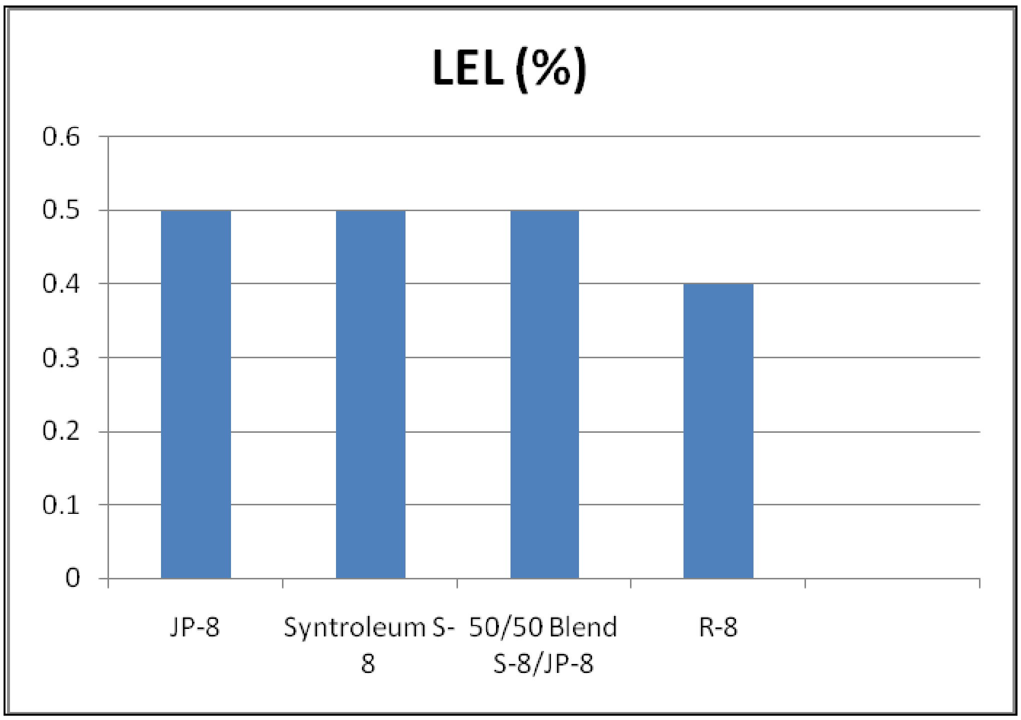


Figure 9. Lower Explosive Limit

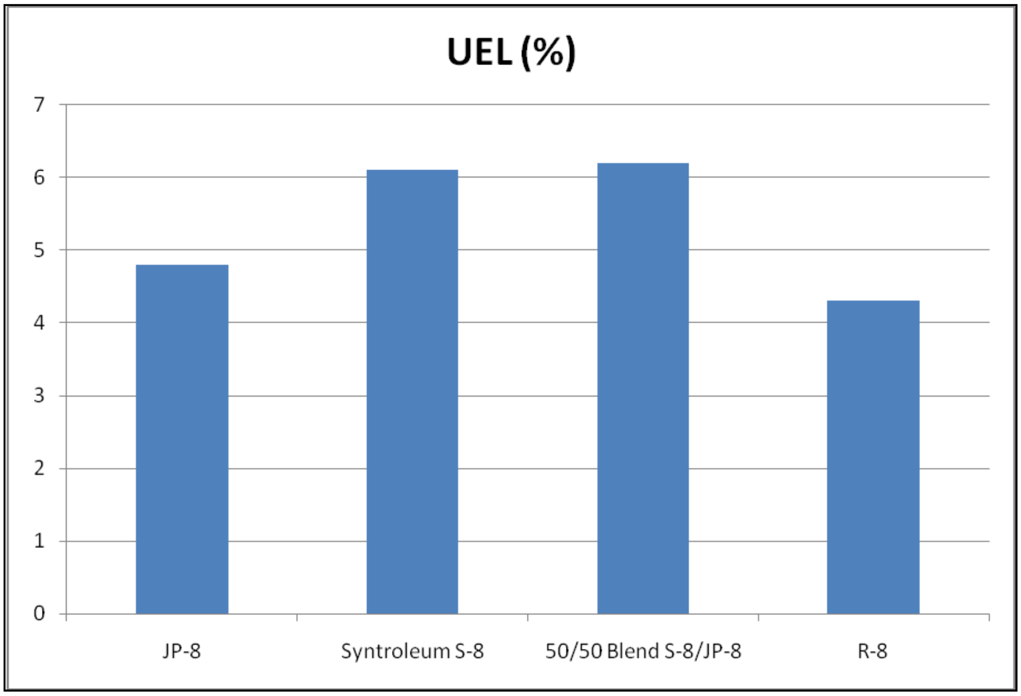


Figure 10. Upper Explosive Limit

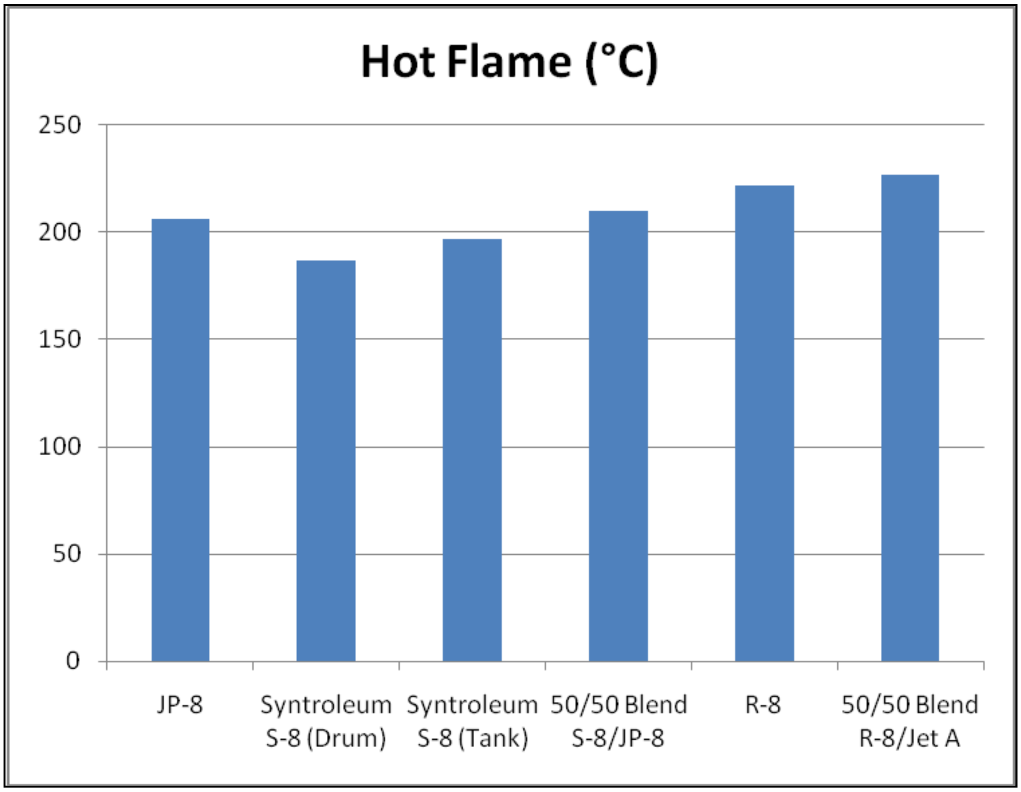


Figure 11. Autoignition Temperature

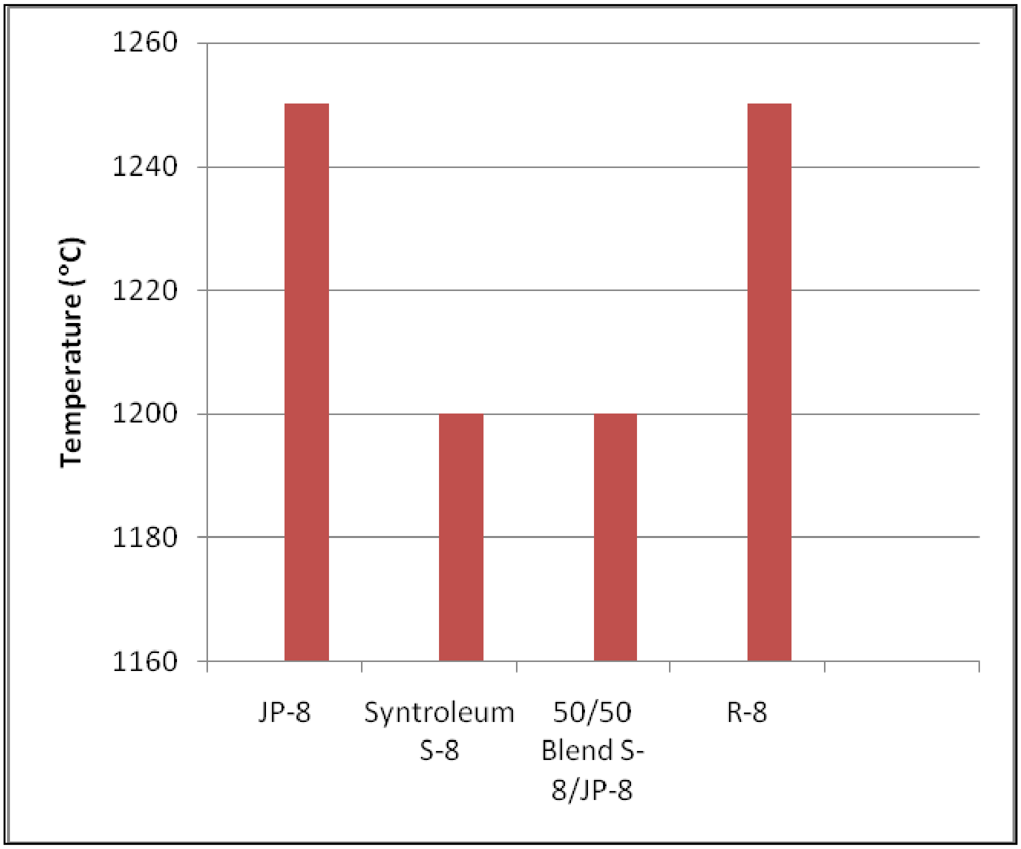


Figure 12. Hot Surface Ignition (°C)

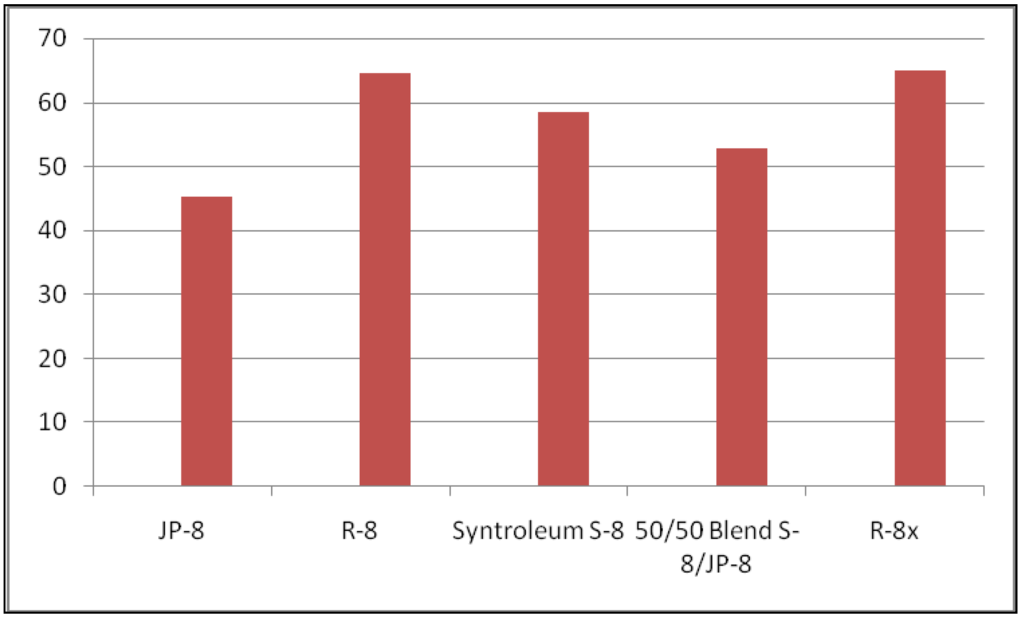


Figure 13. Cetane Index

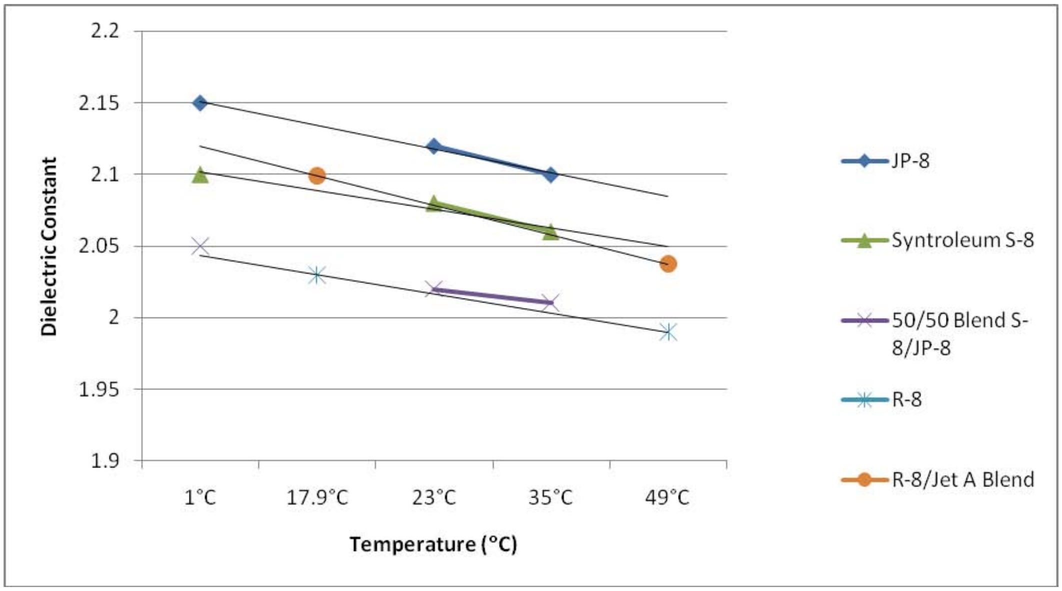


Figure 14. Dielectric Constant (400 Hz) vs. Temperature (°C)

In general, the R-8X fuel appeared to be very similar to the R-8 fuel for most of the properties tested. However, the R-8X fuel did show some anomalies, (JFTOT at 260°C). It is theorized that these anomalies may be a consequence of the small quantity processing or handling. The R-8X also exhibited superior low-temperature behavior when compared to the R-8 fuel, but again this may not prove to be consistent with a larger production run.

Additional FFP information for the R-8 HRJ can be found in a research report prepared by Boeing, UOP, and AFRL in support of the ASTM D4054 fuels qualification and approval process.

5.3 R-8 Pump Evaluations

As expected, the R-8 (unadditized) fuel performed poorly in the pump-down test, Appendix I-1. The test was stopped at 25 hours. Thus, it should be recognized that this fuel has poor lubricity characteristics without CI/LI being added.

SwRI performed additional pump demonstrations and component wear evaluations, (see Appendix I-2). The following summary and conclusions are excerpted from the research report.

"The purpose of this study was to determine the impacts of a QPL-25017 CI/LI additive on fuel injection pump durability with R-8 fuel. The CI/LI additive DCI-4A was used at a 22.5-ppm concentration in R-8 fuel and in a 50/50-percent blend of R-8/Jet-A fuel. In conducting the pump stand tests with the two fuels, it was found that both tests had completed 500-hours of operation with the following observations:

- Minor fuel delivery loss at rated speed
- Small fuel delivery loss at idle speed
- Wear debris minimal
- No unusual deposits

- Polishing to light scuffing wear was seen on components; wear normal for 500-hours of operation
- Rotary fuel injection pumps functioning normally at 500-hours"

The following conclusions were reached:

1) In conducting the R-8 fuel blends pump stand tests, it was found that the tests could be operated to conclusion at 500-hours:
    - R-8 fuel with 22.5-ppm DCI-4A CI/LI additive
    - R-8/Jet-A fuel blend with 22.5-ppm DCI-4A CI/LI additive
    - Light component wear
    - Substantial durability increase over neat R-8 fuel
2) The most frequent out of specification parameters during the post-test pump and fuel injector performance checks were:
    - Tip dryness, and seat sealing of fuel injectors with R-8/Jet-A fuel blend
    - Decreased fuel flow at idle and rated speeds
3) Unusual heavy, brown deposition was not present with either CI/LI treated R-8 fuel.
4) R-8 fuel with 22.5-ppm DCI-4A CI/LI additive was slightly more erratic in fuel delivery throughout the 500-hour test.
5) R-8/Jet-A fuel blend with 22.5-ppm DCI-4A CI/LI additive had slightly less component wear, and slightly better 500-hour delivery performance.

5.4 Material Compatibility of R-8 Synthetic Fuel

The University of Dayton Research Institute and AFRL/RXSA conducted material compatibility testing of the R-8 HRJ fuel. This testing is documented in Evaluation Report SA104002: AFRL/RXS 10-002, Appendix J-1. Materials tested included adhesives, fuel bladders, coatings, sealants and potting compounds, composites, foam, o-rings, hoses, and wire insulation. Testing and evaluation was performed to determine the material compatibility of the R-8 HRJ fuel with nonmetallic fuel system materials. The materials were exposed for 28 days to 100 percent R-8 and a 50/50 blend of JP-8 and R-8 fuels. It was concluded by UDRI that based on comparison to the JP-8 baseline results and JP-8/S-8 SPK blend results, the JP-8/R-8 HRJ blend generally affected materials similarly to the JP-8/S-8 blend. However, a retest was recommended for a few of the materials where there were some differences in the results obtained after aging in the JP-8/R-8 blend versus those obtained after aging in the JP-8/S-8 blend. The following materials were retested and new baseline data was obtained with the same batch of material:

- Nitrile Bladder Inner liner
- AMS-S-4383 nitrile coating
- AMS-S-8802 manganese dioxide cured polysulfide sealant
- AMS 3277 polythioether sealant

The retest results are documented in Evaluation Report SA104002: AFRL/RXS 10-003, Appendix J-2. UDRI concluded from this retest that it does not appear the 50/50 blend of the JP-8/R-8 HRJ fuel degraded the four materials evaluated more than JP-8 alone. However, similar to previous studies, it cannot be concluded that the 100 percent alternative fuels would be suitable for use.

5.5 Combustor Sector Performance

Performance tests (ignition, lean blowout (LBO), gaseous and smoke emissions) were successfully accomplished by the Rolls-Royce North American Technologies, Inc. using an AE3007 combustor 3 cup sector. Figure 15 shows a plot of fuel/air ratio at LBO vs. liner pressure drop %. Figures 16 and 17 show the ignition results at two different T3 temperatures. JP-8 shows a slight advantage in LBO and ignition. Details for this testing will be reported separately.

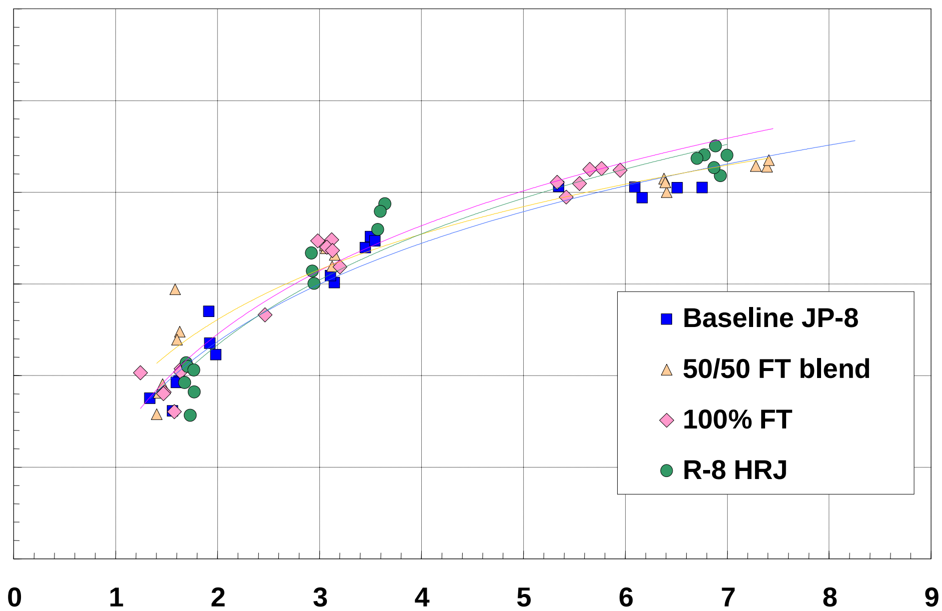


Figure 15. Lean Blowout Characteristics
(Fuel/Air Ratio vs Liner Pressure Drop (%))

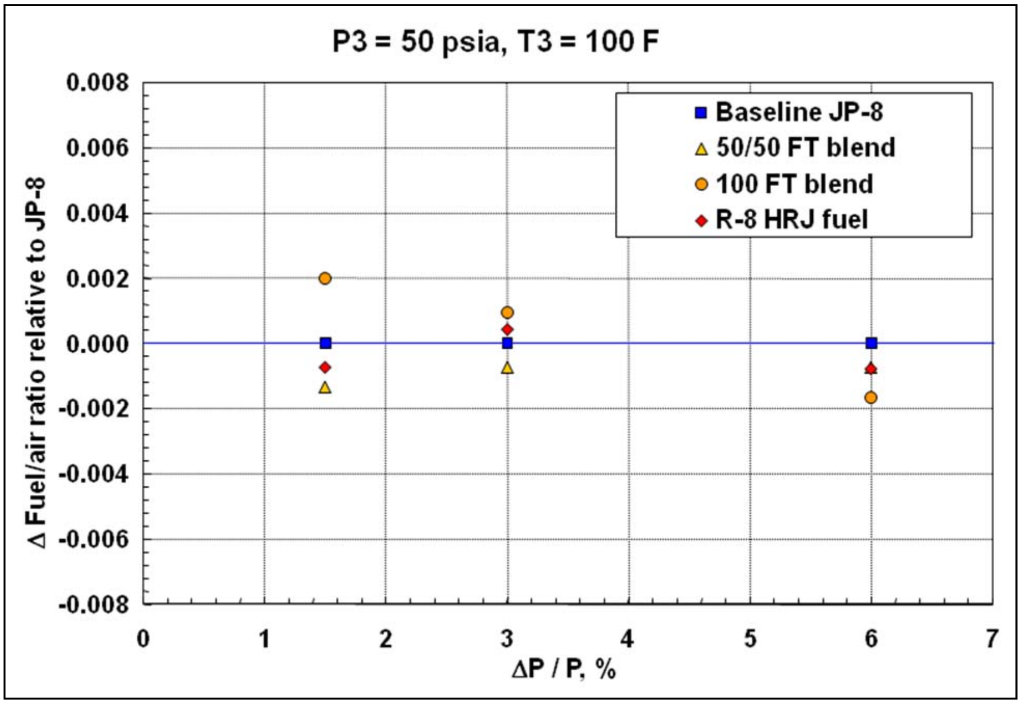


Figure 16. Ignition Results at T3 = 100 °F

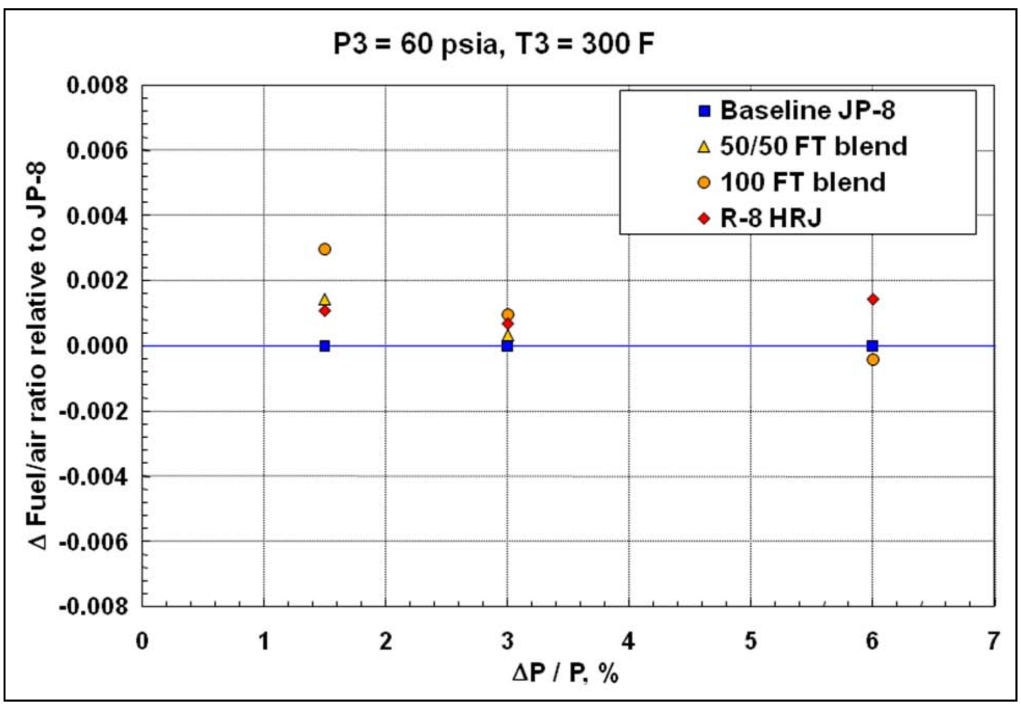


Figure 17. Ignition Results at T3 = 300 °F

5.6 R-8 Technology Development Risk Analysis

A risk model was developed for AFRL/RZPF for assessing the Technology Development of alternative fuels. The risk being evaluated is that risk associated with continuing the process for a particular alternative fuel candidate from technology development into system demonstration and system certification. The model incorporates 74 technical factors and 10 Technology Development completion factors. Six types of requirements are considered: Fuel Property/Characteristics, Material Compatibility, Toxicity, Fire Protection, Aircraft Propulsion and Infrastructure. Risk criteria are in comparison to JP-8, comparison to S-8, experience, and handbook/specification.

5.6.1 R-8 100% Technology Development Risk Assessment

The risk scorecard for 100% R-8 without military additives is shown in Figure 18. Ten items are "flagged" as red, (higher risk requiring further consideration). The ten items are:

1) Aromatic Content
2) Density
3) Volume Swell of Acrylic/Nitrile Hose
4) Sealant Elongation
5) Nitrile Bladder Inner Liner Elongation
6) Lubricity
7) Pump Endurance
8) -40°C Viscosity
9) Hot section materials compatibility test not conducted
10) Combustor nozzle coking evaluation not conducted

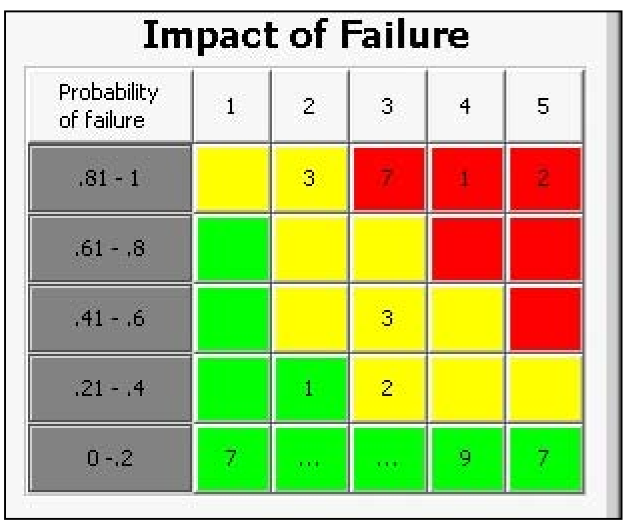


Figure 18. R-8 (100%) Risk Assessments

5.6.2 JP-8/R-8 50/50 Blend Technology Development Risk Assessment

The risk scorecard for a 50% / 50% blend of JP-8 and R-8 HRJ with military additives is shown in Figure 19. Three items are "flagged" as red, (higher risk requiring further consideration). The three items are:

1) Nitrile Bladder Inner Liner Elongation
2) Hot section materials compatibility test not conducted
3) Combustor nozzle coking evaluation not conducted

While the nitrile bladder inner liner material did not meet the objective of 300% after aging at 160°F, the results are reported similar to both JP-8 and S-8 SPK fuels. Hence UDRI has concluded that this did not appear to be a serious concern. It should also be noted that the test temperature condition was purposely elevated, (the operating fluid temperature range per the governing military specification is -65°F to +135°F).

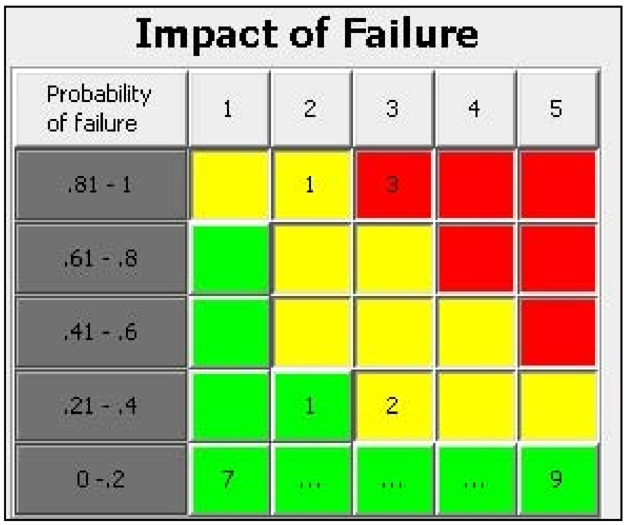


Figure 19. 50% / 50% Blend of JP-8 and R-8 HRJ Risk Assessment

5.7 R-8 Aircraft Performance Impact Assessment

A spreadsheet based analytical model has been developed for AFRL to assess the impact of alternate fuels on aircraft mission range. This model is shown to be within 15 % of the results generated by simulation for 100 % of cases, within 10 *%* of the results generated by simulation for 85 % of cases, and within 5 % of the results generated by the Simulation for 35 % of cases. The model can be applied to fighter/attack missions, strike missions with afterburner dash, and cargo/ferry missions. The primary model assumption is that the impact of fuel properties on range is due to changes in Volume Based Heating Value (BTU/Gal). The R-8 and R-8 blended fuels were modeled with the following results. The model results are provided in Appendix K. The baseline fuel shown as zero impact in the plots is the JP-8 PQIS average value fuel.

Results for the R-8 Blended fuel are summarized in Figure 20. The effect of the lower density from the PQIS average is evident. However all of the mission impacts are less than for a minimum specification JP-8 fuel.

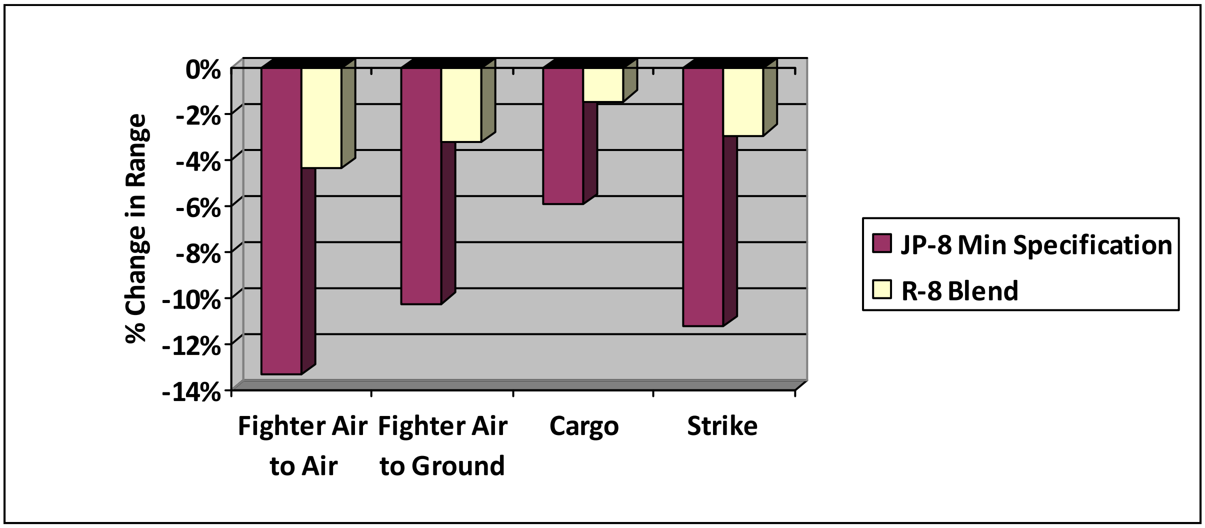


Figure 20. R-8 Performance Comparison to Minimum Specification JP-8

6.0 CONCLUSIONS

1) Conclusions from the R-8 HRJ pilot production and evaluation:

   a) A pilot production of 600 gallons of renewable IPK alternative fuel (termed R-8 for renewable and JP-8 like) was successfully accomplished by the Syntroleum Corporation to a draft R-8 specification. The successful conversion of FOG to a satisfactory aviation fuel product may represent a "worst case" starting material for HRJ fuel alternatives.

   b) The test data and analysis show this fuel to be comparable to the Syntroleum S-8 F-T SPK and supports the proposal for use of R-8 HRJ as a blending stock for jet fuel, up to 50 volume %, just as F-T SPK is allowed to be used in MIL-DTL-83133F.

   c) Evaluations suggest that there is no difference in filtration performance between the baseline fuels and R-8 HRJ.

   d) AFRL/RXSA analyzed the materials compatibility test data and determined that the JP-8/R-8 blend generally appeared to have a very similar affect on materials based on comparison with the JP-8 baseline and JP-8/F-T blend results. Additionally, as with the 100 percent F-T blend, it does not appear the 100 percent R-8 fuel would be suitable for use from a the materials compatibility perspective.

   e) The technology development risk assessment model for the JP-8/R-8 50/50 blend with military additives shows no unexplained high risk. It is noted that neither the hot section materials compatibility test nor nozzle coking evaluation were conducted, (sufficient fuel quantities for these tests were not produced).

   f) The aircraft fuels performance model shows some negative impact to range for both R-8 unblended and blended fuels when compared to the average JP-8. However, neither the unblended nor blended fuels show impact when compared to a minimum specification JP-8.

   g) The R-8 blends, (50 vol %) respond to the addition of MIL-DTL-25017 corrosion inhibitor / lubricity improver additive in a normal fashion, providing adequate pump performance.

   h) Unusual heavy, brown deposits occurred in the test pumps with neat (100%) R-8 HRJ and it is concluded that the unblended and unadditized R-8 HRJ has poor lubricity. Neat R-8 HRJ fuel severely impacts rotary fuel injection pump life.

   i) In general, the R-8X HRJ fuel appeared to be very similar to the R-8 HRJ fuel. However, due to the small quantity of R-8X produced, only a limited set of evaluations were possible.

7.0 RECOMMENDATIONS

1) The R-8 HRJ is recommended for use as a blending stock, up to 50 volume %, just as F-T SPK is allowed to be used in MIL-DTL-83133F.
2) Based on the technology development risk assessment, aircraft performance impact and materials compatibility test results, the neat (100%) R-8 HRJ is not recommended for use.
3) Use of neat (100%) R-8 HRJ without lubricity additive fuel in rotary fuel injection equipment is not recommended.

8.0 REFERENCES

[1] AFRL-RZ-WP-TR-2009-2040 (limited distribution), PROPULSION AND POWER RAPID RESPONSE RESEARCH AND DEVELOPMENT SUPPORT, Delivery Order 0042: Demonstration and Evaluation of Fischer-Tropsch Research Fuels for the DOD Assured Fuels Program, James K. Klein, Klein Consulting LLC, Final report, January 2009.

[2] Boeing, UOP, AFRL draft report, “Evaluation of Bio-Derived Synthetic Paraffinic Kerosenes (Bio-SPKs), Version 1.0, 2009

[3] ASTM D40542, “Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives”

[4] MIL-HDBK-510(USAF), 1 October 2007, DOD Handbook, AEROSPACE FUELS CERTIFICATION

[5] MIL-DTL-83133 Turbine Fuels, Aviation, Kerosene Types, NATO F-34 (JP-8), NATO F-35, and JP-8+100

[6] MIL-PRF-25017 Inhibitor, Corrosion/Lubricity Improver, Fuel Soluble (Metric)

Syntroleum®

Syntroleum Corporation

Final Report

for

Universal Technology Corporation

Subcontract: 07-S530-0042-06-C1

September 2008

Table of Contents

List of Figures and Tables

1. Introduction

As part of the UTC Contract, Syntroleum was required to supply 600 gal of R-8 research fluid, in two lots, for evaluation as military jet fuel. R-8 is a synthetic paraffinic kerosene (SPK) produced from renewable sources such as fats, bi-oils, and greases (referred to by the acronym FOG).

The carbon in these feeds comes from atmospheric CO_2 incorporated in vegetation by photosynthesis and then metabolized in animal fats/greases. As such their combustion is considered to have little effect on total green house gas levels in the atmosphere. Furthermore, unlike "first generation" bio-fuels (e.g. corn-based ethanol), R-8 can be produced from waste fats and greases that do not compete with food crops.

The Bio-Synfining™ process technology used to convert these bio-feeds to SPK is very similar to Synfining®. The Synfining® process has been used by Syntroleum to convert Fischer-Tropsch syncrude to S-8, the SPK which is undergoing certification as a 50/50 blend with JP-8 for USAF aircraft.

The properties of R-8 and S-8 are virtually the same. However, by not requiring gasification and Fischer-Tropsch reactor facilities, the R-8 process offers a low capital cost, short project cycle route to SPK commercialization.

The UTC contract was signed in June 2007 for 500 gal of R-8 research fuel, and was modified later for 100 gal additional volume. Although feedstock acquisition and pretreatment were performed soon after signing the original contract, R-8 production was delayed by a few months due to issues associated with other client projects at Intertek PARC (Pittsburgh, PA), the pilot plant sub-contracted by Syntroleum for this work. To mitigate the effect of the PARC delays on fuel delivery schedule, Syntroleum worked with Southwest Research Institute (San Antonio, TX) to restart their alternative fuels pilot plant. By operating the two facilities in parallel, Syntroleum completed fuel production in July 2008.

2. Process Overview

The Bio-Synfining™ process consists of three steps. First, the feedstock is washed with an aqueous solution to remove contaminants that can reduce conversion efficiency.

Second, the pre-treated feed is mixed with hydrogen and processed through a fixed-bed reactor. This is a vessel packed with a commercially available catalyst that hydrogenates the unsaturated fatty acid chains while removing their oxygen atoms, yielding a high stability hydrocarbon composition and water. This reaction is called "hydrodeoxygenation" (HDO) and is represented by Eq 1 for the illustrative case of oleic acid conversion to n-octadecane.

$$C_{17}H_{33}COOH + 4\ H_2 \rightarrow C_{18}H_{38} + 2\ H_2O \qquad (1)$$

In vegetable oils, the fatty acids are bound to glycerol backbone as triglycerides. During HDO conversion, the glycerol backbone is converted to propane, a marketable coproduct of the process. Animal fats contain enzymes that catalyze the reaction of triglycerides with water (hydrolysis) that frees up the bound fatty acids. Low quality fats and grease are characterized by high levels of free fatty acid (FFA).

For most FOG feedstocks, the HDO product is a C_{15}-C_{18} n-paraffin composition. These hydrocarbons are made of 15 to 18 carbon long molecules. Typical HDO products tend to solidify at temperatures below 20 ˚C (68 ˚F), and as such have limited use as finished fuels.

In the third step, the HDO hydrocarbon is hydrocracked to lower the boiling point distribution and improve cold flow properties. From a molecular standpoint, the long straight-chain n-paraffins are cracked into shorter, branched paraffins (referred to as iso-paraffins). The hydrocracked products fall mainly in the kerosene boiling range and have excellent low temperature properties. The iso-paraffinic mixture is fractionated to meet flammability requirements provided by the MIL-DTL-83133F military aviation fuel specification.

3. Production of R-8 Research Fuel

3.1. Feed Pretreatment: Pretreatment of Fats, Oils and Greases (FOG) is required to reduce the solids contaminant load on the downstream HDO reactor. Contaminants include animal solids, rust particles, and solubilized metals. If not removed, these will deposit in the fixed bed reactors causing excessive pressure drop across the catalyst bed and catalyst activity decrease.

The feed pretreatment process consists of four steps:

(a) Initial filtration to remove the bulk of large particles and solids.

(b) Aqueous solution wash to remove the solubilized metals and phosphorous from the oil layer.

(c) Coalescing the aqueous phase droplets and separation of the clean FOG blend top layer.

(d) Final filtration to remove any solids which may have formed during the acid washing step.

Approximately 2,500 gallons of FOG feeds were acquired from Tyson Foods (Springdale, AR) and blended into a 6,000 gal ISO Container. Table I provides the make-up of the feed blend.

Table I. Make-up of FOG Blend.

FOG Blend Components	
Component	**Mass %**
Poultry Fat	46%
Yellow Grease	18%
Brown Grease	18%
Floatation Grease	9%
Prepared Foods	9%

Initial sample analysis of this 2,500 gal blend is summarized in Table II. In addition to contaminant concentration, of particular importance for aqueous treatment is the high acid number of this blend. The acid number of 94.7 mg/g KOH corresponds to an FFA content of about 47 wt %.

Using bench scale Electrostatic Susceptibility Testing at the Natco R&D Center (Tulsa, OK), it was determined that a typical crude oil desalting process would not be applicable for this type of feed material blend. Specifically, it was shown that FOG blends with high levels of FFA would form very stable rag layers and were difficult to separate. A different approach was required to remove the suspended solids, solubilized metals and phosphorous contributing to high ash (residual inorganics after ignition of the feed).

Table II. Contaminant analysis of FOG feedstock

Sample ID# RDIL 4879		
Ash	ppm	1675
Antek Nitrogen	ppm	920
Antek Sulfur	ppm	69
Specific Gravity		0.912
Viscosity at 100°C	cSt	7.43
Acid Value	mg KOH/g	94.7
ICP Analysis		
Calcium	ppm	285
Iron	ppm	67.3
Potassium	ppm	117
Magnesium	ppm	7.6
Sodium	ppm	123
Phosphorus	ppm	144

Initially, the 2,500 gal FOG blend was filtered through a 10 μm bag filter to remove the larger more coarse solid particles, followed by two successive water washes with oil layer separation. The FOG blend was washed with de-mineralized water at an oil/water ratio of 10:1. The 2,500 gal of FOG blend was pumped out of the first ISO container, contacted with water using a mixing tee and ball valve to impart a slight mixing shear to the two liquid phases, and into a second clean ISO container. The pretreatment equipment setup and flow diagram are shown in Figure 1.

The FOG/H_2O two-phase mixture was allowed to settle overnight at 180-200°F. The water layer was drained off the next morning and the oil layer sampled and analyzed for ash content. This water washing/shear mixing step with phase separation was repeated as a second stage. Analysis of the oil layer after each successive water wash is summarized in Table III.

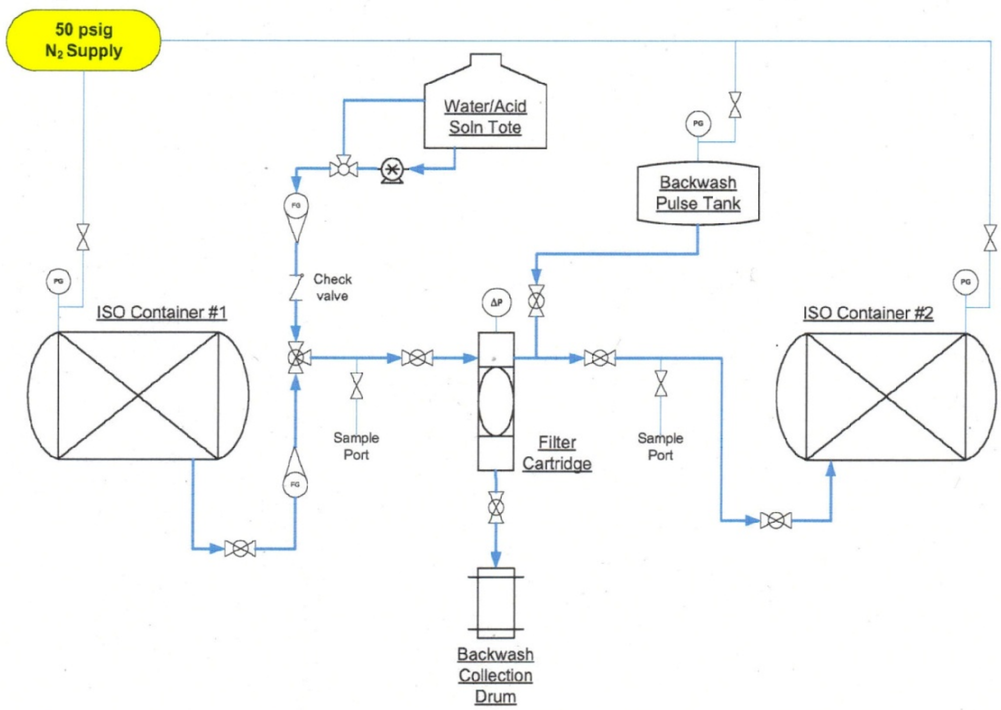


Figure 1. **Feed Pretreatment equipment setup and flow diagram.**

Table III. Oil layer analysis after each water wash cycle.

After 1st Stage Water Wash		
Ash	ppm	1253
Acid Value	mg KOH/g	118
Moisture and Volatiles by Hotplate	mass %	4.2%
After 2nd Stage Water Wash		
Ash	ppm	1090
Acid Value	mg KOH/g	121
Moisture and Volatiles by Hotplate	mass %	2.0%

These results show insufficient removal of contaminants as indicated by the level of ash still present after each wash cycle, thus confirming the Natco conclusions. Also noted is the increase in the Acid Value caused by free fatty acid formation due to hydrolysis of the triglycerides during prolonged exposure to high temperatures.

Parallel laboratory scale experiments showed a significant increase in contaminant removal efficiency by washing the blend with an acid solution. Using the same equipment set-up and flow/shear mixing parameters outlined in Figure 1, the 2,500 gal blend was washed with an aqueous acid solution. As previously done for the two water washes, the 2-phase mixture was allowed to settle overnight at 180-200°F. After the aqueous layer was drained, the oil layer was filtered using a 10 μm filter element and allowed to settle for an additional 24 hrs. A representative sample of the pretreated FOG blend was analyzed with results summarized in Table IV.

Table IV. Final analysis of pretreated feed blend from initial scale-up.

Sample # RDIL 5019		
Ash	ppm	67.2
Nitrogen	ppm	1006
Sulfur	ppm	111
Acid value	mg KOH/mg	129
Moisture (Karl Fisher)	mass %	0.85%
Moisture and all Volatiles	mass %	1.30%
Insoluble impurities	mass %	0.04%
Unsaponifiables	mass %	1.03%
Peroxide value	meq/kg	< 0.2
Thermal stability	meq/kg	2
ICP metals and phosphorus		
Calcium	ppm	14.5
Iron	ppm	6.57
Potassium	ppm	3
Magnesium	ppm	0.532
Sodium	ppm	6.79
Phosphorus	ppm	8.28

Fatty acid profile		
C12:0	%	0.1
C14:0	%	1.03
C14:1	%	0.17
C15:0	%	0.13
C16:0	%	20.5
C16:1	%	3.86
C17:0	%	0.35
C17:1	%	0.22
C18:0	%	8.56
C18:1	%	40.87
C18:2	%	19.49
C18:3	%	1.61
C18:4	%	0.28
C20:0	%	0.22
C20:1	%	1.08
C20:2	%	0.17
C20:4	%	0.23
C22:0	%	0.14

For verification, a second 2,500 gal blend of fresh FOG blend was acquired from Tyson Foods according to the recipe given in Table I. Based on the knowledge gained from the initial scale up pretreatment run, this new feed blend was subjected to the following steps:

a. Initial filtration using a 10 μm back washable filter element.
b. Citric acid mixing/shear contact at oil/acid ratio of 10:1.
c. Coalescing and Separation of the aqueous phase.
d. Final filtration of oil layer through a 10μm element.

Similar results were obtained for this second pretreatment run and are summarized in Table V.

Table V. Final analysis of second pretreated feed blend.

Sample # RDIL 5020		
Ash	ppm	39.4
Nitrogen	ppm	588
Sulfur	ppm	63
Acid value	mg KOH/mg	68.7
Moisture (Karl Fisher)	mass %	1.14%
Moisture and all Volatiles	mass %	1.77%
Insoluble impurities	mass %	0.01%
Unsaponifiables	mass %	0.66%
Peroxide value	meq/kg	0.3
Thermal stability	meq/kg	7
ICP metals and phosphorus		
Calcium	ppm	6.9
Iron	ppm	1.6
Potassium	ppm	9.8
Magnesium	ppm	0.99
Sodium	ppm	22.4
Phosphorus	ppm	18.10

Fatty acid profile		
C14:0	%	0.91
C14:1	%	0.16
C15:0	%	0.11
C16:0	%	22.13
C16:1	%	4.98
C17:0	%	0.29
C17:1	%	0.19
C18:0	%	8.43
C18:1	%	39.51
C18:2	%	19.1
C18:3	%	1.46
C18:4	%	0.1
C20:0	%	0.18
C20:1	%	0.66
C20:2	%	0.25
C20:4	%	0.51
C22:0	%	0.11

The contaminant levels of the pretreated FOG blends shown in Tables IV and V are acceptable for the Hydrodeoxygenation (HDO) step of the process.

3.2. Hydrodeoxygenation (HDO): Forty drums of the pretreated feedstock were shipped to Southwest Research Institute (SwRI) for the HDO campaign. These corresponded to the two pretreated feed lots characterized in Tables IV and V.

The SwRI Alternative Fuels Pilot Plant was restarted for this project. Most of the original equipment was brought back in service and used for our project. However, the control system and a few instruments had become obsolete and had to be replaced. The operating flow scheme of the pilot plant is shown in Figure 2.

The catalyst in the two stage HDO reactor system was activated according to the Syntroleum "sulfiding" procedure before introduction of FOG feed on February 28, 2008. Bio-feed conversion to n-paraffin product was confirmed by GC and specific gravity measurements.

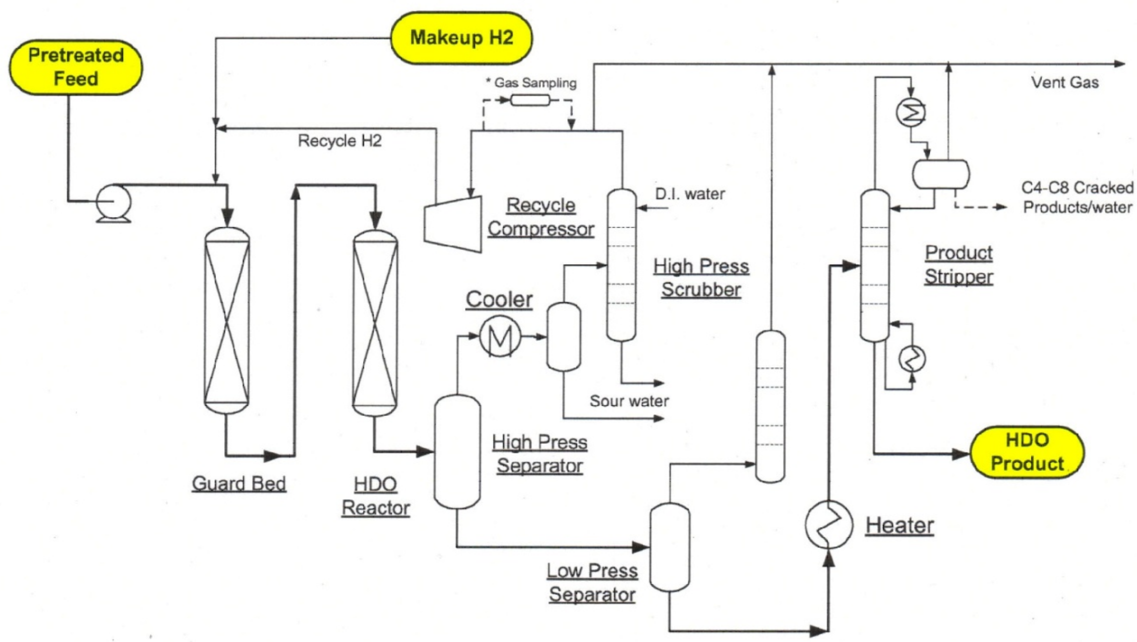


Figure 2. Operating flow scheme of the SwRI Alternative Fuels pilot plant

The HDO product was analyzed daily to ensure fatty acid/glyceride conversion. Two types of analysis were conducted on a routine basis, specific gravity and gas chromatography (GC). The specific gravity of the feedstock was about 0.92. The theoretical specific gravity of a C_{16}-C_{18} n-paraffin is 0.78. An increasing trend in product specific gravity is thus a first indication of decreasing catalyst activity.

A GC technique involving calibration with n-paraffin standards was used for the daily HDO product composition analysis. Thus in addition to "simulated distillation," the actual n-paraffin composition was measured to confirm that the desired paraffin products were being produced. Figure 3 is a trend chart of the paraffin composition variation during the HDO campaign.

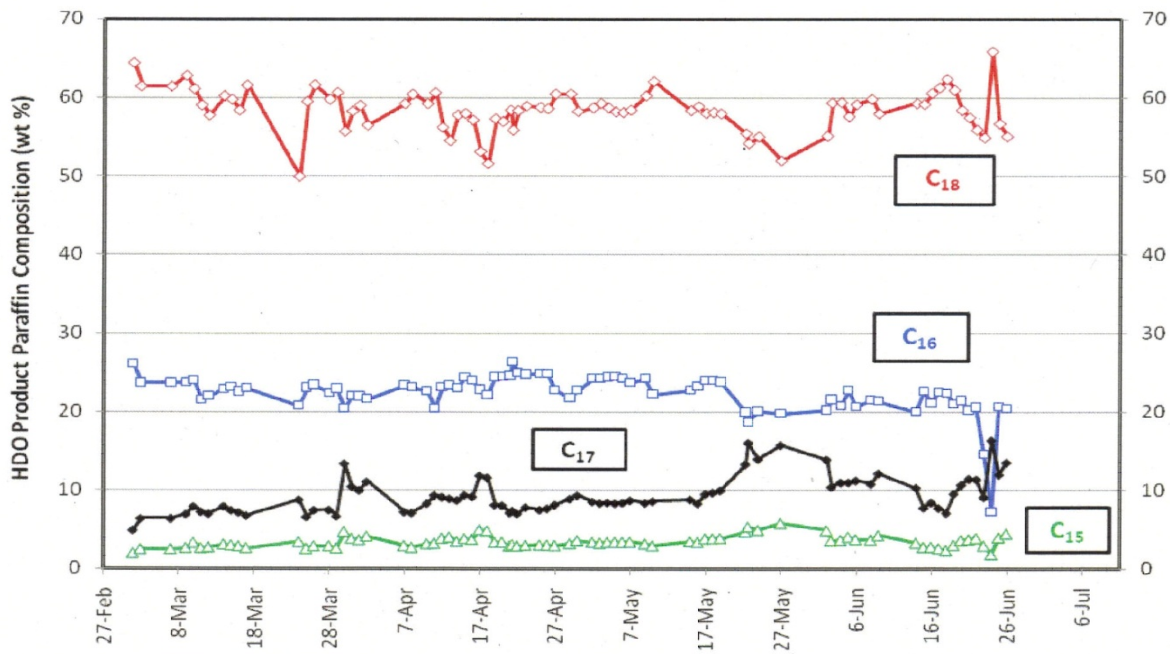


Figure 3. HDO product composition trend during bio-feed conversion campaign

As indicated in Figure 3, the intermediate product remained a 90+% C_{15}-C_{18} paraffin composition throughout the HDO production campaign. There was a drop in the C_{18}/C_{17} ratio during the first week of run. Since the feedstock was virtually all made of C_{18} and C_{16} fatty acids, either as glycerides or FFA (see Tables IV and V), the presence of C_{17} and C_{15} n-paraffins indicates deoxygenation via loss of a carbon from the fatty acid chain—a mechanism referred to as decarboxylation. Analysis of CO and CO_2 in the recycle hydrogen confirmed that decarboxylation remained constant for most of the run. In general, removal of oxygen as water (Eq 1) is preferred. This deoxygenation mechanism retains all the fatty acid/glyceride carbons in the hydrocarbon product, resulting in higher fuel yield.

Referring to Figure 3, the increase in decarboxylation in the mid-late May period may be attributed to a drop in performance due to guard bed fouling. After replacing the guard bed media (last week of May), decarboxylation returned to the low levels encountered during most of the run.

The components falling outside of the C_{15}-C_{18} range include paraffins produced from conversion of the C_{14-} and C_{20+} fatty acids present in the feed blend at 2-3 wt % (see Tables IV and V), as well as light cracked products, and unconverted heavies. Of concern are high levels of light cracked products and unconverted heavies which adversly affect product yield. These can be monitored using the simulated distillation 5% and 95% recovery temperatures. An increase in the 95% recovery temperature indicates an increase in the level of unconverted heavies and decrease in catalyst activity. Similarly, a decrease in the 5% recovery temperature indicates an increase in the concentration of light cracked products and decrease in catalyst selectivity. These two variables were tracked during the run and are summarized in Figure 4. As observed in this trend chart, the unconverted heavies and light cracked products remained virtually unchanged throughout the run, indicating good catalyst stability.

Deoxygenation performance was also checked by testing intermediate product drums directly for residual oxygen. All drums tested showed oxygen below detection limit of 0.1 wt %.

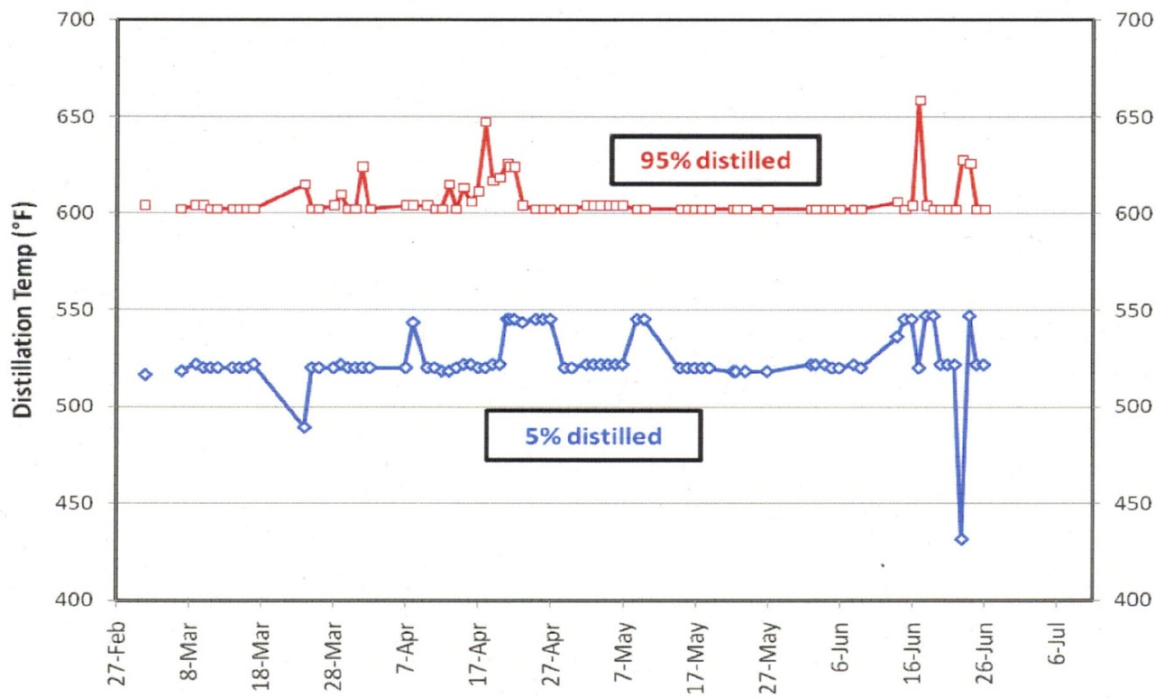


Figure 4. Simulated Distillation Temperature Range of Hydrocarbons from HDO Campaign

3.3. Hydrocracking/Isomerization (HI): The HDO intermediate product effluent containing mostly C_{15} –C_{18} n-paraffin was hydrocracked/isomerized in order to meet freeze point and boiling point distribution properties outlined by the Military Specification MIL-DTL-83133F for aviation type SPK fuel. The n-paraffins were reacted with hydrogen in a fixed bed reactor containing a proprietary HI catalyst. The reaction took place at elevated temperatures to achieve high per pass conversion for both the hydroisomerization and the C_{16}^{+} hydrocracking reactions. Co-products from this reaction include paraffinic naphtha and LPG.

Operation Summary-- The hydrocracking/isomerization and fractionation of the HDO intermediate n-paraffin product was done in the P-63 fixed bed reactor at Intertek PARC. The 600 gallon jet fuel run was split into two lots. The first 250 gal lot included production from April 23 to June 17, 2008. Production of the second 350 gal lot was completed on July 24, 2008. A flow schematic of the PARC Pilot Plant configuration used for this jet fuel run is shown in Figure 5.

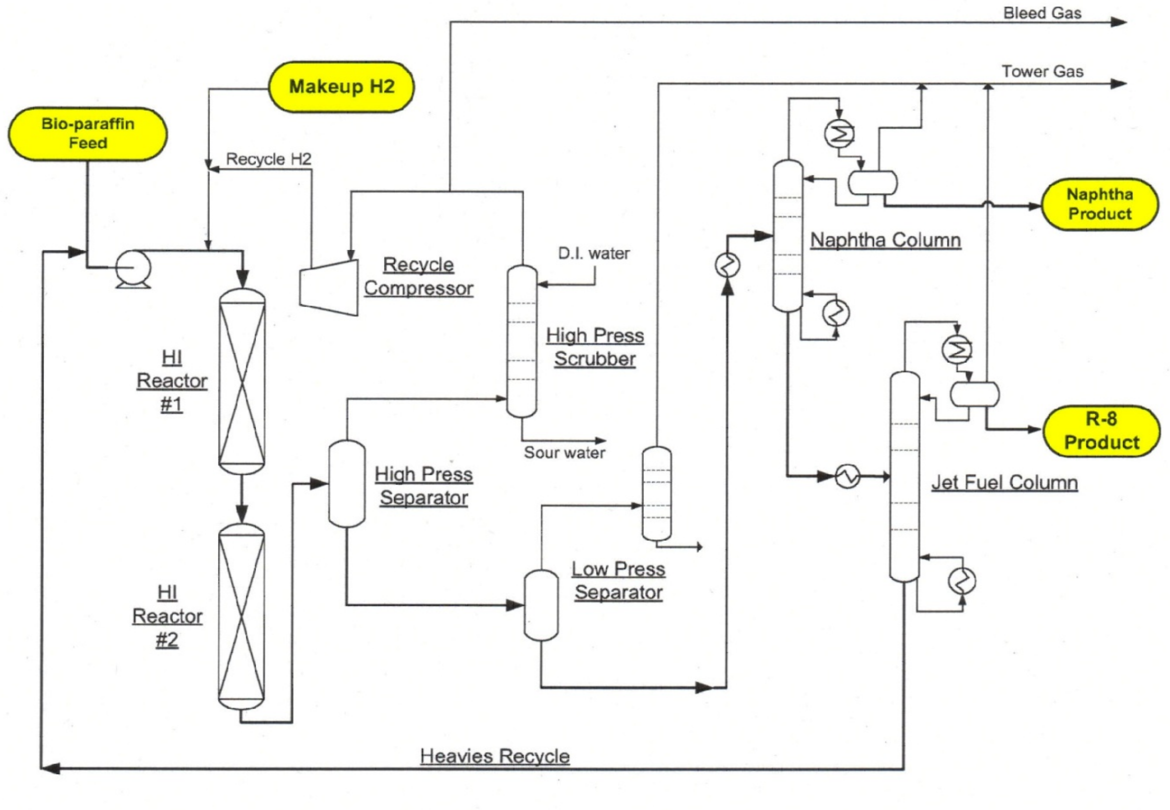


Figure 5. **Operating flow scheme of the Intertek PARC Pilot Plant during R-8 production**

The PARC unit consisted of two fixed-bed reactors in series with a total catalyst volume of 4850 cc, operating with a liquid hourly space velocity (LHSV) ranging from 0.5 to 1.4 hr^{-1}. After reacting with hydrogen-rich treat gas, the hydrocracked/isomerized paraffin liquid was directed to the fractionation train. Referring to Figure 5, three separators/distillation columns were used in series to fractionate and recover a finished SPK product meeting the proper boiling point distribution, flammability and cold flow property specifications. The low boiling point hydrocarbons were stripped off in the Naphtha Column, and the high boiling point hydrocarbons were recycled back to the reactor inlet. The finished R-8 Synthetic Paraffinic Kerosene is the middle distillate product collected as the overhead stream of the Jet Fuel Column.

Product Properties-- Key product quality characteristics including freeze point, flash point and distillation cut points were measured daily throughout the HI production campaign. Trend charts in Figure 6 illustrate the variability of these key parameters during both production lots. After a brief startup and process lineout period, flash point and boiling point distribution parameters were maintained within specification limits during the entire run.

Figure 6 also shows two periods of 2–3°C upward drift in the freeze point, just above the -47 °C specification limit. Each lot was an accumulation of these daily analyzed drain periods, and it was critical that the final blended product's cold flow properties remained below upper specification limit. We determined during the HI run that the freeze point of a blend of R-8 SPK can be predicted by the freeze points of its blended components according to Eq 2.

$$\text{Freeze Point}_{(A+B)} = \nu_A\,(FP_A) + \nu_B\,(FP_B) \qquad (2)$$

In Eq 2 ν_A = volume fraction of SPK component A, ν_B = volume fraction of SPK component B, with FP_A and FP_B being each separate component's respective freeze point. This empirically determined relationship was validated for individual component freeze points ranging from -43°C to -56°C.

The P-63 unit at PARC was able to produce 8 to 10 gallons of R-8 per day, which was collected and consolidated sequentially into 55 gal drums, and additized with 25 mg/L of butyrated hydroxytoluene (BHT) antioxidant. At the end of each lot collection period (five drums for Lot #1 and seven drums for Lot #2), pristine clean drums were used for lot homogenization. Equal portions from each daily collection drum were blended into the clean drums so that fuel properties were consistent among drums within each lot. Freeze point was verified for each drum after homogenization of both lots. Final lot analysis compared to the MIL-DTL-83133F specification is summarized in Table VI. As observed from this table, R-8 meets all the specifications except density. This is the case with Fischer-Tropsch SPK and other high hydrogen content fuels.

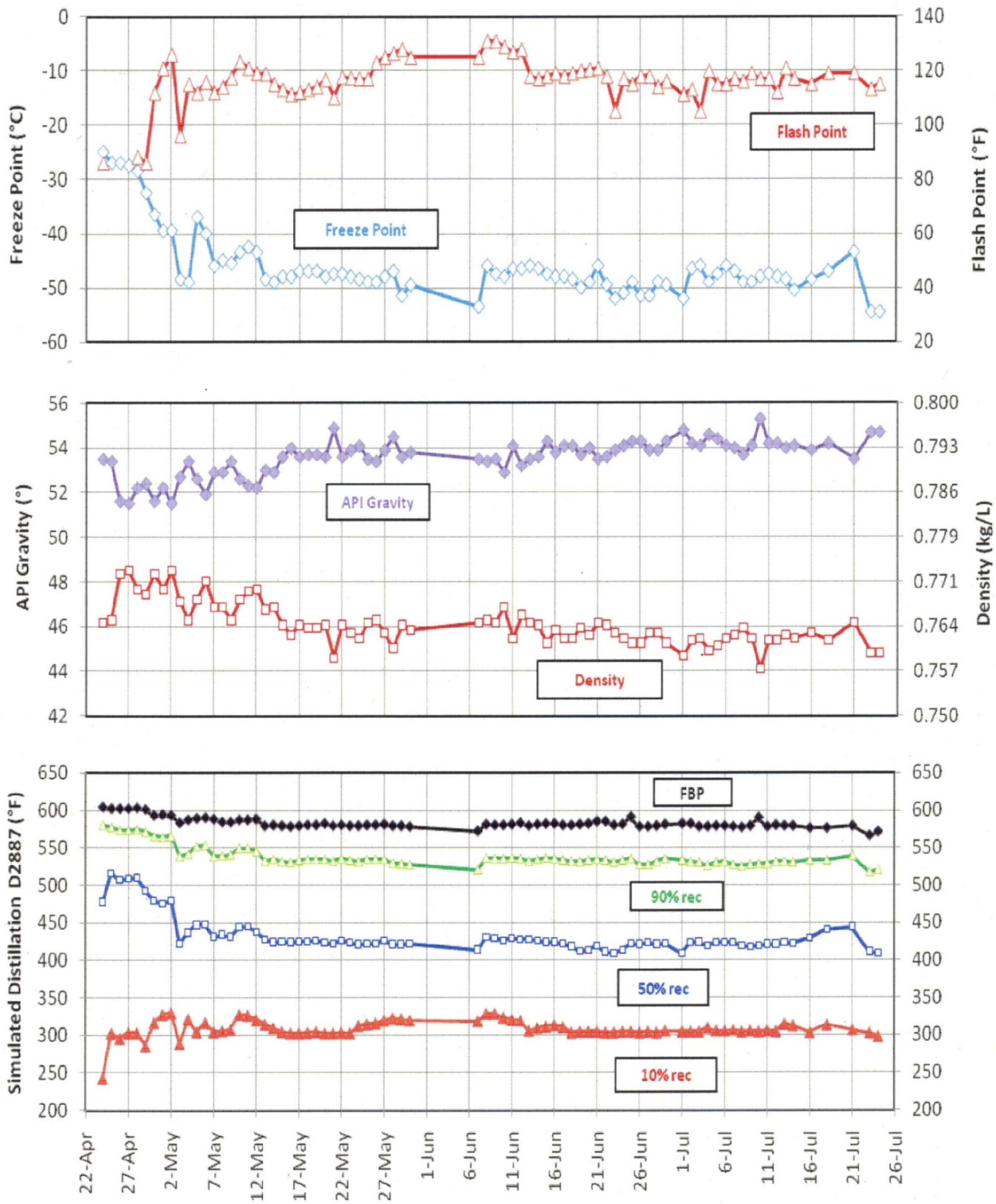


Figure 6. Trend Chart – HI Run – Daily Product Properties

Table VI. **Selected SPK product properties compared to MIL-DTL-83133F Specification.**

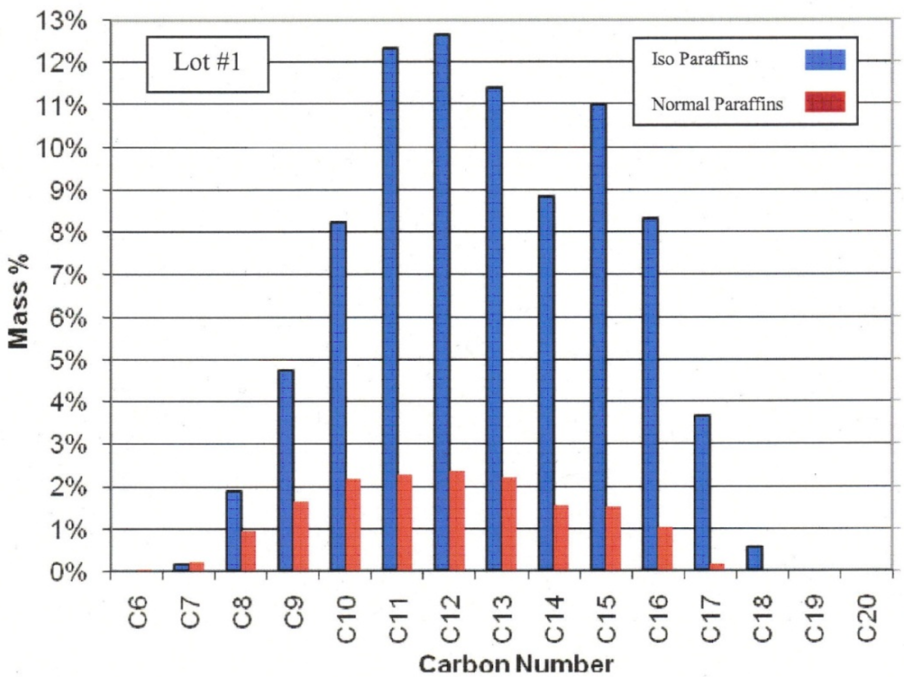
Property	Units	Test Method	MIL-DTL-83133F	Syntroleum SPK R-8 Lot #1	Syntroleum SPK R-8 Lot #2
Say bolt Color		D156	Report	+30	+30
Total Acid Number	mg KOH/g	D3242	0.015 (max)	0.005	*
Total Aromatics	mass %	D5186 [(1)]	25 (max)	1.1	*
Mono-Aromatics	mass %			1.0	
Poly-nuclear Aromatics	mass %			0.1	
Sulfur	ppm	D5453	3000	1.5	< 1.0
Distillation, IBP	°C	D2887	Report	105	107
10% recovered	°C		186 (max)	157	151
20% recovered	°C		Report	174	169
50% recovered	°C			218	216
90% recovered	°C			279	277
FBP	°C		330 (max)	308	304
Flash Point	°C	D93	38 (min)	48	48
Density	kg/L	D4052	0.775 – 0.840	0.7645	0.7623
API Gravity	°	D4052	37.0 - 51.0	53.6	54.1
Freezing Point	°C	D5972	-47	-48	-49.5
Kinematic Viscosity @-20°C	cSt	D445	8.0 (max)	5.15	5.11
Net Heat of Combustion	MJ/kg	D4809	42.8 (min)	43.84	*
Hydrogen Content	mass %	D3701	13.4 (min)	15.27	*
Smoke Point	mm	D1322	25.0 (min)	> 50	*
Cetane Index		D976	Report	68.2	67.7 [(2)]
Cu Strip Corrosion		D130	No. 1 (max)	1a	*

Notes:
1. Lot #1 R-8 was also analyzed using ASTM D1319 resulting 1.4% Aromatics, 1.5% Olefins and 97.1% Saturates (vol %)
2. Cetane Number, ASTM D613 was also determined for Lot #2 R-8 = 64.2

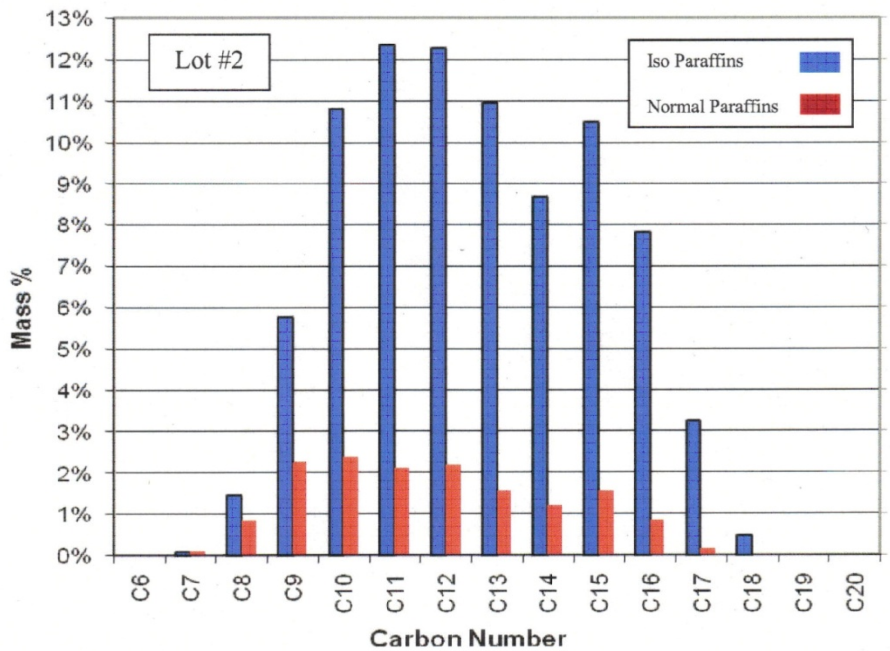
* Property not determined due to timing and/or budgetary constraints.

The molecular structure corresponding to the above physical properties was analyzed by carbon distribution chromatography (GC) and is summarized in Figure 7. The ratio of branched paraffin to n-paraffin, calculated as an iso/normal ratio was between 5.1:1 and 5.5:1, implying that 84-85% of the n-paraffins were converted to iso-paraffins during the hydrocracking/isomerization step of the process. The isoparaffin content of R-8 SPK is the same as the Fischer-Tropsch S-8.

3.4. Certificates of Analysis: The CoA sheets provided with each of the two lots are presented in the Appendix. Lot 1 was delivered to SwRI Fuels Department and Lot 2 to AFRL.



Lot #1 R-8 SPK	
Carbon Distribution and Iso/Normal Ratio	
Mass %	
C_6	0.1%
C_7	0.4%
C_8	2.8%
C_9	6.4%
C_{10}	10.4%
C_{11}	14.6%
C_{12}	15.0%
C_{13}	13.6%
C_{14}	10.4%
C_{15}	12.5%
C_{16}	9.4%
C_{17}	3.8%
C_{18}	0.6%
Iso/Norm =	5.1:1



Lot #2 R-8 SPK	
Carbon Distribution and Iso/Normal Ratio	
Mass %	
C_7	0.2%
C_8	2.3%
C_9	8.0%
C_{10}	13.2%
C_{11}	14.5%
C_{12}	14.5%
C_{13}	12.5%
C_{14}	9.9%
C_{15}	12.1%
C_{16}	8.7%
C_{17}	3.4%
C_{18}	0.5%
Iso/Norm =	5.5:1

Figure 7. Carbon Distribution and Iso/Normal paraffin analysis for each R-8 SPK Lot.

4. Summary and Conclusions

In addition to producing 600 gal of R-8 research fluid from a waste fat/grease feed blend, the project demonstrated the robustness of the Bio-Synfining™ process for production of SPK jet fuel. Referring to the Figure 8 photograph, the brown slushy feedstock was converted to n-paraffins having poor cold flow properties, and then isomerized into clean SPK.

The R-8 product was tested and found to conform to all fuel property specifications outlined in MIL-DTL-83133 except density (0.762-0.764 vs. 0.775 g/mL minimum). The lower density is the result of SPK's high hydrogen-to-carbon ratio—which gives the fuel its low particulate emission and superior thermal stability. The R-8 lots were also analyzed for hydrocarbon type and degree of isomerization, and found to be compositionally very similar to Fischer-Tropsch SPK products.

The process and product data collected during this project and reported here confirm the commercial readiness of the Bio-Synfining™ SPK. This process seems to provide the USAF with the means to meet its synthetic fuels targets, while reducing carbon footprint.

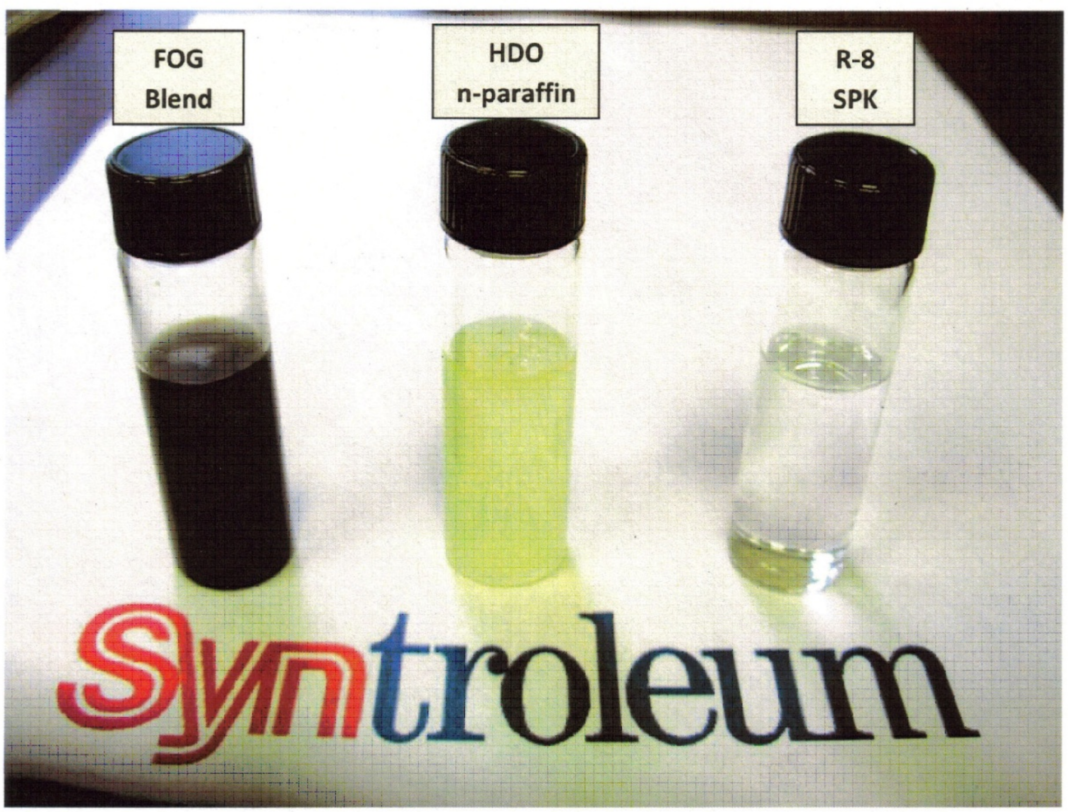


Figure 8. Photograph showing the FOG blend, HDO intermediate, and final SPK product.

APPENDIX A-1

Certificate of Analysis

Syntroleum®

SYNTROLEUM® R-8
SYNTHETIC JET FUEL

Syntroleum R-8 is synthetic jet fuel meeting the general requirements of MIL-DTL-83133F. It is not suitable for use in aircraft and is provided for development purposes only. This fuel contains between 23 and 29 mg/L phenolic antioxidant to improve storage stability.

SYNTHETIC DISTILLATE JET FUEL

Lot 1 | Date: 06/20/08

PHYSICAL PROPERTIES	TEST METHOD	UNITS	SPECIFICATION VALUE	ACTUAL
Density	ASTM D-4052	kg/L	0.75-0.77	0.7645
API	ASTM D-4052	°	51.6-56.5	53.6
Flash Point, min	ASTM D-93	°C	38	48
Ash	ASTM D-482	wt %	Report	< 0.001
Kinematic Viscosity @ 40°C	ASTM D-445	cSt	Report	1.44
Freeze Point, max	ASTM D-5982	°C	-47	-48
Cetane Index	ASTM D-976		Report	68.2
Saybolt Color	ASTM D-156		Report	+30
Distillation, IBP,% recovered	ASTM D2887	°C	Report	105
10% recovered, max		°C	186	157
20% recovered		°C	Report	174
50% recovered		°C	Report	218
90% recovered		°C	Report	279
FBP, max		°C	330	308

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Contact: Syntroleum 5416 South Yale Ave, Ste 400 Tulsa, OK 74135	QA/QC Approval	Approval to Ship	6/20/08 Date

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Revision Date: 16 June 2008

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06/20/2008 09:27 4128265444 PARCTECH PAGE 02

APPENDIX A-1

Certificate of Analysis

Syntroleum®

SYNTROLEUM® R-8
SYNTHETIC JET FUEL

Syntroleum R-8 is synthetic jet fuel meeting the general requirements of MIL-DTL-83133F. It is not suitable for use in aircraft and is provided for development purposes only. This fuel contains between 23 and 29 mg/L phenolic antioxidant to improve storage stability.

SYNTHETIC DISTILLATE JET FUEL

Lot __2__ Date: __7/31/08__

PHYSICAL PROPERTIES	TEST METHOD	UNITS	SPECIFICATION VALUE	ACTUAL
Density	ASTM D-4052	kg/L	0.75-0.77	0.7623
API	ASTM D-4052	°	51.6-56.5	54.1
Flash Point, min	ASTM D-93	°C	38	48
Ash	ASTM D-482	wt %	Report	<0.001
Kinematic Viscosity @ 40°C	ASTM D-445	cSt	Report	1.45
Freeze Point, max	ASTM D-5982	°C	-47	-49.5
Cetane Index	ASTM D-976		Report	67.7
Saybolt Color	ASTM D-156		Report	+30
Distillation, IBP,% recovered	ASTM D2887	°C	Report	107
10% recovered, max		°C	186	150.9
20% recovered		°C	Report	169.1
50% recovered		°C	Report	216.2
90% recovered		°C	Report	277.0
FBP, max		°C	330	304.4

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IPK Jet Fuel from Bio-Synfining™ (R-8) vs. FT (S-8), Commercial, and Military Specifications

Syntroleum

Property	Units	ASTM D 1655 Jet A-1	MIL-83133E JP-8	S-8 (typical[1])	R-8 [2]
Flash Point	°C	38 min.	38 min.	46	47
Distillation EP	°C	300 max.	300 max.	280	275
Viscosity @-20°C	cSt	8.0 max.	8.0 max.	5.5	4.58
Freezing Point	°C	-47 max.	-47 max.	-48	-55
Density	g/ml	0.775-0.840	0.775-0.840	0.76	0.76
Heat of Combustion	MJ/kg	42.8 min.	42.8 min.	43.8	44.2
Smoke Point	mm	25 min.	25 min.	>50	33.4
Sulfur	ppm	3,000 max.	3,000 max.	<1	1.2
Hydrogen	mass%	none	13.4 min.	15.4	15.3
Color (Saybolt)	-	none	report	+30	+30

Notes
1. FT/GTL sample; iso/normal=4.2
2. Edible tallow; iso/normal ratio = 6.7

R-8 meets/exceeds all commercial jet fuel specs except density

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APPENDIX B

Syntroleum Fuel Analysis & R-8 MSDS R-8 HRJ Specification Evaluations

R-8 Renewable Jet Fuel — Page1

MATERIAL SAFETY DATA SHEET

SECTION 1 - PRODUCT SOURCE AND IDENTITY

Supplier identity and address	Product description: Date: Aug. 20, 2007
Syntroleum Corp. 4322 S. 49th W Ave. Tulsa, OK 74107	Name: R-8 Renewable Jet Fuel Purpose: Jet fuel Proprietary device: Code: SC R8
North America Emergency: 800-424-9300 Others: 703-527-3887 (collect)	Product information: 918-592-7900

SECTION 2 - SHIPPING CLASSIFICATION

Proper Shipping Name, Hazard Class, UN/NA Number Packing Group, Emergency Response Guide Number

Hydrocarbons, liquid, n.o.s., 3, UN3295, PG III
ERG 128

Labels required per 49 CFR 172.101:	Flammable liquid
Size for "Limited quantity" per 49 CFR 173.150-4:	1 gal. max. in 66# max. package
Reportable Quantity ("RQ") per 49 CFR172.101:	None or not possible in one non-bulk package

SECTION 3- SAFETY RATINGS AND HAZARDOUS INGREDIENT INFORMATION

Reporting required by Title III Sec 313, 40 CFR 372, 29 CFR 1910.1 — Exposure Limit Values

CAS#	313	Material or Component	%	RQ#	TWA	STEL
437986-20-4	No	C7-C18 Alkane Rich Hydrocarbon Blend	100	None	100 ppm as Stoddard Solvent	

No component is listed in "THRESHOLD LIMIT VALUES AND BIOLOGICAL EXPOSURE INDICES FOR 2007" of ACGIH except as noted above. Components listed in TITLE III SEC 313 (EPCRA) are indicated by "Yes" above.

Note: The purpose of this MSDS is to provide safe handling, shipping and disposal information for users of the product. It is not intended to, nor does it, provide complete or extensive toxicological data on the product or its components. Users who require this information are referred to primary suppliers of the ingredients of interest.

Emergency overview: Flammable liquid. Ground equipment when transferring. Do not expose to open flame, sparks or static electricity. Keep containers covered when not in use.

Hazard Categories:	Health	Fire	Pressure	Reactivity	Reference 49 CFR 171.8, OSHA 29 CFR 1910.1200 and SARA 302/311/312/313.
Immediate	Yes	Yes	No	No	
Delayed	No	XXX	XXX	XXX	

HMIS Hazard ratings: Health 1 Fire 2 Instability 0 Other B (Glasses, gloves)

NFPA 704 Hazard Ratings: Health 1 Flammability 2 Reactivity 0 Special NA

Hazard Ratings: Least: 0 Slight: 1 Moderate: 2 High: 3 Extreme: 4

Threshold limit value: Not established on product.

TOSCA Status: All ingredients listed	CERCLA RQ: See Sec 2.
California Prop. 65: None	Ingredients on cancer lists: None
Reproductive implications: None	

SECTION 4 - PHYSICAL AND CHEMICAL PROPERTIES

Appearance:	Clear, colorless liquid	Flash point deg. F (cc):	100-125'F (PM)
Odor:	Hydrocarbon	Boiling range deg. C:	127-288 (260-550F)
Specific gravity:	Approx. 0.76	Vapor pressure 20 deg C:	<0.3 kPa @ 20'C
pH reaction:	Not applicable	Freezing point deg. C:	NA
Vapor density: (air=1):	>1	Solubility in water:	Nil
VOC Content:	760 g/l		
California Rule 102 (66):	Contains no photo chemically active materials.		

APPENDIX B
Syntroleum Fuel Analysis & R-8 MSDS R-8 HRJ Specification Evaluations

R-8 Renewable Jet Fuel — Page2

SECTION 5 - SAFE HANDLING AND STORAGE

General	Flammable liquid. Ground equipment when transferring. Do not expose to open expose to open flame, sparks or static electricity. Keep containers covered when not in use. Do not expose to excessive heat or sunlight during storage.
Protective equipment	
Eyes	Safety glasses or goggles should be worn if there is possibility of eye contact.
Skin	Impermeable gloves such as rubber, PVC or neoprene are recommended.
Respiratory protection	None normally required. If risk of inhalation occurs, select and use equipment according to OSHA/NIOSH guidelines for nuisance mists.
Ventilation	A well ventilated work environment is recommended.
Other	Vapors may collect in low places and may ignite or cause asphyxiation.

SECTION 6- HEALTH SAFETY DATA

Effects of acute or chronic over exposure	
Eyes	Slightly irritating to eyes. No chronic effects known.
Skin	Can cause irritation from repeated exposure.
Inhalation	Mists may be irritating to breathing passages.
Ingestion	Not a likely source of chronic exposure.

SECTION 7 - PHYSICAL STABILITY AND REACTIVITY DATA

Explosive limits		Flash point:	See Sec 4
Upper No data	Lower No data	Conditions to avoid:	Exposure to ignition sources.
Chemical stability	Stable	Hazardous decomposition products: Product will burn, but is otherwise stable.	
Hazardous polymerization	Cannot occur	Incompatibility:	None known

SECTION 8- EMERGENCY RESPONSE PROCEDURES

Fire	Extinguishing media	Foam, halon, dry chemical, any ABC Class extinguisher
	Special procedures	Water will coo; containers, but may spread the fire.
	Unusual hazards	Heavy, black smoke produced in a fire.
First Aid	Eyes	Flush with water for at least 15 min. Seek medical attention. See Sec. 6.
	Skin	Wash exposed skin with soap and water until gone. Remove affected clothes rinse off product and wash clothes before reuse.
	Inhalation	If affected, remove individual to fresh air, get medical attention at once if there is any discomfort.
	Ingestion	Dilute by giving large amounts of milk or water. Get medical attention immediately. Do not induce vomiting.
Spills	Small / large spill	Small amounts may be flushed to drain. Comply with federal, state and local regulations on reporting spills. Keep out of waterways and storm sewers.

Product as made has the characteristic of ignitability, like " Unlisted Hazardous Waste D001", RQ 100#.

Information herein has been compiled from sources considered to be accurate and reliable, but is not guaranteed to be so. Since conditions of use are beyond our control we make no warranties of any kind.

MSDS prepared by: R.N. Miller 1-800-342-3577

Syntroleum Corporation

Final Report

for

Universal Technology Corporation

Subcontract: 08-S590-0011-05-C1

November 2008

APPENDIX C
Syntroleum Corporation R-8X Production Final Report

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APPENDIX C
Syntroleum Corporation R-8X Production Final Report

List of Figures and Tables

APPENDIX C
Syntroleum Corporation R-8X Production Final Report

1. Introduction

In July 2008, as the production of 600 gal of R-8 research fluid (prototype jet fuel derived from low value animal fats/greases) was coming to an end, UTC and Syntroleum agreed to a new contract for converting five gal of seaweed oil. This contract required delivery of 1 – 4 gal of the derived fuel, designated R-8X, along with certificate of analysis.

To ensure steady-state operation during R-8X fuel production and to minimize risk of cross-contamination with R-8 material already in the system, Syntroleum requested additional seaweed oil from AFRL. In all, four 5-gal buckets of seaweed oil were obtained and converted to R-8X. About 9 gal of representative fuel was thus produced. The R-8X product was shipped along with the certificate of analysis to AFRL during the first week of August 2008.

The Bio-Synfining™ conversion process used for producing R-8X was described in the final report for R-8 production (*1*). The present report provides characterization data on the seaweed oil feedstock, describes the conversion steps performed, presents R-8X analytical results, and discusses differences with the more standard Bio-Synfining™ feeds and products.

2. Conversion Process

2.1. Feedstock Analysis: Seaweed oil was received from Global Seawater, Inc. (Phoenix, AZ). It was a liquid at ambient conditions with a turbid green appearance. When left standing at room temperature, a solid precipitate was observed. The oil was analyzed for fatty acid profile and contaminants concentration. The results are summarized in Table I.

Table I. Seaweed Oil Analysis Summary

Sample # RDIL 5022		
Ash	ppm	121
Acid value	mg KOH/mg	2.7
Moisture and all Volatiles	mass %	2.23%
Insoluble impurities	mass %	0.04%
Unsaponifiables	mass %	0.87%
ICP metals and phosphorus		
Calcium	ppm	12.8
Iron	ppm	1.29
Potassium	ppm	2.03
Magnesium	ppm	8.53
Sodium	ppm	2.75
Phosphorus	ppm	25.7

Fatty acid profile		
C16:0	%	7.66
C16:1	%	0.15
C18:0	%	2.51
C18:1	%	14.72
C18:2	%	70.97
C18:3	%	2.20
C20:0	%	0.43
C20:1	%	0.32
C20:2	%	<0.1
C22:0	%	0.28
C22:1	%	0.19
C24:0	%	0.12

The fatty acid composition of Table I is very similar to sunflower oil (*2*). It is high in linoleic acid (C18:2) and total C18 fatty acid content. In terms of free fatty acid (FFA) content and type of contaminants, the seaweed oil is similar to most common vegetable oils.

Acid number of 2.7 mg KOH/g translates to FFA of 1.4%. This low FFA content means that virtually all fatty acids are in the form of triglycerides.

The total contaminants content (all solubilized metals and phosphorus) of 53 ppm is significantly less than waste animal fats/greases (about 1,000 ppm). Since the level of contaminants was only 10-20 ppm higher than Bio-Synfining™ pretreatment targets, the oil was processed through the hydrodeoxygenation reactor without the usual pretreatment steps such as acid washing.

2.2. Hydrodeoxygenation (HDO): The pilot plant HDO reactor was switched from fat/grease to seaweed oil on June 23, 2008. The average bed temperature increased immediately by about 100

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°F. This was most likely due to the higher level of unsaturation in the seaweed oil, and the proportionally greater heat realease from the exothermic hydrogenation reaction. (Polyunsaturation, as measured by C18:2 plus C18:3, is 73% for seaweed oil compared to 17% for chicken fat and only 4% for beef tallow.)

After the reactor returned to the target operating temperature range, samples of the intermediate product were taken. The composition of the steady-state HDO reactor product is presented in Table II.

Table II. Composition of Hydrodeoxygenated Seaweed Oil

Paraffin Carbon No.	Concentration (wt %)
$C8^-$	1.92
C9	0.093
C10	0.172
C11	0.222
C12	0.157
C13	0.186
C14	0.261
C15	1.83
C16	7.28
C17 [(a)]	17.1
C18 [(a)]	65.8
C19 [(a)]	1.33
$C20^+$ [(b)]	3.65

Notes:
(a) GC indicates presence of minor amount of linear olefin in addition to n-paraffin
(b) GC indicates presence of minor amounts of oxygenates in addition to n-paraffins

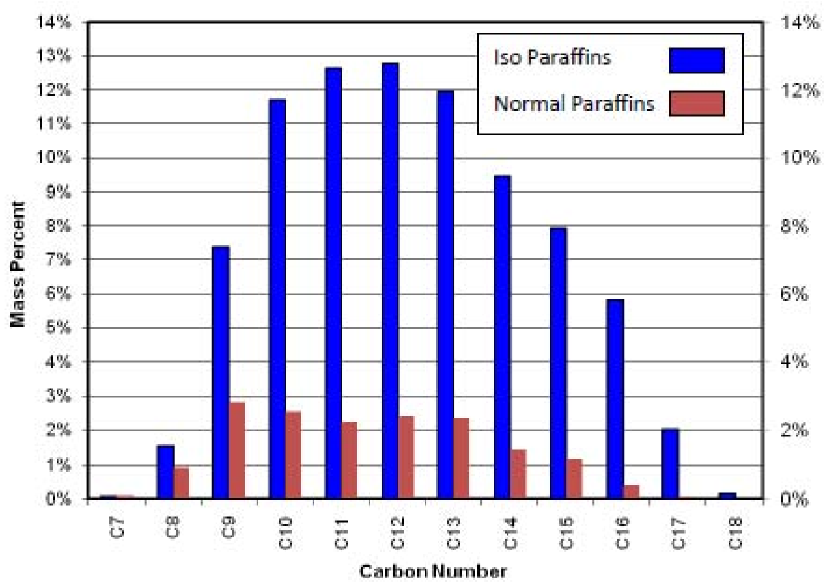
As observed in Table II, the seaweed oil HDO product was mainly n-heptadecane and n-octadecane. This was of course expected given the high C18 fatty acid concentration of the oil. As a result, the intermediate product was a crystalline solid at room temperature.

In contrast, animal fat derived HDO products formed from triglycerides with lower C18/C16 fatty acid ratios, are not as rich in $C17^+$ components and are typically liquids at ambient temperatures.

2.3. Hydrocracking/Isomerization (HI): Regardless of its animal, vegetable, or seaweed oil origin, the HDO paraffin composition cannot meet the required low temperature properties for jet fuel applications without the additional HI step. The HI reactor feed was switched to hydrodeoxygenated seaweed oil composition of Table II. The transition material was purged from the system before sampling. The flash point and freezing temperature of the post-purge HI product was measured and was found to meet specifications. As such, no adjustment to the HI reactor system was necessary and steady-state operation was soon established. A total of 9.3 gal of R-8X product was collected.

R-8X fuel properties are discussed in Section 3. The corresponding carbon number distribution and paraffin branching profile, as measured by GC, is presented in Figure 1. The analysis shows that 98% of this synthetic paraffinic kerosene (SPK) lies in the desired C8-C16 range with an iso/normal ratio of 5:1. This degree of isomerization is about optimum for "flexible JP-8" applications. Ratios below 4:1 typically do not meet the -47 °C freezing point target for aviation fuel. On the other hand, an iso/normal ratio greater than 6:1 depresses the fuel's cetane number. Since the U.S. military's "flexible JP-8" or "battlefield-use fuel of the future" needs to be suitable for both diesel and jet engines (*3*), the iso/normal ratio has to be maintained in the 4:1 to 6:1 range.

Figure 1. Carbon number distribution and corresponding iso/normal ratio for R-8X SPK



R-8X SPK	
Carbon Distribution and Iso/Norm Ratio	
Mass %	
C_7	0.2%
C_8	2.5%
C_9	10.2%
C_{10}	14.2%
C_{11}	14.9%
C_{12}	15.2%
C_{13}	14.3%
C_{14}	10.9%
C_{15}	9.1%
C_{16}	6.2%
C_{17}	2.1%
C_{18}	0.2%
Iso/Norm =	5.0:1

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3. Product Properties

3.1. Comparison with R-8: Table III provides a summary of key R-8X attributes for use in military jet fuel applications. The results from R-8 tests, as well as JP-8 and SPK (R-8/S-8) specifications are also included in Table III. (JP-8 specifications were obtained from Table 1 of MIL-DTL-83133F.)

Table III. Comparison of R-8X Properties with R-8, and Conformance to JP-8 Specifications

			Specification Values		Product Shipped to AFRL		
Specification Test	Test Method	Units	JP-8	R-8/S-8	R-8 Lot 1	R-8 Lot 2	R-8X
Density	ASTM D-4052	kg/L	0.775-0.840	0.75-0.77	0.7645	0.7623	0.7612
API	ASTM D-4052	°	37.0-51.0	51.6-56.5	53.6	54.1	54.4
Flash Point	ASTM D-93	°C	≥38	≥38	48	48	46
Ash	ASTM D-482	wt %	Report	Report	<0.001	<0.001	<0.001
Kinematic Viscosity @ 40 °C	ASTM D-445	cSt	Report	Report	1.44	1.45	1.32
@ -20 °C	ASTM D-445	cSt	≤8.0	≤8.0	5.15	5.11	4.61
Freezing Point	ASTM D-5982	°C	≤-47	≤-47	-48	-49.5	-55.5
Cetane Index	ASTM D-976		Report	Report	68.2	67.7	66.7
Saybolt Color	ASTM D-156		Report	Report	+30	+30	+30
Smoke Point	ASTM D-1322		≥ 25	≥ 40	>50	>50	>50
Sulfur	ASTM D-5453	ppm	≤3000	≤1	1.5	0.3	0.3
Distillation °C	ASTM D-2887						
IBP		°C	Report	Report	105	107	108
10% recovered		°C	≤186	≤186	157	151	148
20% recovered		°C	Report	Report	174	169	166
50% recovered		°C	Report	Report	218	216	210
90% recovered		°C	Report	Report	279	277	271
FBP		°C	≤330	≤330	308	304	300

Just like R-8, R-8X conforms to all JP-8 specifications except density. The density does, however, conform to the military requirement for SPK to be used in JP-8 blends (Table A-1 of MIL-DTL-83133F). As discussed in the final report for the R-8 production campaign (*1*), the low density is due to the high H:C ratio of the product and characteristic of all SPK fuels.

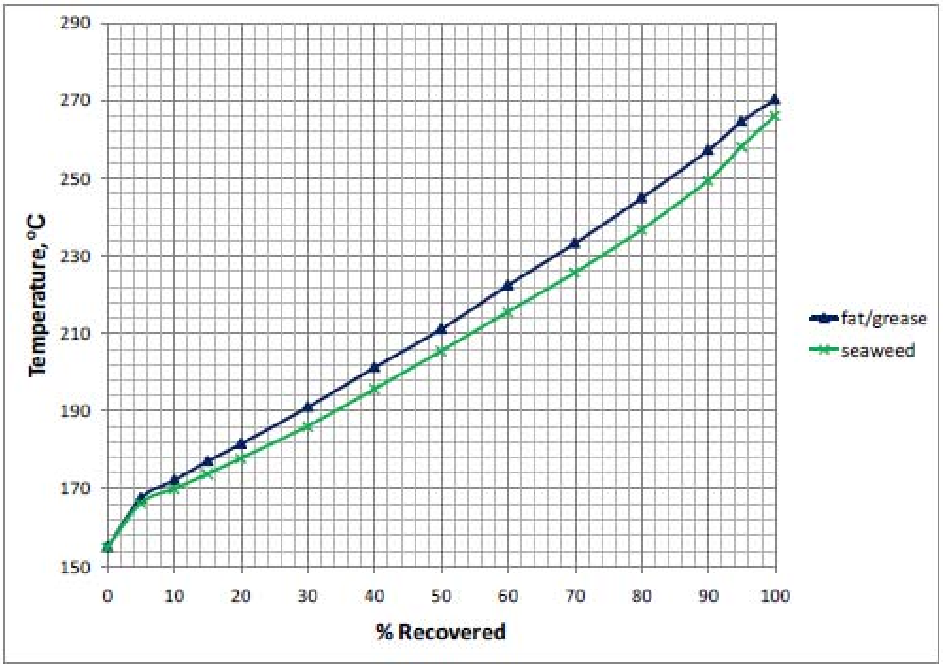
R-8X freezing point is about six degrees centigrade lower than the fat/grease-based R-8 fuel. Because no HI reactor system changes were made when processing the two feeds, the lower freezing point is a direct consequence of the HDO product differences. Two major dissimilarities were noted.

First, organic nitrogen present in the seaweed-derived paraffins was significantly lower than their fat/grease counterpart: 4 ppm vs. 50 ppm average. Nitrogen compounds form ammonia in the HI reactor, which inhibits the cracking activity of the catalyst. Therefore, the catalyst activity improved with the seaweed oil derived feed resulting in a freezing point reduction. In extended operations, HI reactor conditions are modified to account for changes in residual nitrogen thereby producing a product with consistent freezing point.

Second, the $C17^+$ paraffin content of the seaweed-derived intermediate was 88%, compared to about 65% for animal fat/grease intermediate hydrocarbons. Higher molecular weight n-paraffins crack more easily, reducing freezing point. Again, minor adjustments to HI reactor system operating conditions in response to changes in intermediate paraffin carbon number distribution is expected to result in good control of SPK product properties.

Despite the six degrees centigrade difference in freeze point, the final SPK fuels R-8 and R-8X display very little overall variability. The distillation curves plotted in Figure 2 show the similarity in the two fuels' boiling point distribution.

Figure 2. Distillation curves (ASTM D-86) for SPK from seaweed oil (R-8X) and fat/grease (R-8 Lot 2)



3.2. Certificate of Analysis: The R-8X product was collected in a drum and additized with 25 mg/L of butyrated hydroxytoluene (BHT) antioxidant. The homogeneous blend was then transferred into smaller containers for transport to AFRL. The CoA for the R-8X fuel is presented as Figure 3.

APPENDIX C
Syntroleum Corporation R-8X Production Final Report

Figure 3. **Certificate of analysis shipped with R-8X SPK fuel**

Certificate of Analysis

Syntroleum®

SYNTROLEUM® R-8X
SYNTHETIC JET FUEL

Syntroleum R-8X is synthetic jet fuel meeting the general requirements of MIL-DTL-83133F. It is not suitable for use in aircraft and is provided for development purposes only. This fuel contains between 23 and 29 mg/L phenolic antioxidant to improve storage stability.

SYNTHETIC DISTILLATE JET FUEL

Lot __1__ Date: _7/31/08__

PHYSICAL PROPERTIES	TEST METHOD	UNITS	SPECIFICATION VALUE	ACTUAL
Density	ASTM D-4052	kg/L	0.75-0.77	0.7612
API	ASTM D-4052	°	51.6-56.5	54.4
Flash Point, min	ASTM D-93	°C	38	48
Ash	ASTM D-482	wt %	Report	<0.001
Kinematic Viscosity @ 40°C	ASTM D-445	cSt	Report	1.32
Freeze Point, max	ASTM D-5982	°C	-47	-55.5
Cetane Index	ASTM D-976		Report	66.7
Saybolt Color	ASTM D-156		Report	+30
Distillation, IBP,% recovered	ASTM D2887	°C	Report	108
10% recovered, max		°C	186	148.1
20% recovered		°C	Report	166.2
50% recovered		°C	Report	209.6
90% recovered		°C	Report	271.4
FBP, max		°C	330	299.5

Health and Safety: The product(s) described herein may require precautions in handling and use. If deemed necessary, Material Safety Data Sheets (MSDS) for Syntroleum products are included with this document. You may also obtain this information by writing to us at the address below. Always consult the Material Safety Data Sheet for products you consider using.

Contact	QA/QC Approval	Approval to Ship	Date
Contact: Syntroleum 5416 South Yale Ave, Ste 400 Tulsa, OK 74136	QA/QC Approval	Approval to Ship	07/31/08

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4. Summary and Conclusions

Seaweed oil was converted to synthetic paraffinic kerosene (SPK) using the Bio-Synfining™ process. This bio-renewable fuel, designated the name R-8X, meets all SPK fuel specifications (e.g. R-8 and S-8). R-8X also conforms to all JP-8 specs except density.

In terms of operability, seaweed oil processed without any issues. The notable differences with animal fat/grease were (1) higher heat release during hydrodeoxygenation (from hydrogenation of the highly unsaturated feedstock), and (2) lower residual nitrogen in the intermediate paraffin product. As expected from the fatty acid profile of seaweed oil, the intermediate product had a higher concentration of $C17^+$ n-paraffins. These differences were found to be well within the operating window of Bio-Synfining™, thus demonstrating the feedstock flexibility of the process.

Overall, the seaweed oil received for this project is a suitable feedstock that makes a high quality SPK product. About nine gallons of the R-8X SPK fuel were delivered to AFRL for further evaluation.

APPENDIX C
Syntroleum Corporation R-8X Production Final Report

References

1. "Production of R-8 Research Fluid"; Final Report for Universal Technology Corporation, Subcontract 07-S530-0042-06-C1; Syntroleum Corp., Tulsa, OK; Sept. 2008.

2. Bokisch, M. *Fats and Oils Handbook*, AOCS Press: Champaign, IL, 1998; Table 4.4.

3. Lamprecht, D. *Energy & Fuels* **2007**, 21, 1448-1453.

APPENDIX D

Experimental Jet Fuel Evaluation -- Tier I and II

TECHNICAL MEMORANDUM FOR ANALYSIS OF R-8/R-8X HYDROPROCESSED RENEWABLE FOR JET (HRJ) FUELS FROM SYNTROLEUM

Document Summary

This document details analytical testing results performed-to-date on a hydroprocessed renewable for jet (HRJ) research fuel termed R-8 received by AFRL/RZPF from Syntroleum Corporation. Specifically, analyses were performed on R-8 samples received from the beginning and end of a large-scale production run to investigate both specification and non-specification properties and consistency during the fuel production. In addition, analysis of a second experimental fuel, termed R-8X, was performed herein. The fuels were evaluated according to the first two tiers of RZPF's "Experimental Jet Fuel Evaluation." In addition to evaluation of the neat fuel, JP-8 additives were added to the R-8, and the resulting fuel was blended 50/50 by volume with a representative JP-8. Comparisons were made to the current JP-8 specification (Military Specification MIL-DTL-83133F), a representative petroleum-derived JP-8 jet fuel, and a natural-gas-derived Fischer-Tropsch (F-T) fuel previously evaluated by the USAF (termed S-8).

When comparing the results for the R-8 and R-8X samples to the JP-8 fuel specification and a representative JP-8 sample, the only considered properties which did not satisfy current requirements were specific gravity/density, conductivity, FSII, and lubricity. Of those four properties, all but density could be made to fall within the specification limits with the addition of JP-8 additives. However even with JP-8 additives, the total aromatic contents of the R-8 and R-8X fuels are significantly below the level typically found in petroleum-derived aviation fuels, which may result in the inability of the neat fuel to directly satisfy required "Fit-For-Use" properties without blending with a JP-8 fuel.

From the testing that was performed, there appeared to be reasonable consistency in the R-8 production run. There were only slight differences in the two R-8 fuels from the beginning and the end of the run, with the largest difference being in the total aromatic content of the two fuels. In addition, the R-8X fuel is very similar to the R-8 fuel for most of the properties tested. An exception to this is that the R-8X exhibits superior low-temperature behavior to the R-8 fuel. Additional testing will be performed on the R-8 fuel.

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Approved By:

// *signed* //
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APPENDIX D

Experimental Jet Fuel Evaluation -- Tier I and II

Introduction

The R-8 and R-8X hydroprocessed renewable for Jet (HRJ) fuels produced by Syntroleum Corp. were received by the Fuels Branch, US Air Force Research Laboratory, (RZPF) on August 1, 2008 and assigned the internal identification numbers POSF-5469 and POSF-5470, respectively. The R-8 and R-8X fuels underwent evaluation for use as a propulsion fuel for military aviation systems according to the Tier I and II outlined in the "Experimental Jet Fuel Evaluation" protocol developed by RZPF. The R-8 fuel with JP-8 additives and a 50% blend by volume of R-8/JP-8 were also assigned internal identification numbers (POSF-5480 and POSF-5536, respectively), and were subjected to a majority of the same evaluations as the R-8 and R-8X fuels. Comparisons were made to the current JP-8 fuel specification (MIL-DTL-83133F), a specification JP-8 fuel (POSF-4751), and a synthetic fuel (S-8) derived from natural-gas via the Fischer-Tropsch (F-T) process previously acquired from Syntroleum (POSF-4909). In addition, a sample of R-8 from the beginning of the production run (POSF-5439) which was previously analyzed is compared to provide information concerning consistency of the fuel production run. A list of the fuel samples used in this study is shown in Table D-1.

Table D-1. List of Fuel Samples Evaluated

POSF No.	Manufacturer/ Source	Fuel Description
5470	Syntroleum	R-8X HRJ
5469	Syntroleum	R-8 HRJ
5439	Syntroleum	R-8 HRJ (initial)
5480	Syntroleum	R-8 w/ JP-8 additives
4909	Syntroleum	S-8 w/ JP-8 additives
5536	Syntroleum/WPAFB	R-8/JP-8 50/50 Blend
4751	WPAFB	JP-8

MIL-DTL-83133 Specification Evaluation

The R-8, R-8X, R-8 with JP-8 additives and R-8/JP-8 50/50 blend fuels (POSF-5469, POSF-5470, POSF-5480, and POSF-5536) were evaluated according to the current military jet fuel specification (MIL-DTL-83133F) for all JP-8 specification properties, some of which are discussed below. Results from testing with these four fuels along with JP-8 (POSF-4751), S-8 (POSF-4909) and the initial R-8 (POSF-5439) fuels are shown in Table D-2.

Acid Number (D3282). The acid numbers of the R-8, R-8X and R-8/JP-8 blend fuels (0.002 to 0.005 mg KOH/g) are all within the specification limit, and similar to those of the S-8 and JP-8 (0.004 and 0.003 mg KOH/g).

Aromatics (D1319). The R-8 and R-8X fuels, like the S-8 fuel, contain less than 2 volume % aromatics as determined by the JP-8 specification method D1319. Both fuels meet the JP-8 specification for aromatic content (which is 25 volume % maximum), but they are much lower than the representative JP-8 sample 0(18 volume %). The R-8/JP-8 blend contains 9.7 volume %, which is considerably higher than the synthetic fuels, but still lower than the 95% confidence interval for the range of aromatic content of the jet fuels procured by DOD in FY2005 (10-23% by volume). It should be noted that the accuracy of method D1319 for non-petroleum derived fuels with low aromatic content may be subject to increased variability. Analysis by D6379 (discussed below) or D5186 (required for analysis of aromatic content in Synthetic Paraffinic Kerosene per MIL-DTL-83133F) may provide improved accuracy.

Distillation (D86). The R-8, R-8X, and blend fuels have boiling ranges similar to the JP-8 and S-8 fuels, with 10% and 100% recovery temperatures within the specification limits.

Flash Point (D93). The flash points of the R-8, R-8X and blend fuels (46-50°C) meet the JP-8 minimum specification requirement of 38°C, and are between the flashpoints of the S-8 (45°C) and JP-8 (51°C) fuels.

Freeze Point (D5972). The freeze points of the R-8 and blend fuels, ranging from -48°C to -51°C, meet the specification maximum (-47°C), and are comparable to the freeze points of the S-8 and JP-8 fuels (-51°C). The freeze point of the R-8X (-57°C) is significantly below the specification maximum and all other fuels.

-20°C Viscosity (D445). The -20°C viscosities of the R-8 (5.4 cSt) and R-8/JP-8 blend fuels (5.1 cSt) are within the JP-8 specification of 8 cSt maximum, and slightly higher than those of the S-8 (4.9 cSt) and representative JP-8 (5.0 cSt) fuels; whereas the -20°C viscosity of R-8X (4.7 cSt) fuel is just below the S-8 and representative JP-8 values.

-40°C Viscosity (D445). -40°C viscosity is a JPTS specification, not a JP-8 specification. The -40°C viscosities of the R-8 fuels (11.5 cSt) are just below the JPTS specification maximum of 12 cSt, and above the S-8 and representative JP-8 values (9.5 and 9.9 cSt, respectively). The -40°C viscosity of the R-8/JP-8 blend (10.9 cSt) is also higher than the S-8 and JP-8 values; however the R-8X value (9.8 cSt) is approximately the same.

Heat of Combustion (D4809). The measured heats of combustion on a mass basis for the R-8 and R-8X fuels (44.3 and 44.2 MJ/kg, respectively) satisfy the fuel specification (42.8 MJ/kg minimum), are slightly higher than the value for the S-8 (43.9 MJ/kg), and are above the value for the representative JP-8 fuel (43.1 MJ/kg). The heat of combustion of the 50/50 blend (43.8 BTU/lb) is between the R-8 and JP-8 values, as would be expected based on dilution theory.

Specific Gravity (D4052). Ranging from 0.762 to 0.766, the specific gravities of the R-8 and R-8X are all below the JP-8 specification range of 0.775 to 0.840 and the representative JP-8 (0.804), but slightly above than the specific gravity of the S-8 (0.756). The R-8/JP-8 blend has an intermediate specific gravity (0.783) that meets the JP-8 specification.

Conductivity, FSII, and Lubricity. The R-8 and R-8X fuels (POSF-5469 and POSF-5470) have low conductivity and FSII levels (0), and high lubricity values (0.92 and 0.89, respectively). The addition of JP-8 additives to the R-8 (POSF-5480) brought the conductivity, FSII and lubricity to within specification limits. The R-8/JP-8 blend (POSF-5536) is outside the procurement specification for FSII (0.08 volume %) as a result of the initial FSII level in the JP-8 (0.07 volume %).

Thermal Stability (JFTOT –D3241). The R-8 and R-8/JP-8 blend fuels meet the JP-8 specification limit for thermal stability at 260°C (≤3 tube rating and ≤25 mm Hg change in pressure). In addition, the R-8X fuel was tested for breakpoint, which was determined to be at 345°C.

APPENDIX D
Experimental Jet Fuel Evaluation -- Tier I and II

Table D-2. Results of Specification Testing

Specification Test	Spec Requirement	5470 R-8X	5469 R-8	5439 R-8 (initial)	5480 R-8 w/ JP-8 additives	4909 S-8 w/ JP-8 additives	5536 R-8 / JP-8 50/50 Blend	4751 JP-8
Total Acid Number, mg KOH/g	≤ 0.015	0.002	0.002	NA	0.005	0.004	0.003	0.003
Aromatics, vol %	≤ 25	0.4	0.0	1.6	0.6	0.0	9.7	19.6
Olefins, vol %	≤ 5	0.4	0.0	0.4	0.2	0.0	1.0	0.8
Mercaptan Sulfur, % mass	≤ 0.002	0.000	0.000	NA	0.000	0.000	0.000	0.000
Total Sulfur, % mass	≤0.3	<0.0003	<0.0003	NA	0.00	0.0023	0.0190	0.0383
Distillation:								
IBP, °C	≤ 205	152	158	145	155	144	159	158
10% recovered, °C		171	175	173	174	167	179	182
20% recovered, °C		179	185	185	185	177	188	190
50% recovered, °C		208	215	219	215	206	212	208
90% recovered, °C		254	260	263	261	256	256	245
EP, °C	≤ 300	269	274	276	273	275	270	268
Residue, % vol	≤ 1.5	1.2	0.8	1.1	1.4	1.5	1.4	1.2
Loss, % vol	≤ 1.5	0.9	0.2	0.5	0.6	0.9	1.4	0.6
Flash point, °C	≥ 38	48	48	46	50	45	50	50
Cetane Index (calculated)		62.8	64.5	63.1	63.9	66.0	56.6	44.2
Freeze Point, °C	≤ -47	-57	-49	-48	-50	-51	-51	-51
Viscosity @ -20°C, cSt	≤ 8.0	4.7	5.5	NA	5.3	4.9	5.1	5.0
Viscosity @ -40°C, cSt	≤ 12.0	9.8	11.5	NA	11.5	9.5	10.9	9.9

NA = Not analyzed due to insufficient sample volume

*Value outside specification limit

Table D-2. Results of Specification Testing *(Cont'd)*

Specification Test	Spec Requirement	5470 R-8X	5469 R-8	5439 R-8 (initial)	5480 R-8 w/ JP-8 additives	4909 S-8 w/ JP-8 additives	5536 R-8 / JP-8 50/50 Blend	4751 JP-8
Heat of Combustion (calculated), MJ/kg	≥ 42.8	44.1	44.1	44.0	44.1	44.2	43.7	43.2
Heat of Combustion (measured), MJ/kg	≥ 42.8	44.2	44.3	44.1	44.1	43.9	43.8	43.1
Hydrogen Content, % mass	≥ 13.4	15.2	15.3	NA	15.2	15.4	14.5	13.8
Smoke Point, mm	≥ 19	>40	>40	NA	>40	42	33	22
Copper Strip Corrosion	≤ 1	1a	1a	NA	1a	1a	1a	1a
Thermal Stability @ 260°C:								
Tube Deposit Rating	≤ 3	<2**	2	NA	1	1	1	1
Change in Pressure, mm Hg	≤ 25	1	0	NA	0	0	0	0
Existent Gum, mg/100mL	≤ 7.0	<1	<1	NA	<1	0.6	<1	1.0
Particulate Matter, mg/mL	≤ 1.0	0.3	0.1	NA	0.4	1.0	0.7	0.7
Filtration Time, minutes	≤ 15	7	6	NA	6	10	5	4
Water Reaction	≤ 1b	1	1	NA	1	1	1	1
FSII, % vol	0.10-0.15	0.00* (0.10)	0.00*	NA	0.11	0.10	0.08*	0.07*
Conductivity, pS/m	150 to 600	0*	0*	NA	520	456	265	72*
API Gravity @ 60°F	37.0 to 51.0	54.2*	54.1*	53.3*	54.0*	55.6*	49.1	44.4
Specific Gravity @ 15°C	0.775 to 0.840	0.762*	0.762*	0.766*	0.763*	0.756*	0.783	0.804
Lubricity (BOCLE), wear scar mm	≤ 0.85	0.89* (0.54)	0.92*	NA	0.56	0.58	0.56	0.53

NA = Not analyzed due to insufficient sample volume

*Value outside specification limit (value in parentheses is from fuel with JP-8 additives)

**Results were obtained at a temperature of 345°C, which was determined to be the breakpoint of the fuel.

**At 350°C, the results for thermal stability were a visual tube rating of 3 and a change in pressure of 0.

APPENDIX D
Experimental Jet Fuel Evaluation -- Tier I and II

Non-Specification Evaluation

The Syntroleum R-8 and R-8X fuels underwent Tier I and II evaluations for selected non-specification analyses. The results of these analyses were compared to results obtained for S-8, JP-8, and initial R-8 fuels. Additionally, comparison of the R-8/JP-8 50/50 blend sample was made for selected analyses.

Hydrocarbon Type Analysis (D6379 & D2425). Petroleum-derived jet fuels typically contain 80-90% paraffins (normal-, *iso*- and cyclo- species), 10-20% aromatic species and 1% other compounds. The R-8 and R-8X fuels contain 96-99 volume % paraffins (normal- and *iso*-), 1-3 volume % cyclo-paraffins and 0.3-1 volume % aromatics, as shown in Tables D-3 and D-4. There was a significant variation between aromatic content of the R-8 fuel from the beginning of the production run (POSF-5439) at 1 volume % and the R-8 fuel from the end of the run (POSF-5469) at 0.3%. As expected, the hydrocarbon type concentrations of the JP-8/R-8 50/50 blend (POSF-5536) are intermediate between the R-8 and JP-8 concentrations.

GC-MS/*n*-Paraffins Analysis. The R-8 and R-8X fuels are comprised of similar amounts of *n*-paraffins (12-13 weight % and 14 weight %, respectively), which are lower than in the S-8 (17 weight %) and the representative JP-8 fuel (19 weight %) (see Table D-5). The *n*-paraffin molecular weight distributions for the R-8 and R-8X fuels are lower than typically observed in JP-8 fuels, with a higher percentage of lower molecular-weight paraffins in the C_7-C_9 range. The distributions are similar to that observed for the S-8 fuel. Comparisons of the *n*-paraffin distributions obtained using Gas Chromatography-Mass Spectrometry (GC-MS) for the various fuels are shown in Figures D-1 and D-2.

Chromatographic Comparison of Fuels. Comparisons of the chromatograms from the GC-MS analysis of the R-8, R-8X, S-8, JP-8, and R-8/JP-8 blend are shown in Figures D-3, D-4, and D-5. The R-8X fuel has lower concentrations of C_{16}-C_{19} and a higher concentration of C_9 normal paraffins than the other fuels, which would contribute to its lower freeze point. The R-8 fuel from the end of the production run (POSF-5469) is slightly different than the fuel from the beginning of the run (POSF-5439) in normal paraffin concentration and distribution, especially at the low (C_7-C_9) and high (C_{15}-C_{17}) molecular-weight ranges. The relative distributions of the R-8 and R-8X fuels are flatter than observed for JP-8, and more similar to that observed for the S-8.

Scanning Brookfield Viscosity. The low-temperature rotational (dynamic) viscosities of the fuels were measured using a Scanning Brookfield Viscometer. Viscosity curves for the R-8, R-8X, R-8/JP-8 blend, S-8, and representative JP-8 are shown in Figure D-6. All five fuels display similar behavior between -20°C and -40°C. Between -40°C and -53°C the viscosity of the R-8 fuel increases at a faster rate than the S-8 and JP-8, and R-8X fuels. At -53°C there is a sharp increase in the JP-8 viscosity (coinciding with its cloud point); whereas the R-8, S-8, and R-8X fuels display more gradual increases in viscosity below this temperature. In addition, from -55°C to -61°C the R-8X viscosity is lower than all the other fuels. However, at -61°C the R-8X has a sharp increase in viscosity that is similar to that displayed by the JP-8 fuel at its cloud point. The viscosity behavior of the R-8/JP-8 blend is intermediate between the R-8 and JP-8.

Quartz Crystal Microbalance (QCM). The thermal stability of the R-8 and R-8X fuels was assessed using the QCM under typical experimental conditions (140°C, air saturated fuel, 15 hours). Total mass accumulation results for the fuels are shown in Table D-6 and indicate that the fuels produce low levels of deposition, ranging from 0.3 $\mu g/cm^2$ to 1.5 $\mu g/cm^2$. These levels are similar to that of the S-8 (0.4 μg/cm^2) and lower than the representative JP-8 fuel (3.0 μg/cm^2). The HRJs are faster oxidizers than the JP-8 and S-8 (see Figures D-7 and D-8); however the R-8 fuel from the end of the batch (POSF-5469 and POSF-5480) was slower than the initial R-8 fuel and the R-8X fuel because of added antioxidant.

Surface Tension. Room temperature surface tension measurements of the R-8, R-8X, and R-8/JP-8 blend fuels were made using a tensiometer with a platinum-iridium ring. These were compared to previous measurements of S-8 and representative JP-8 fuels (Table D-7). The R-8, R-8X, R-8/JP-8 blend, and S-8 fuels all have surface tensions in the range of 22 to 24 dynes/cm; whereas the JP-8 has a higher surface tension (25.5 dynes/cm).

Polar Species Measurement. Semi-quantitative measurements of the polar species concentrations in the fuels were made using high pressure liquid chromatography (HPLC). Like the S-8 fuel, the R-8 and R-8X fuels contain no detectable levels of polar components by HPLC (Table D-8).

Metals by ICP-MS. The R-8 and R-8X fuels were analyzed by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) for a representative group of fifteen metals of interest in fuels (Table D-9). There were no quantifiable levels of metals above the kerosene baseline in either of the fuels. Kerosene (with < 20 ppb total metals) is used as the baseline in order to account for the carbon matrix interference in the fuels.

Table D-3. Aromatic Species Analysis by ASTM D6379 for R-8, R-8X, S-8, JP-8 and R-8/JP-8 50/50 Blend Samples

	5470 R-8X	5469 R-8	5439 R-8 (initial)	4909 S-8	5536 R-8/JP-8 50/50 Blend	4751 JP-8
D6379 (vol.%)						
Mono-aromatics	0.6	0.3	1.0	<0.2	9.8	19.1
Di-aromatics	<0.2	<0.2	<0.2	<0.2	0.6	1.1
Total Aromatics	**0.6**	**0.3**	**1.0**	**<0.2**	**10.4**	**20.2**
Total Saturates	**99.4**	**99.7**	**99.0**	**>99.8**	**89.6**	**79.8**

APPENDIX D
Experimental Jet Fuel Evaluation -- Tier I and II

Table D-4. Hydrocarbon Type Analysis by ASTM D2425 for R-8, S-8, JP-8 and 50/50 R-8/JP-8 Blend Samples

	5470 R-8X	5469 R-8	5439 R-8 (initial)	4909 S-8	5536 R-8/JP-8 50/50 Blend	4751 JP-8
D2425 (vol.%)						
Paraffins (normal + iso)	96	99	96	>99	77	56
Cycloparaffins	3	1	3	<1	10	18
Dicycloparaffins	<1	<1	<1	<1	2	6
Tricycloparaffins	<1	<1	<1	<1	<1	<1
Alkylbenzenes	0.5	<0.5	0.8	<0.5	6.7	12
Indans and Tetralins	<0.5	<0.5	<0.5	<0.5	3.0	7.0
Indenes and C_nH_{2n-10}	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Naphthalene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Naphthalenes	<0.5	<0.5	<0.5	<0.5	0.5	1.0
Acenaphthenes	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Acenaphthylenes	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Tricyclic Aromatics	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Total	100	100	100	100	100	100

Table D-5. Weight Percent of *n*-Paraffins for R-8, S-8, JP-8 and R-8/JP-8 50/50 Blend Samples

	5470 R-8X	5469 R-8	5439 R-8 (initial)	4909 S-8	5536 R-8/JP-8 50/50 Blend	4751 JP-8
n-Paraffins (wt.%)						
n-Heptane	0.11	0.13	0.31	0.14	0.11	0.10
n-Octane	0.89	0.80	1.09	1.32	0.56	0.34
n-Nonane	2.92	2.28	1.68	2.60	1.71	1.21
n-Decane	2.59	2.47	2.05	3.23	2.98	3.48
n-Undecane	2.20	2.10	1.98	3.18	3.14	4.24
n-Dodecane	1.78	1.64	1.57	2.46	2.65	3.71
n-Tridecane	1.53	1.23	1.15	1.94	2.02	2.84
n-Tetradecane	0.94	0.92	0.81	1.18	1.33	1.79
n-Pentadecane	0.66	0.80	0.58	0.70	0.83	0.87
n-Hexadecane	0.21	0.60	0.80	0.35	0.43	0.27
n-Heptadecane	0.033	0.052	0.072	0.090	0.070	0.089
n-Octadecane	0.009	0.026	0.036	0.010	0.024	0.024
n-Nonadecane	<0.001	<0.001	<0.001	0.002	0.004	0.008
Total n-Paraffins	**13.9**	**13.1**	**12.1**	**17.2**	**15.9**	**19.0**

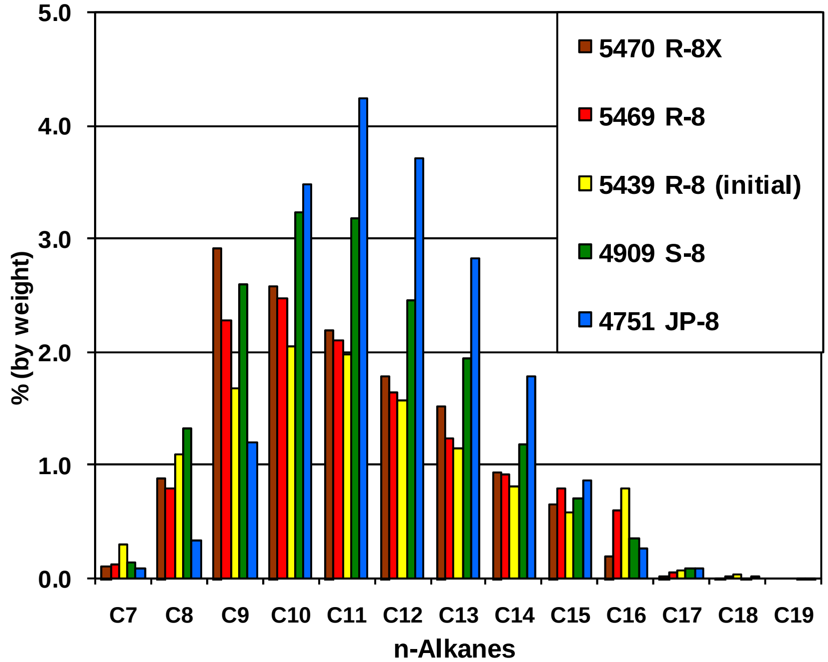

Figure D-1. Weight Percent of *n*-Paraffins (C_7-C_{19}) for R-8, R-8X, S-8 and JP-8 Samples

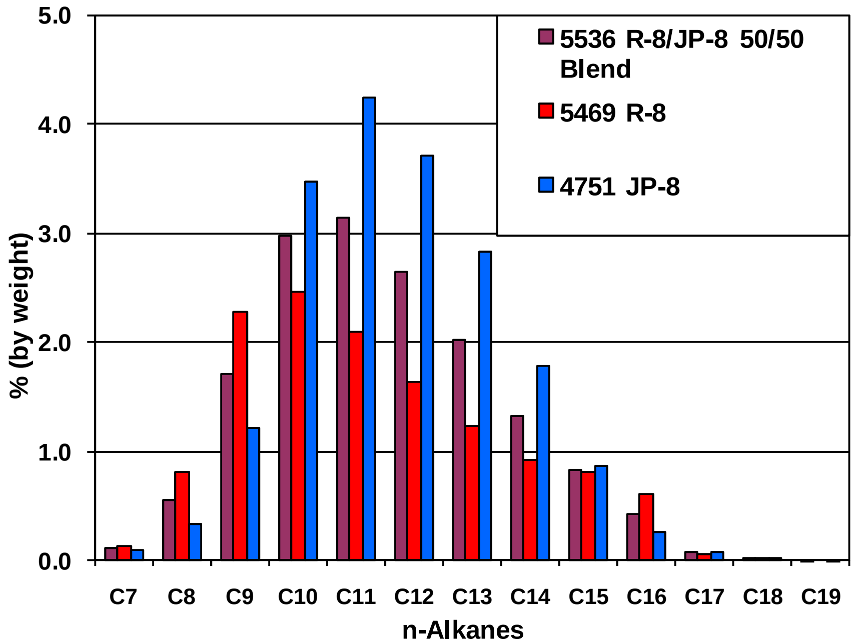

Figure D-2. Weight Percent of *n*-Paraffins (C_7-C_{19}) for R-8, R-8/JP-8 50/50 Blend and JP-8 Samples

APPENDIX D
Experimental Jet Fuel Evaluation -- Tier I and II

Weight % n-Paraffins				
	C_7-C_9	C_{10}-C_{13}	C_{14}-C_{16}	C_{17}-C_{19}
5470	3.9	8.1	1.8	0.042
5469	3.2	7.4	2.3	0.079
4909	4.1	10.8	2.2	0.10
4751	1.7	14.3	2.9	0.12

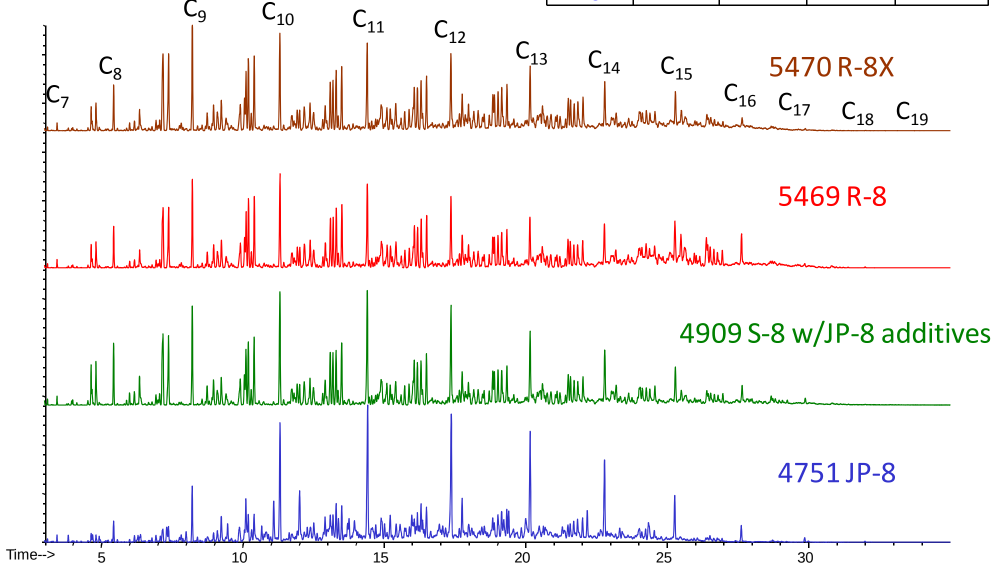

Figure D-3. Chromatograms of R-8X, R-8, S-8 and JP-8 Samples

Weight % n-Paraffins				
	C_7-C_9	C_{10}-C_{13}	C_{14}-C_{16}	C_{17}-C_{19}
5469	3.2	7.4	2.3	0.079
5439	3.1	6.7	2.2	0.11
4909	4.1	10.8	2.2	0.10

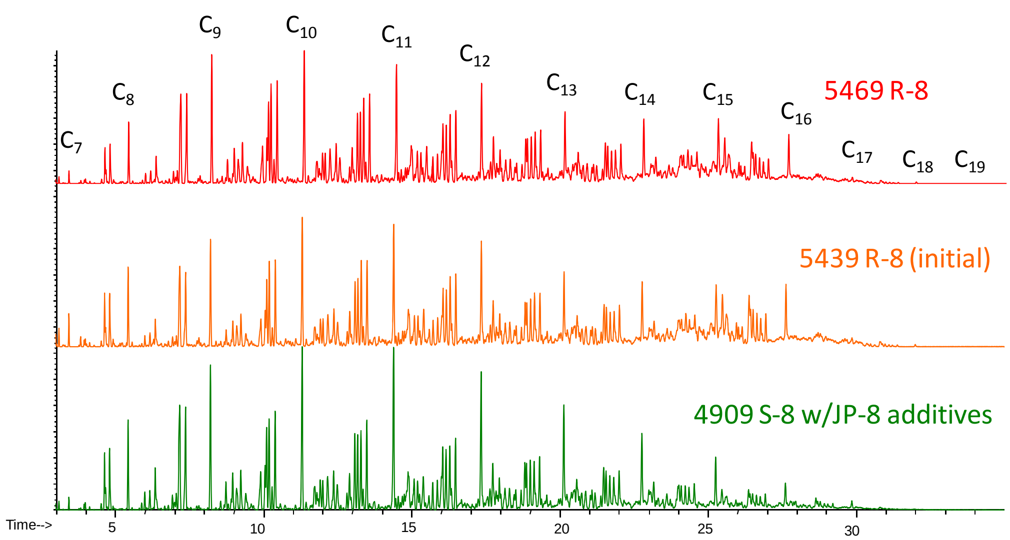

Figure D-4. Chromatograms of R-8 and S-8 Samples

Weight % n-Paraffins				
	C_7-C_9	C_{10}-C_{13}	C_{14}-C_{16}	C_{17}-C_{19}
5536	2.4	10.8	2.6	0.099
5480	3.2	7.4	2.3	0.079
4751	1.7	14.3	2.9	0.12

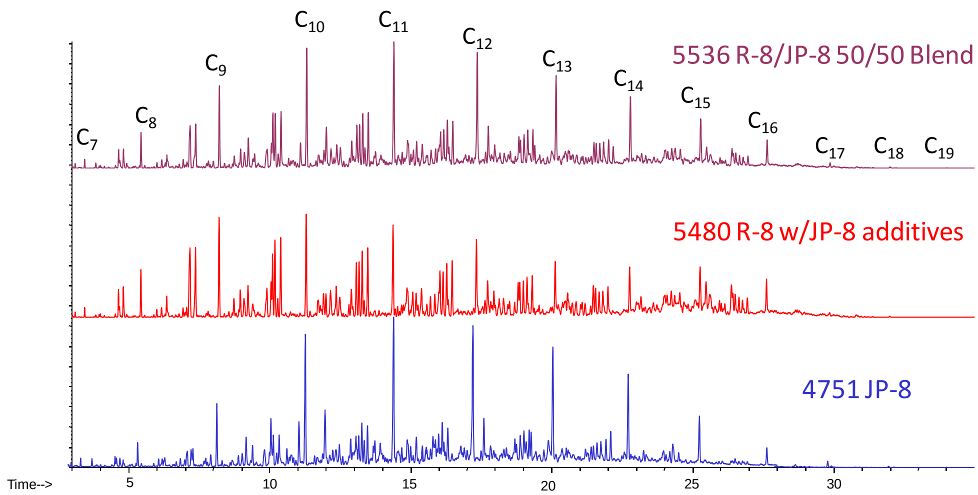

Figure D-5. Chromatograms of R-8/JP-8 50/50 Blend, R-8 and JP-8 Samples

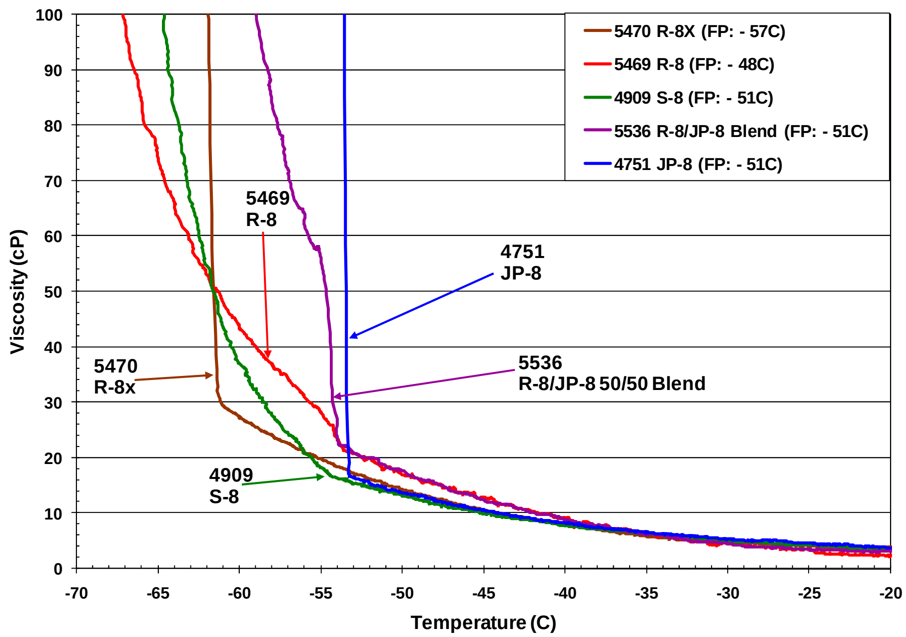

Figure D-6. Scanning Brookfield Viscosity Curves of R-8X, R-8, S-8, R-8/JP-8 50/50 Blend and JP-8 Samples

Table D-6. Data From QCM Thermal Stability Analysis

POSF No.	Fuel Description	15 Hr Mass Accumulation ($\mu g/cm^2$)
5470	R-8X	0.9
5469	R-8	0.3
5480	R-8 w/ JP-8 additives	0.6
5439	R-8 (initial)	1.5
4909	S-8	0.4
4751	JP-8	3.0

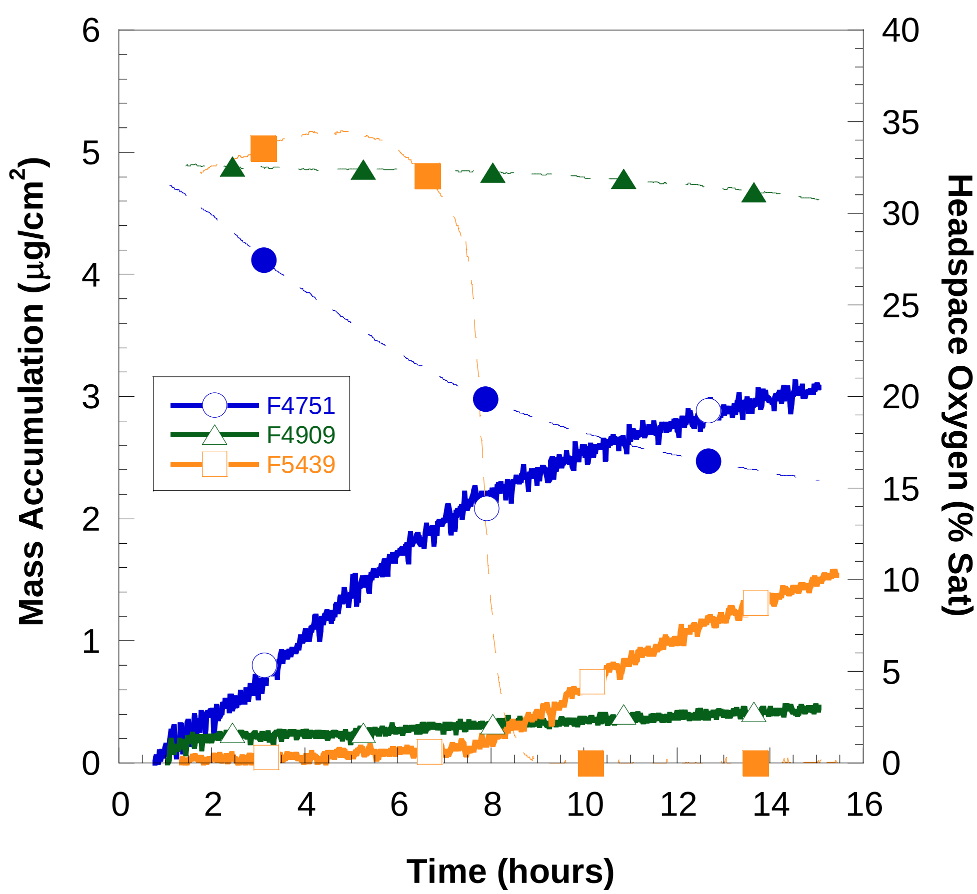

Figure D-7. Mass Accumulation (Solid Curves, Closed Symbols) and Headspace Oxygen Profiles (Dashed Curves, Open Symbols) From QCM Analysis of R-8, S-8 and JP-8

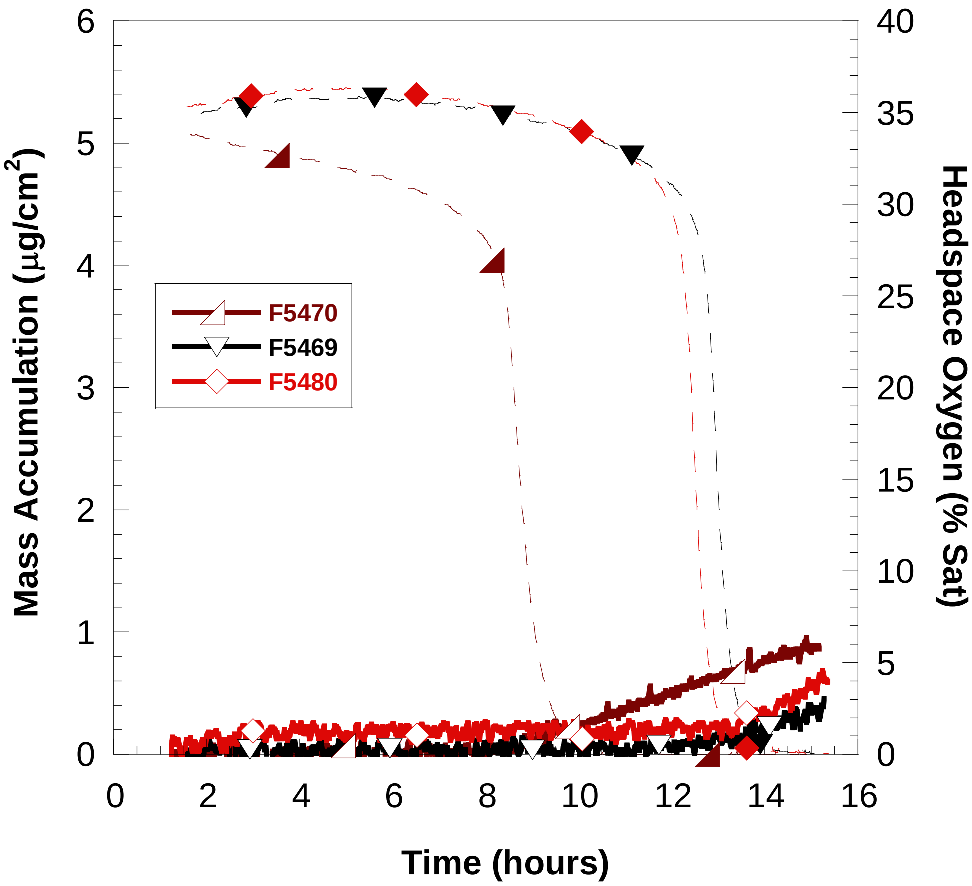

Figure D-8. Mass Accumulation (Solid Curves, Closed Symbols) and Headspace Oxygen Profiles (Dashed Curves, Open Symbols) From QCM Analysis of R-8 and R-8X

Table D-7. Surface Tension

POSF No.	Fuel Description	Surface Tension (dynes/cm)
5470	R-8X	22.9
5469	R-8	23.5
5480	R-8 w/JP-8 additives	22.6
4909	S-8 w/JP-8 additives	23.7
5536	R-8/JP-8 50/50 Blend	23.8
4751	JP-8	25.5

Table D-8. HPLC Polars

POSF No.	Fuel Description	Polars by HPLC (mg/L)
5470	R-8X	< 20
5469	R-8	< 20
4909	S-8 w/JP-8 additives	< 20
4751	JP-8	160

Table D-9. Metals Analysis by ICP-MS

Fuel	Elemental Composition (ppb wt)[1]														
	Al	**Cd**	**Cr**	**Cu**	**Fe**	**Pb**	**Mn**	**Mo**	**Ni**	**P**	**Ag**	**Sn**	**Ti**	**V**	**Zn**
5469	<	<	<	<	<	<	<	<	<	<	<	<	<	<	<
5470	<	<	<	<	<	<	<	<	<	<	<	<	<	<	<
4751	<	<	<	7	<	<	<	<	<	<	33	<	<	<	<
Kerosene[2]	43	5	450	3	35	2	4	2	4	118	2	3	7	2	4

[1] "<" means value below quantitation limit (i.e. ≤2x kerosene baseline).

[2] Elevated baseline values (i.e. Al, Cr, Fe, and P) due to matrix interference.

Mar 17, 2009

Addendum 1

Water results by Karl Fischer (D6304) for the two fuels are:

R-8 (5469): 31 ppm by wt.
R-8X (5470): 18 ppm by wt.

APPENDIX E

Investigation of Oxidative Stability Characteristics of Syntroleum R-8 Alternative Fuel (POSF 5469) Using ECAT Flow Reactor System

Dr. Matthew J. Dewitt, University of Dayton Research Institute

The ECAT Flow Reactor System was used to preliminarily evaluate the relative oxidative stability characteristics of a hydroprocessed renewable for jet (HRJ) research fuel, termed R-8, in a flowing environment. The system has previously been used to evaluate thermal stability characteristics of fuels under both oxidative and pyrolytic conditions (Edwards and Krieger, 1995; Minus and Corporan, 1998; DeWitt and Zabarnick, 2002; Harrison and Zabarnick, 2006; Balster et al., 2008). The reaction zone of the ECAT is comprised of a 36-inch actively heated section where the fuel is exposed to sufficient temperature to promote the desired reaction chemistry. The outer wall temperature profile of the reaction tube is monitored using thermocouples (TC) strap-welded at various locations. The bulk fuel outlet temperature is monitored using a TC that is inserted into the outlet fuel flow approximately 7-inches downstream of the actively heated zone. After exiting the reaction zone, the fuel is cooled and passed through a 7μm sintered filter element to remove any solids that are entrained in the fluid. The stability characteristics are determined by quantifying the total carbon deposition on the internal surface of the reaction tube and on the downstream filter.

The oxidative stability experiments in this study were conducted using a 50-inch long, 0.125-inch o.d., 0.085-inch i.d. tube constructed of 316 stainless steel, a reaction pressure of 550 psig and a volumetric flow rate of 10 ml/min. The furnace temperature was set to obtain a target maximum wall temperature of approximately 650°F (bulk ~600°F). These reaction conditions have previously been shown to be adequate for complete consumption of the dissolved oxygen in the fuel within the reaction zone. Studies were conducted to compare the oxidative stability characteristics of the R-8 fuel with that of a typical JP-8 fuel (designated POSF-4177). A total reaction time of 6 hours was used which was previously shown to be sufficiently adequate to discern differences in deposition between various neat and additized fuels without being time-prohibitive. Each test was conducted twice to provide a measure of the reproducibility. A comparison of the surface deposition profiles and typical average wall temperature measurements for testing with the R-8 and JP-8 fuels are shown in Figure E-1. The R-8 fuel demonstrated excellent oxidative stability characteristics during testing resulting in minimal surface deposition on the reaction tube. In addition, the bulk deposits collected on the downstream filter were reduced by over an order of magnitude (approximately 200 μg versus 4,000 μg for JP-8). The stability characteristics exhibited by this fuel are similar to those observed for a JP-7 fuel, which is a specialty fuel designed to be stable for high-temperature applications (DeWitt and Zabarnick, 2002). The negligible deposition for R-8 is also very similar to various Synthetic Paraffinic Kerosenes (SPKs) produced by the Fischer-Tropsch (F-T) process, as discussed in a previous publication (Edwards et al., 2004; Harrison and Zabarnick, 2006). The ECAT results are consistent with the previous thermal stability evaluation of R-8 using the Quartz Crystal Microbalance (QCM).

The improved stability characteristics of R-8 relative to the specification JP-8 are most likely due to the absence of heteroatomic-containing species in these fuels which have previously been implicated as promoters of undesirable deposit formation in the oxidative regime. Previous analysis of this fuel via HPLC resulted in no detectable levels of polar components. The stability of R-8 and other SPKs is better than that typically observed on the ECAT for a JP-8 fuel with the use of the currently qualified JP-8+100 thermal stability additive package (Heneghan et al., 1996). Pyrolytic (> 1000°F) testing was not conducted with the R-8 fuel; however, based on the chemical composition of the fuel and similarities to SPKs which have previously been tested, it is expected that the R-8 fuel will exhibit higher reactivity and deposition propensity than a typical JP-8 fuel.

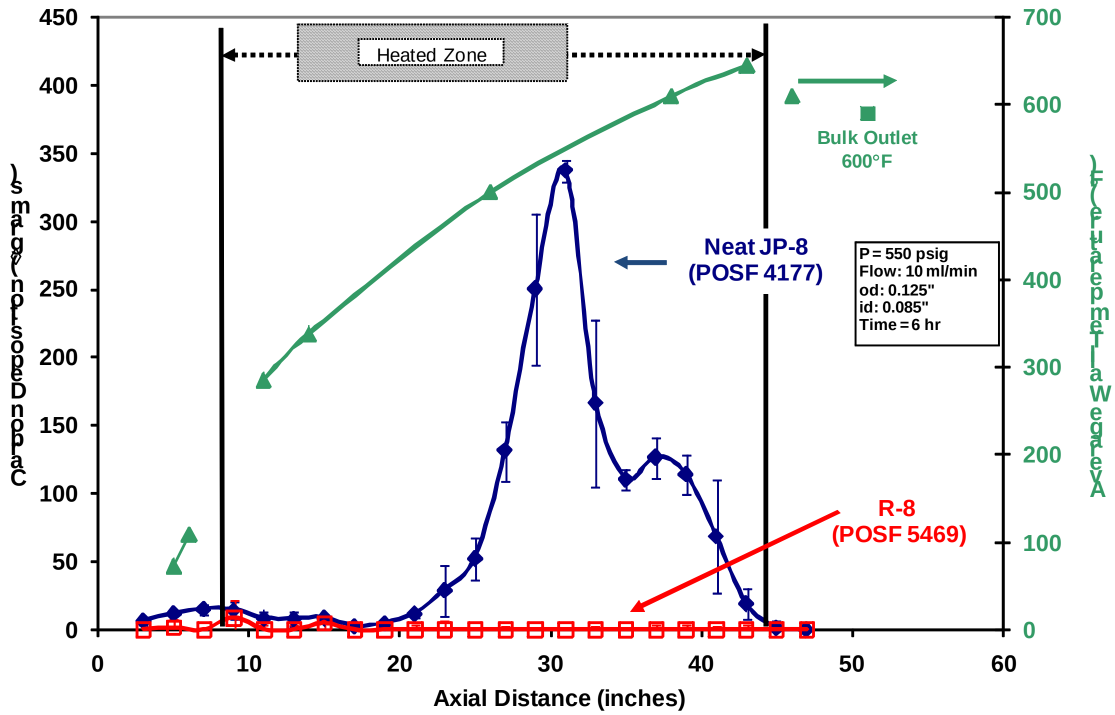

Figure E-1. Comparison of Carbon Deposition and Wall Temperature Profiles for Oxidative Stability Testing on ECAT Flow Reactor System with the R-8 (POSF 5469) and a Standard JP-8 Fuel (POSF 4177) for 6 Hours of Reaction Time.

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Investigation of Oxidative Stability Characteristics of Syntroleum R-8 Alternative Fuel (POSF 5469) Using ECAT Flow Reactor System

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APPENDIX F

Volume Swell of Selected Polymeric Materials in POSF 4751, 4909, 5480, and 5646

Dr. John L. Graham, University of Dayton Research Institute

Purpose

Evaluate the volume swell of selected polymeric materials in POSF 4751 (JP8), 4909 (FT), 5480 (R8), and 5646 (R8x) to estimate the degree to which the acute material compatibility of R8 and R8x compares with that of the FT fuel.

Experimental

Materials

A total of 7 fuels were used in this study as listed in Table 1 including the 4 primary test fuels and the three alternative fuels prepared as 50% blends with the JP8. The fuels were provided by AFRL-RZPF and used as-received. The aromatic content of these fuels has been reported as listed in Table 1. The materials used in this study are listed in Table 2. These materials were provided by the University of Dayton Research Institute's Non-structural Materials Division and used as-received.

Approach

The evaluation of the acute material compatibility was based primarily on the volume change the polymeric materials exhibited after being immersed in the test fuels for 40 hours at room temperature. Volume swell is a very basic response of a polymer on exposure to an organic fluid such as jet fuel and reflects the overall strength of interaction between the fluid and polymer. However, since volume swell by itself can be confounded by other factors such as the extraction of components such as plasticizers by the fuel additional analyses are used to further examine the strength of interaction between the fuel and polymer. This includes an estimate of the mass fraction of fuel absorbed using thermogravimetric analysis (TGA) and examining how the major class fractions of the fuels (the alkanes and aromatics) partition into the polymers from the overlying fuel.

The volume swell of the O-rings were measured by optical dilatometry at room temperature. Briefly, two samples measuring approximately 2mm x 2mm x 1mm were placed in a clear glass vial along with 10 mL of the test fuel. Starting at 2 minutes after being immersed in the fuel the samples were digitally photographed every 20 seconds for the next 3 minutes. At 6 minutes total elapsed time the samples were photographed every 60 minutes for the next 40 hours. After the aging period was completed the cross-sectional area was extracted from the digital images and taken as a characteristic dimension proportional to the volume. The results reported below are the average values obtained from the two samples. At the conclusion of the aging period the mass fraction of fuel absorbed by one of the two samples was determined by thermogravimetric analysis (TGA). The remaining sample was cut into smaller sections, two of which were analyzed by GC-MS. By comparing the GC-MS analysis of the small samples with an identical analysis of the fuel, the relative solubility of the major classes of fuel components were summarized in terms of their respective polymer-fuel partition coefficients.

The overall basis for comparison of the experimental results is the recent experience with blends of FT and JP8 fuels. Briefly, it has been demonstrated that blends up to 50% FT and JP8 are likely to be compatible with JP8, therefore as part of this study data was obtained using an FT fuel, 50% FT in JP8, and a JP8 considered representative of a typical JP8. The results from these fuels and fuels blends were then taken as being representative of the acute volume swell behavior in an FT blending stock, a representative 50% FT/JP8 blend, and a representative JP8. In this comparison the largest differences would be expected in the contrasts between the neat fuels (FT, R8 and R8x) while more moderate difference would be expected between the 50% JP8 blends. Therefore, when considering the potential differences between the three fuels the most sensitive analysis would involve comparing the neat fuels while the an analysis of the likely performance of the 50% fuels blends would involve comparing the fuel blends used in this study.

Results and Discussion

O-rings

The volume swell, TGA, and GC-MS results for the O-ring materials are summarized in Tables 3-6 and Figures 1 and 2. These results show that the volume swell behavior of the nitrile rubber and fluorosilicone O-ring materials were very similar in the FT, R8, and R8x source fuels as well as the fuel blends. The volume swell of the fluorocarbon O-ring materials aged in R8 was similar to those aged in the FT fuel while those aged in R8x were somewhat lower than the FT. Close examination of the GC-MS results shows that the solubility of the alkanes present in the R8x were also somewhat lower than the alkanes present in either the FT or the R8 fuels. However, while the difference in the neat fuels is measurable, the absolute difference in the volume swell behavior is very small.

Hoses and Bladders

The volume swell, TGA, and GC-MS results for the hoses and bladder materials are summarized in Tables 7-10 and Figures 3 and 4. These results show that the overall volume swell behavior of these materials in the FT, R8, and R8x source fuels as well as the fuel blends were very similar. (Note that due to its high rate and large extent of volume swell the aging time of MIL-T-5578 was limited to 45 minutes.) Close examination of the results shows that R8x exhibited slightly less volume swell towards the EC-614-01 epichloro-hydrin hose and EF 5904C polyurethane bladder materials, but the differences are quite small. No significant differences were observed in the solubility of the alkanes or the aromatics present in any of the source fuels or blends.

Sealants

The volume swell, TGA, and GC-MS results for the sealant materials are summarized in Tables 11-14 and Figures 5 and 6. These results show that the overall volume swell behavior of these materials in the FT, R8, and R8x source fuels as well as the fuel blends were similar. Close examination of the results shows that R8x exhibited slightly less volume swell towards the sealant materials as compared to the FT while the R8 showed volume swell that was slightly higher, but the differences are quite small. Similarly, very small differences were observed in the partition coefficients with the solubility of the alkanes in the R8x being slightly lower than those found the in the FT while the solubility of the alkanes in the R8 were comparable or slightly higher than the FT.

It should be noted that the non-curing groove sealants proved somewhat problematic to work with due to their consistency and geometry (soft, inhomogeneous, sticky materials), but nothing stood out in the data that would suggest the behavior of these materials in R8 or R8x would be significantly different than the FT fuel or fuel blends.

Films

The volume swell, TGA, and GC-MS results for the film materials are summarized in Tables 15-18 and Figures 7 and 8. These results show that the response of Teflon, Nylon, and Kapton to all of the fuels was very small. Furthermore, the GC-MS analysis showed that these materials not only absorbed very little fuel, what fuel they did absorb showed little to no selectivity towards the aromatics over the alkanes indicating that their interactions with the fuel will have little or no correlation with the aromatic content. The overall result is that these materials showed a similar, and very limited, response to all of the fuels and fuel blends.

Of the film materials examined, only the polyethylene showed a significant volume swell. Briefly, the R8 exhibited a volume swell character towards the polyethylene that was slightly higher than the FT while the R8x was similar to the FT. The GC-MS analysis also showed that this material exhibits only a modest selectivity towards the aromatics resulting in the volume swell showing a similarly modest response to the aromatic content of the fuels and fuel blends.

Miscellaneous

The volume swell, TGA, and GC-MS results for the polyurethane foam and the polysulfide potting compound are summarized in Tables 19-22 and Figures 9 and 10. Obtaining accurate volume swell data on the polyurethane foam proved problematic as the geometry of the small samples proved unstable. However, the mass fraction of fuel absorbed as measured by TGA shows that this material absorbed somewhat more of the R8 as compared to the FT while the material absorbed somewhat less of the R8x. The GC-MS analysis also showed this material exhibits a significant selectivity towards the aromatics in the test fuels and this is reflected in the mass fraction of fuel absorbed increasing with the aromatic content as shown in Figure 40. These results suggest that the polyurethane foam will exhibit somewhat greater volume swell when exposed to R8 as compared to the FT fuel and slightly less volume swell in the R8x as compared to the FT. However, it is not clear what, if any, these effects would have on the performance of the foam.

With respect to the polysulfide potting compound, as shown in Figure 9, it was found to shrink in all of the fuels and fuel blends. However, the TGA results showed the material absorbed at least a small amount of fuel and the mass fraction of fuel absorbed was proportional to the aromatic content. Taken together, these results show that this material does indeed swell when exposes to the fuels and fuel blends, but the extent of volume swell is more than offset by the extraction of material from the potting compound by the various fuels. Therefore, the extent of volume swell is a convolution of these two effects; the efficiency at which the potting compound absorbs fuel and the efficiency at which the fuel extracts components from the potting compound. Overall the amount of shrinkage in the neat FT, R8, and R8x fuels was small (between 2.3 and 3.5%) and increased as FT > R8 > R8x. However, the differences between the 50% fuel blends were quite small; between 1.5% and 1.7%. The GC-MS analysis showed that the polysulfide potting compound exhibited a high degree of selectivity towards the aromatics present in the fuels and fuel blends resulting in a response to the fuels that showed a strong correlation with aromatic content.

Overall Results

A broad overview of the results presented above for the individual materials exposed to the various fuels and fuel blends shows that in general the behavior observed in the FT, R8, and R8x blends are similar. However, if the results are closely examined, it appears that the volume swell observed in R8 is similar to that of the FT more often than the R8x, and the volume swell observed in the R8x is more often slightly less than what is found in the FT, and this general observation is borne out by a relatively simple statistical treatment of the data. Specifically, if the volume swell of the FT and R8 and the FT and R8x are treated as paired differences and the sign of the difference is considered (whether the volume swell was greater than or less than the FT without considering the magnitude of the difference) it can be shown that the overall behavior of the R8 is indeed similar to that of the FT while the overall behavior of the R8x shows a volume swell that is slightly less than the FT. Specifically, considering all of the volume swell results for the neat FT, R8, and R8x it can be shown that the R8 exhibits volume swell that is greater than that observed for the FT for 15 of the 23 materials (65%). Similarly, it was found that R8x exhibits volume swell that is greater than that observed for the FT for only 4 of the 23 materials (17%). With regard to the 50% fuel blends the differences become somewhat smaller with 57% of the materials aged in R8 showing volume swell that is greater than FT and 43% of the materials aged in R8x exhibiting greater volume swell than the FT. A more rigorous statistical analysis was also performed using a least-square linear fit of the data in the form of the volume swell versus the fuel blending ratio. This approach has the advantage that it uses all of the available data and is less sensitive to the uncertainty associated with the individual tabulated point values. This analysis shows that when exposed to the neat fuels 65% of the materials aged in the R8 showed volume swell that was greater than that found in the FT fuel and 17% of the materials aged in the R8x showed greater volume swell as compared to the FT (essentially the same results as found from using the tabular data). In the 50% fuel blends 57% of the materials aged in the R8 showed volume swell that was greater than that found in the FT fuel and 26% of the materials aged in the R8x showed greater volume swell as compared to the FT. This indicates that with respect to the overall behavior of polymeric materials aged in these fuels the behavior of R8 will be very similar to that of the FT. In contrast, polymeric materials exposed to R8x will on-average exhibit volume swell that is slightly less than what is found in FT fuel. The experimental data indicates the absolute value of the differences will be small, particularly in the 50% fuel blends, but the statistical analysis shows that although the difference are small, they are real and measurable.

Conclusions

Based on the analysis of the volume swell, mass fraction of fuel absorbed, and analysis of the fuel absorbed the overall compatibility of R8 and R8x with polymeric fuel system materials should be comparable to that of FT. Overall, it is anticipated that the volume swell character of fuel blends based on R8 will be similar to those based on FT, while fuel blends based on R8x may show volume swell that is slightly less than fuel blends involving FT fuels.

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Table 1: Fuels Used in this Study

POSF	Aromatics	Description
4751	18.8%	JP8
4909	0.0%	FT + JP8 Additives
5480	1.0%	R8 + JP8 Additives
5644	9.4%	50% 4909 in 4751
5645	9.9%	50% 5480 in 4751
5646	0.5%	R8x + JP8 Additives
5647	9.7%	50% 5646 in 4751

Table 2: Polymeric Materials Used in this Study

Description	Material	Sample ID
O-ring	Nitrile	N0602
O-ring	Fluorosilicone	L1120
O-ring	Low Temperature Fluorocarbon	V0835
O-ring	Fluorocarbon	V1226
Hose (Aerial)	Acrylic Nitrile	AC-603-01
Hose (Ground)	Epichloro-hydrin	EC-614-01
Bladder (Inner Liner)	Nitrile	EF 51956
Bladder (Inner Liner)	Polyurethane	EF 5904 C
Bladder (Self-Sealing)	Nitrile	MIL-T-5578
Sealant	Polysulfide Dichromate Cured	PR 1422
Sealant	Polysulfide Manganese Cured	PR 1440
Sealant	Polysulfide Lightweight	PR 1776
Sealant	Polythioether	PR 1828
Sealant	Polyurethane	PR 2911
Sealant	Fluorosilicone	Q4-2817
Sealant (Groove Injection)	Polysulfide	PR 705
Sealant (Groove Injection)	Fluorosilicone	Q4-2805
Film	Teflon	Teflon
Film	Kapton	Kapton
Film	Nylon	Nylon
Film	Polyethylene	Polyethylene
Foam	Polyurethane	MIL-PRF-87260
Potting Compound	Polysulfide	CS 3100

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Table 3: Summary of the Volume Swell of the O-ring Materials

Material	Description	Volume Swell, %v/v						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
N0602	Nitrile Rubber	12.28	1.29	6.56	1.72	6.66	1.13	6.60
L1120	Fluorosilicone	6.72	6.31	7.24	5.85	6.49	5.44	7.50
V0835	Fluorocarbon	0.70	0.64	0.75	0.75	0.65	0.44	0.55
V1226	Fluorocarbon	0.27	0.26	0.20	0.34	0.18	0.07	0.11

Table 4: Summary of the Mass Fraction of Fuel Absorbed by the O-ring Materials

Material	Description	Fuel Absorbed, %m/m						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
N0602	Nitrile Rubber	14.95	6.73	10.91	6.88	10.89	6.89	10.98
L1120	Fluorosilicone	3.97	3.19	3.59	3.58	3.00	3.50	3.20
V0835	Fluorocarbon	1.37	1.35	1.37	1.25	1.39	0.99	1.20
V1226	Fluorocarbon	0.35	0.34	0.27	0.36	0.34	0.21	0.23

Table 5: Summary of the Aromatic Partition Coefficients for the O-ring Materials

Material	Description	Polymer-Fuel Partition Coefficients, Aromatics, kpf						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
N0602	Nitrile Rubber	0.420	n.a.	0.419	0.398	0.429	0.381	0.393
L1120	Fluorosilicone	0.131	n.a.	0.132	0.119	0.123	0.111	0.131
V0835	Fluorocarbon	0.091	n.a.	0.103	0.116	0.097	0.109	0.109
V1226	Fluorocarbon	0.075	n.a.	0.081	0.059	0.075	0.052	0.080

Table 6: Summary of the Alkane Partition Coefficients for the O-ring Materials

Material	Description	Polymer-Fuel Partition Coefficients, Alkanes, kpf						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
N0602	Nitrile Rubber	0.135	0.103	0.113	0.102	0.113	0.101	0.110
L1120	Fluorosilicone	0.069	0.057	0.067	0.060	0.061	0.062	0.066
V0835	Fluorocarbon	0.014	0.015	0.015	0.016	0.014	0.011	0.016
V1226	Fluorocarbon	0.008	0.009	0.009	0.009	0.008	0.006	0.008

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Table 7: Summary of the Volume Swell of the Liner and Hose Materials

Material	Description	Volume Swell, %v/v						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
AC-603-01	Acrylic Nitrile	-0.88	-10.63	-6.61	-9.19	-6.83	-9.41	-5.72
EC-614-01	Epichloro-hydrin	2.52	-1.47	0.60	-1.14	0.46	-1.99	-0.24
EF 51956	Nitrile Rubber	0.97	-0.49	0.10	-0.61	0.18	-0.54	0.39
EF 5904C	Polyurethane	19.38	7.68	13.08	7.52	13.18	6.70	13.02
MIL-T-5578	Nitrile Rubber	592	392	438	351	499	373	431

Table 8: Summary of the Mass Fraction of Fuel Absorbed by the Liner and Hose Materials

Material	Description	Fuel Absorbed, %m/m						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
AC-603-01	Acrylic Nitrile	15.71	7.54	11.31	7.50	11.53	7.23	11.55
EC-614-01	Epichloro-hydrin	6.24	2.91	4.46	2.88	3.90	2.06	4.18
EF 51956	Nitrile Rubber	5.17	1.42	3.10	1.91	2.93	1.53	3.00
EF 5904C	Polyurethane	15.02	5.77	9.94	5.84	10.10	4.98	9.84
MIL-T-5578	Nitrile	*	*	*	*	*	*	*

*Samples not suitable for TGA.

Table 9: Summary of the Aromatic Partition Coefficients for the Liner and Hose Materials

Material	Description	Polymer-Fuel Partition Coefficients, Aromatics, kpf						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
AC-603-01	Acrylic Nitrile	0.43	n.a.	0.47	0.44	0.48	0.44	0.47
EC-614-01	Epichloro-hydrin	0.29	n.a.	0.29	0.28	0.30	0.27	0.30
EF 51956	Nitrile Rubber	0.34	n.a.	0.35	0.36	0.33	0.33	0.34
EF 5904C	Polyurethane	0.55	n.a.	0.52	0.47	0.54	0.49	0.55
MIL-T-5578	Nitrile	*	n.a.	*	*	*	*	*

*Samples not suitable for GC-MS analysis.

Table 10: Summary of the Alkane Partition Coefficients for the Liner and Hose Materials

Material	Description	Polymer-Fuel Partition Coefficients, Alkanes, kpf						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
AC-603-01	Acrylic Nitrile	0.14	0.12	0.13	0.11	0.13	0.12	0.13
EC-614-01	Epichloro-hydrin	0.05	0.04	0.04	0.04	0.04	0.04	0.04
EF 51956	Nitrile Rubber	0.06	0.05	0.05	0.05	0.05	0.05	0.05
EF 5904C	Polyurethane	0.12	0.09	0.09	0.09	0.10	0.09	0.10
MIL-T-5578	Nitrile	*	*	*	*	*	*	*

*Samples not suitable for GC-MS analysis.

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Table 11: Summary of the Volume Swell of the Sealant Materials

Material	Description	Volume Swell, %v/v						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
PR 1422	Polysulfide	3.46	0.29	1.64	0.56	1.46	-0.44	1.13
PR 1440	Polysulfide	0.41	-1.84	-1.24	-1.53	-0.72	-2.42	-1.17
PR 1776	Polysulfide	0.58	-1.81	-0.60	-1.12	0.04	-1.85	-0.82
PR 1828	Polythioether	4.62	0.82	2.57	0.84	2.84	0.10	2.19
PR 2911	Polyurethane	5.80	1.11	3.35	1.28	3.46	0.35	3.34
Q4-2817	Fluorosilicone	-0.93	-1.63	-1.20	-1.38	-1.18	-1.70	-1.07
PR 705	Polysulfide	4.35	1.92	2.27	1.26	2.41	0.80	2.72
Q4-2805	Fluorosilicone	4.25	2.20	1.59	0.98	0.13	0.44	-1.30

Table 12: Summary of the Mass Fraction of Fuel Absorbed by the Sealant Materials

Material	Description	Fuel Absorbed, %m/m						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
PR 1422	Polysulfide	3.66	2.09	3.13	2.37	3.27	1.51	2.81
PR 1440	Polysulfide	2.60	1.35	2.30	1.30	2.16	0.90	1.77
PR 1776	Polysulfide	3.77	2.30	3.03	2.50	3.23	1.97	3.09
PR 1828	Polythioether	4.44	1.54	2.65	1.76	3.08	1.05	2.83
PR 2911	Polyurethane	7.12	3.20	4.28	2.51	5.37	2.46	5.03
Q4-2817	Fluorosilicone	2.13	0.97	1.79	1.38	1.78	0.66	1.79
PR 705	Polysulfide	4.15	1.61	2.27	0.94	0.87	3.07	2.42
Q4-2805	Fluorosilicone	3.49	2.27	3.19	2.43	2.97	2.73	2.82

Table 13: Summary of the Aromatic Partition Coefficients for the Sealant Materials

Material	Description	Polymer-Fuel Partition Coefficients, Aromatics, kpf						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
PR 1422	Polysulfide	0.24	0.00	0.23	0.14	0.24	0.14	0.24
PR 1440	Polysulfide	0.21	0.00	0.22	0.19	0.20	0.12	0.21
PR 1776	Polysulfide	0.23	0.00	0.23	0.13	0.21	0.11	0.20
PR 1828	Polythioether	0.24	0.00	0.27	0.22	0.26	0.22	0.26
PR 2911	Polyurethane	0.36	0.00	0.34	0.31	0.32	0.28	0.34
Q4-2817	Fluorosilicone	0.12	0.00	0.13	0.11	0.12	0.10	0.12
PR 705	Polysulfide	0.31	0.00	0.29	0.25	0.27	0.25	0.28
Q4-2805	Fluorosilicone	0.21	0.00	0.19	0.21	0.20	0.20	0.19

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Table 14: Summary of the Alkane Partition Coefficients for the Sealant Materials

Material	Description	Polymer-Fuel Partition Coefficients, Alkanes, kpf						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
PR 1422	Polysulfide	0.05	0.04	0.04	0.03	0.04	0.02	0.04
PR 1440	Polysulfide	0.03	0.02	0.03	0.03	0.02	0.02	0.02
PR 1776	Polysulfide	0.05	0.04	0.05	0.04	0.04	0.04	0.04
PR 1828	Polythioether	0.03	0.03	0.03	0.02	0.03	0.02	0.02
PR 2911	Polyurethane	0.06	0.05	0.05	0.05	0.05	0.04	0.05
Q4-2817	Fluorosilicone	0.04	0.04	0.03	0.03	0.03	0.03	0.03
PR 705	Polysulfide	0.17	0.09	0.08	0.08	0.11	0.10	0.13
Q4-2805	Fluorosilicone	0.15	0.13	0.12	0.12	0.13	0.10	0.12

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Table 15: Summary of the Volume Swell of the Film Materials

Material	Description	Volume Swell, %v/v						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
Teflon	Teflon	0.13	0.16	0.00	0.20	0.03	0.19	0.00
Kapton	Kapton	-0.02	0.23	0.00	-0.05	-0.06	0.16	0.16
Nylon	Nylon	0.23	0.11	0.35	0.20	0.34	0.19	0.06
Polyethylene	Polyethylene	2.27	1.42	1.76	1.65	1.94	1.42	1.71

Table 16: Summary of the Mass Fraction of Fuel Absorbed by the Film Materials

Material	Description	Fuel Absorbed, %m/m						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
Teflon	Teflon	*	*	*	*	*	*	*
Kapton	Kapton	*	*	*	*	*	*	*
Nylon	Nylon	*	*	*	*	*	*	*
Polyethylene	Polyethylene	4.07	2.98	3.32	2.89	3.26	2.50	3.25

*Below detection limit

Table 17: Summary of the Aromatic Partition Coefficients for the Film Materials

Material	Description	Polymer-Fuel Partition Coefficients, Aromatics, kpf						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
Teflon	Teflon	0.008	n.a.	0.009	0.008	0.008	0.005	0.008
Kapton	Kapton	0.006	n.a.	*	*	*	*	*
Nylon	Nylon	0.002	n.a.	0.003	*	0.004	*	0.003
Polyethylene	Polyethylene	0.124	n.a.	0.122	0.126	0.132	0.124	0.119

*Below detection limit

Table 18: Summary of the Alkane Partition Coefficients for the Film Materials

Material	Description	Polymer-Fuel Partition Coefficients, Alkanes, kpf						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
Teflon	Teflon	0.005	0.010	0.007	0.008	0.005	0.005	0.005
Kapton	Kapton	0.007	0.008	*	0.007	*	0.012	0.009
Nylon	Nylon	0.004	0.004	0.006	0.004	0.006	0.002	0.005
Polyethylene	Polyethylene	0.086	0.082	0.080	0.086	0.086	0.087	0.081

*Below detection limit

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Table 19: Summary of the Volume Swell of the Miscellaneous Materials

Material	Description	Volume Swell, %v/v						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
Foam	Polyurethane	2.45	2.73	8.08	4.45	5.00	5.04	5.94
Potting	Polysulfide	-0.43	-2.30	-1.69	-2.98	-1.50	-3.49	-1.47

Table 20: Summary of the Mass Fraction of Fuel Absorbed by the Miscellaneous Materials

Material	Description	Fuel Absorbed, %m/m						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
Foam	Polyurethane	13.33	4.15	8.53	6.28	11.07	2.72	8.05
Potting	Polysulfide	2.30	0.94	1.31	1.23	1.41	0.44	1.14

Table 21: Summary of the Aromatic Partition Coefficients for the Miscellaneous Materials

Material	Description	Polymer-Fuel Partition Coefficients, Aromatics, kpf						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
Foam	Polyurethane	0.53	n.a.	0.53	0.22	0.48	0.52	0.46
Potting	Polysulfide	0.32	n.a.	0.33	0.17	0.33	0.20	0.34

Table 22: Summary of the Alkane Partition Coefficients for the Miscellaneous Materials

Material	Description	Polymer-Fuel Partition Coefficients, Alkanes, kpf						
		4751 JP8	4909 FT	5644 FT + JP8	5480 R8	5645 R8 + JP8	5646 R8X	5647 R8X + JP8
Foam	Polyurethane	0.34	0.25	0.28	0.19	0.26	0.15	0.22
Potting	Polysulfide	0.03	0.02	0.02	0.02	0.02	0.02	0.03

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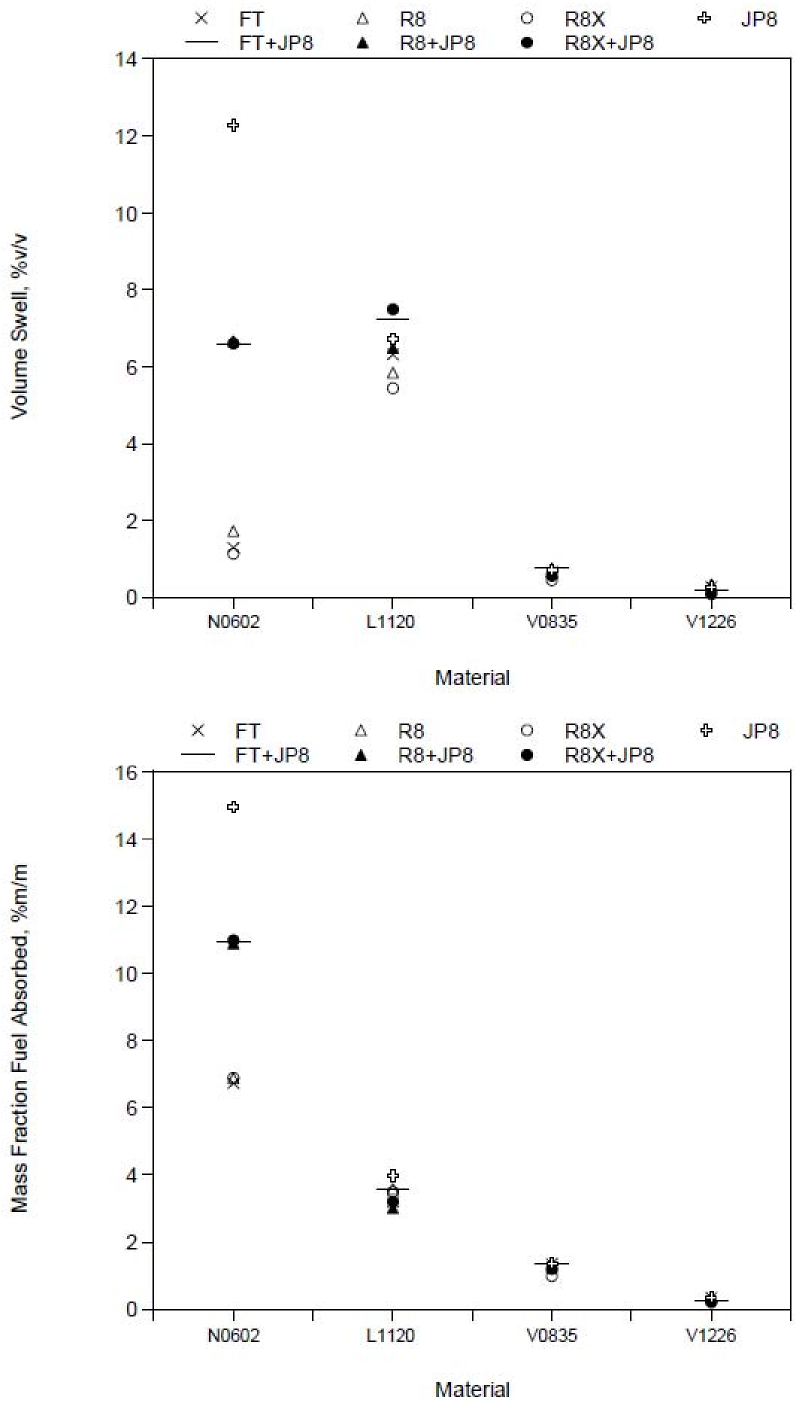

Figure 1. Summary of the volume swell (top) and mass fraction of fuel absorbed (bottom) for the O-ring materials.

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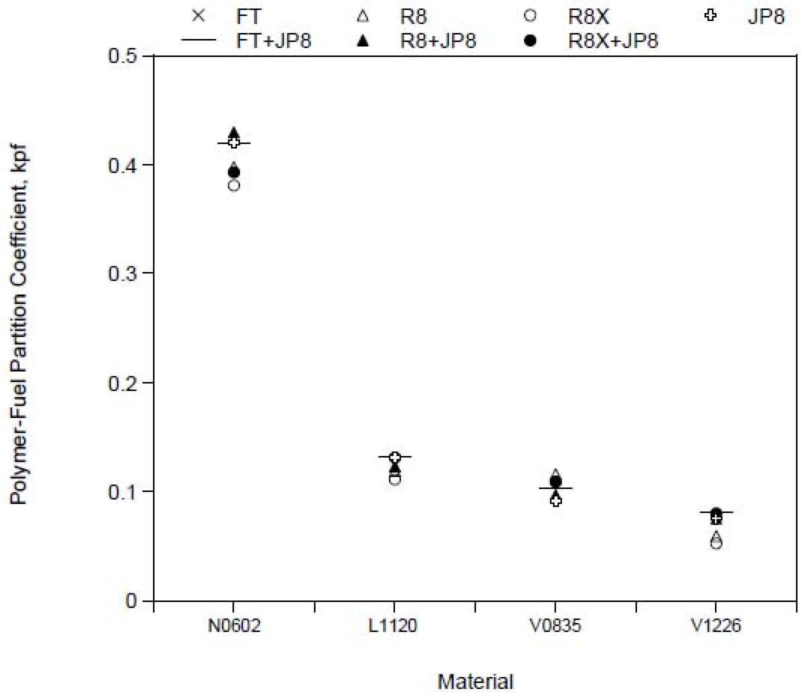

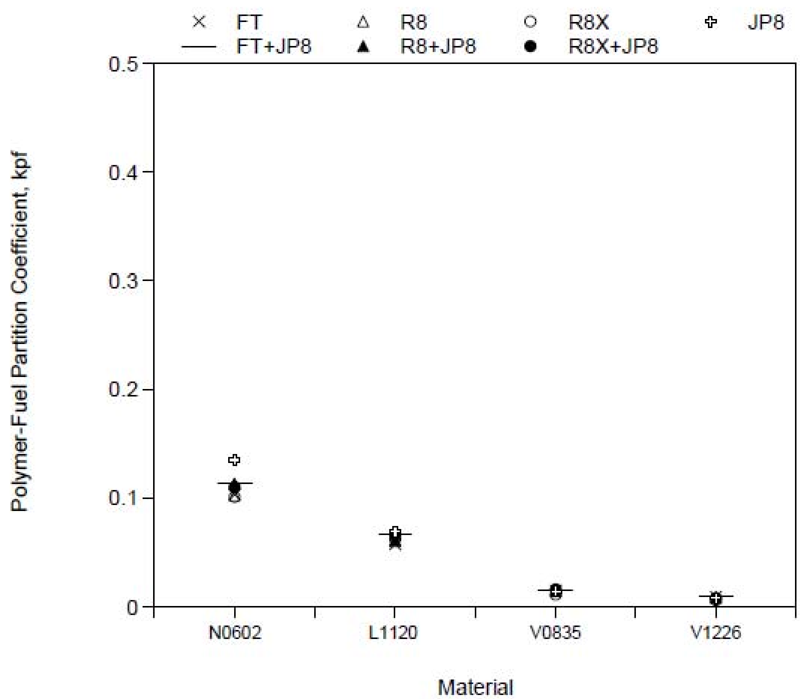

Figure 2. Summary of the polymer-fuel partition coefficients for the aromatics (top) and alkanes (bottom) absorbed by the O-ring materials.

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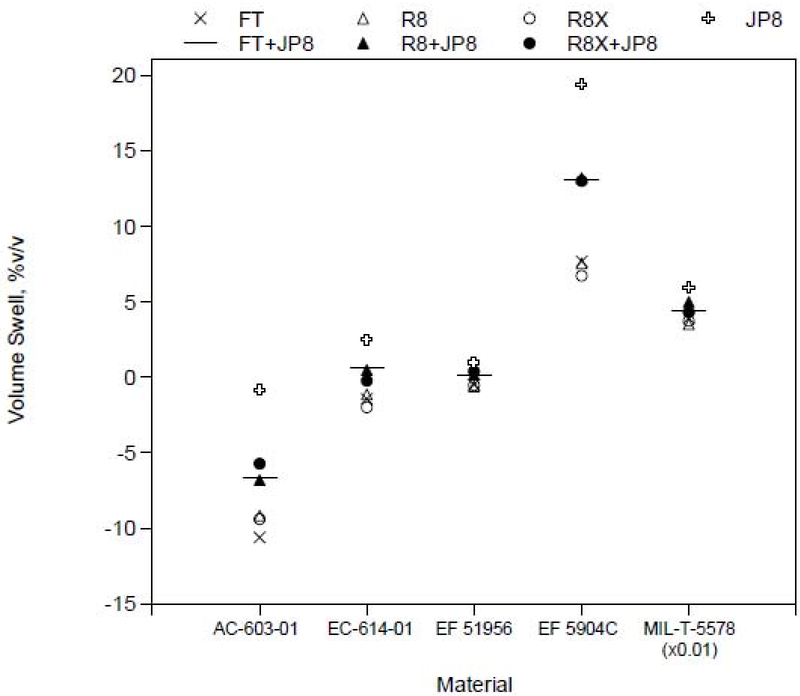

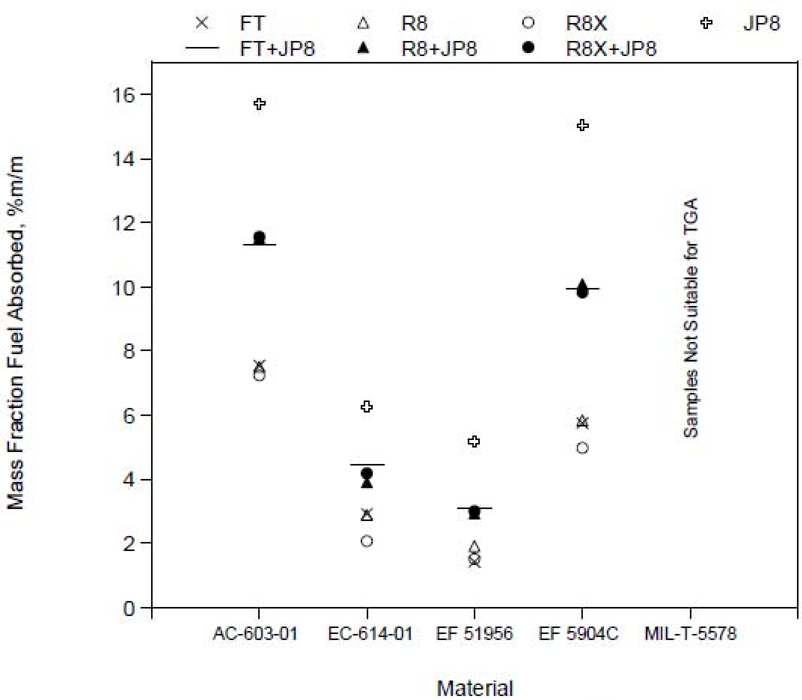

Figure 3. Summary of the volume swell (top) and mass fraction of fuel absorbed (bottom) for the liner and hose materials.

APPENDIX F
Volume Swell of Selected Polymeric Materials in POSF 4751, 4909, 5480, and 5646

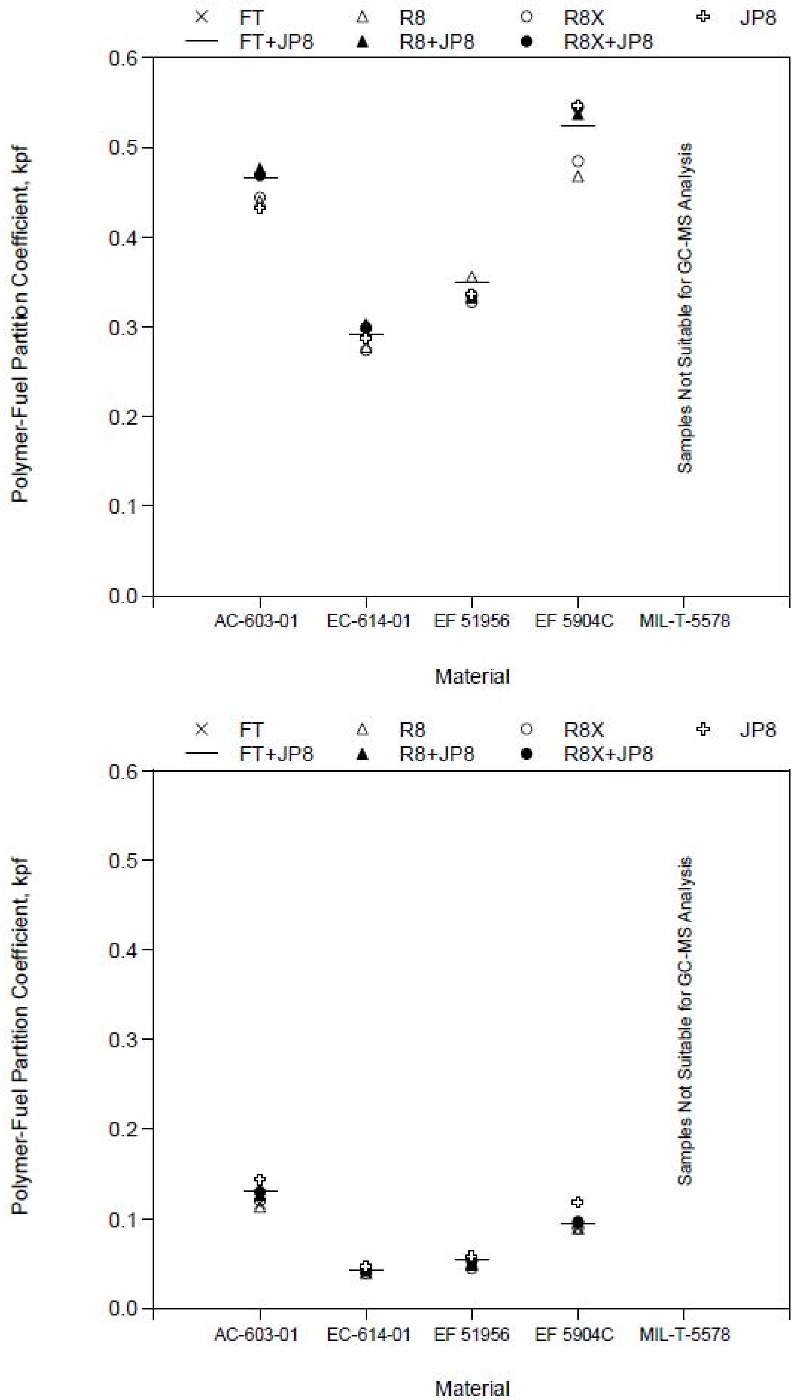

Figure 4. Summary of the polymer-fuel partition coefficients for the aromatics (top) and alkanes (bottom) absorbed by the liner and hose materials.

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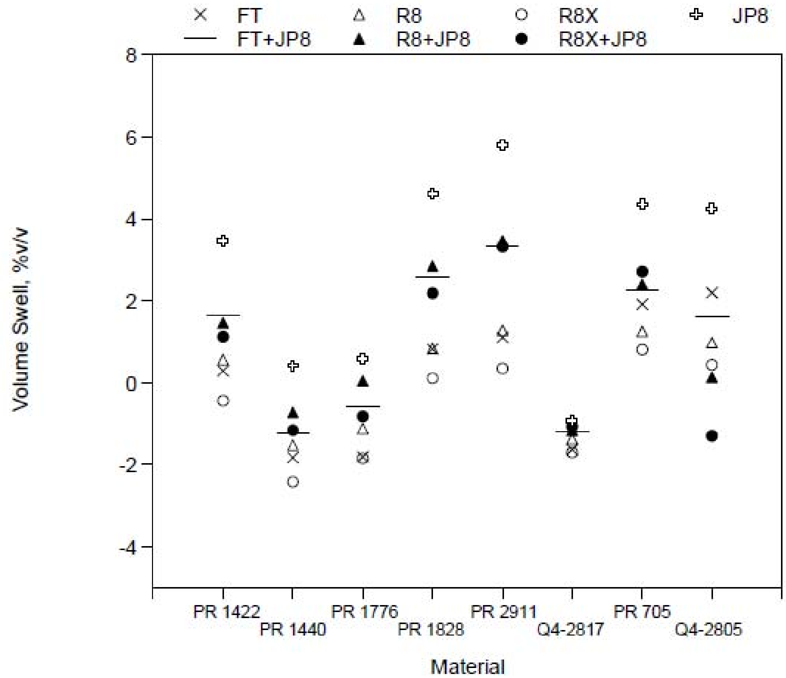
APPENDIX F
Volume Swell of Selected Polymeric Materials in POSF 4751, 4909, 5480, and 5646



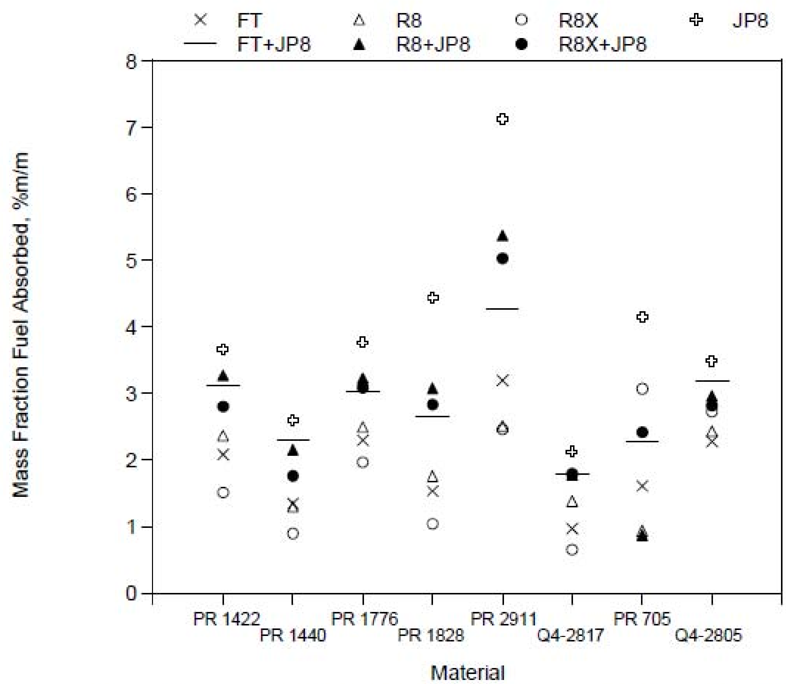


Figure 5. Summary of the volume swell (top) and mass fraction of fuel absorbed (bottom) for the sealant materials.

APPENDIX F
Volume Swell of Selected Polymeric Materials in POSF 4751, 4909, 5480, and 5646

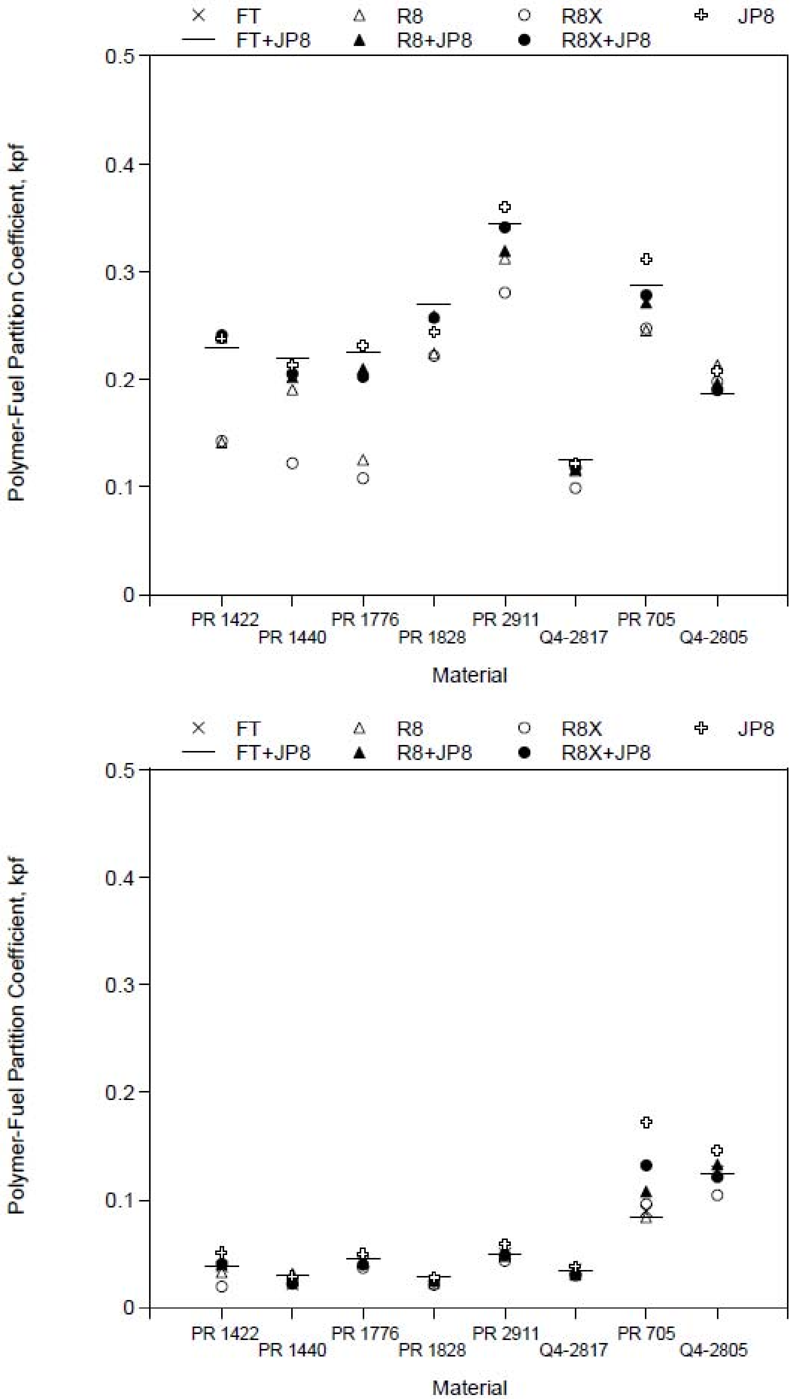


Figure 6. Summary of the polymer-fuel partition coefficients for the aromatics (top) and alkanes (bottom) absorbed by the sealant materials.

APPENDIX F
Volume Swell of Selected Polymeric Materials in POSF 4751, 4909, 5480, and 5646

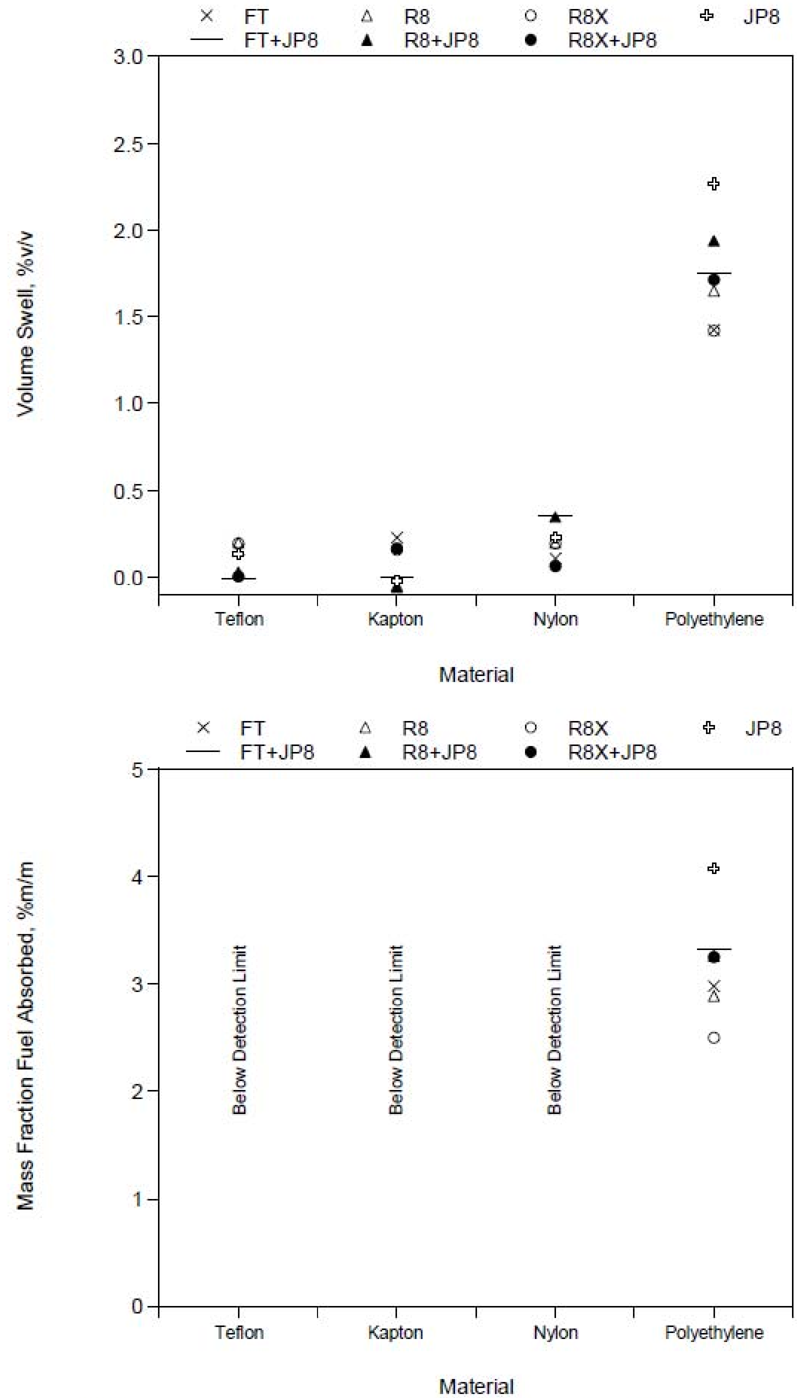


Figure 7. Summary of the volume swell (top) and mass fraction of fuel absorbed (bottom) for the film materials.

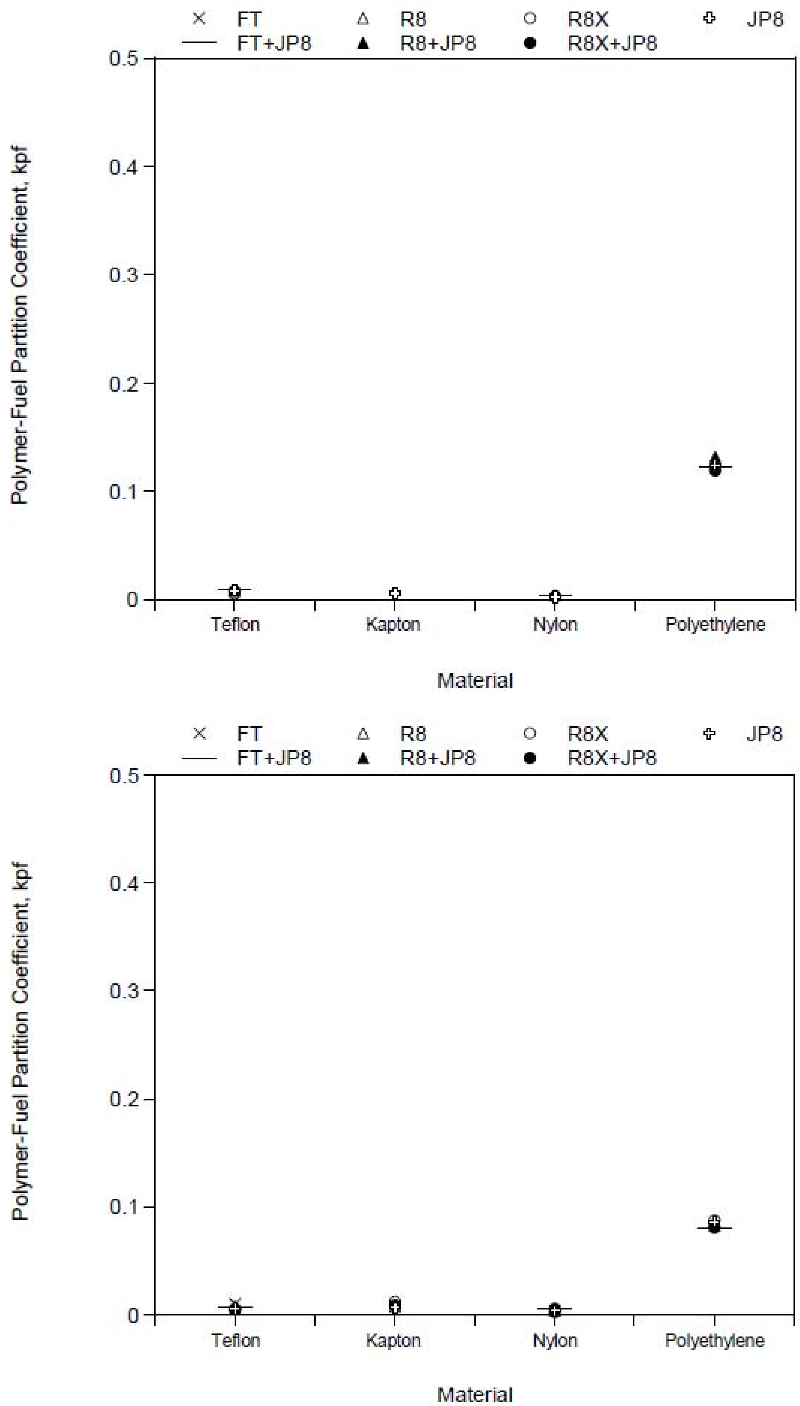


Figure 8. Summary of the polymer-fuel partition coefficients for the aromatics (top) and alkanes (bottom) absorbed by the film materials.

APPENDIX F
Volume Swell of Selected Polymeric Materials in POSF 4751, 4909, 5480, and 5646

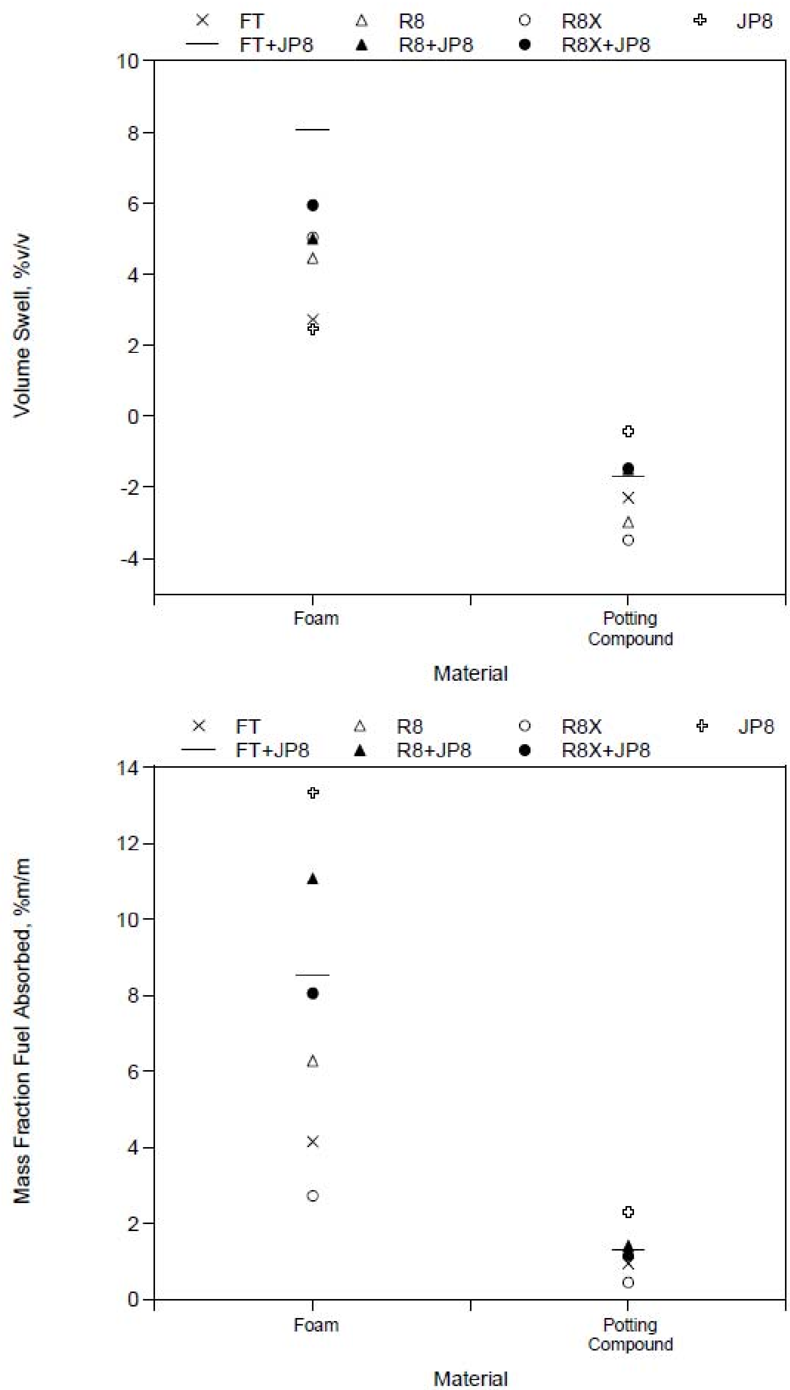


Figure 9. Summary of the volume swell (top) and mass fraction of fuel absorbed (bottom) for the miscellaneous materials.

APPENDIX F
Volume Swell of Selected Polymeric Materials in POSF 4751, 4909, 5480, and 5646

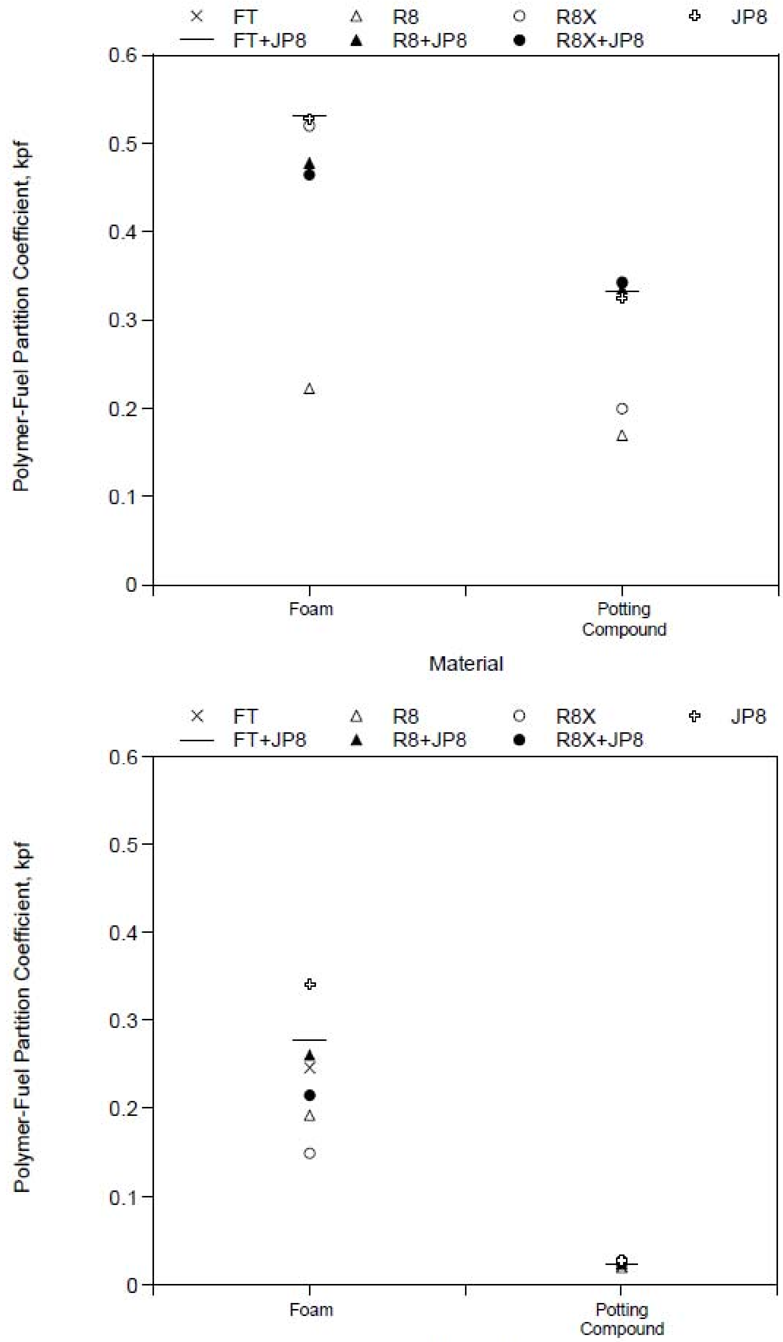


Figure 10. Summary of the polymer-fuel partition coefficients for the aromatics (top) and alkanes (bottom) absorbed by the miscellaneous materials.

APPENDIX G

Preliminary Evaluation of Aerosol and Gaseous Emissions of Neat R-8 and a 50/50 Volume Percent Blend of R-8/JP-8 Compared to Specification JP-8

Christopher D. Klingshirn, University of Dayton Research Institute

Abstract

The gaseous and particulate emission characteristics of a research fuel received from Syntroleum (designated R-8 and assigned internal code 5469) was compared to a specification JP-8 (assigned 3773) using the T63-A-700 turbo shaft engine located at the USAF/AFRL WPAFB Propulsion Directorate. Gaseous and particulate matter emissions of novel fuel candidates are needed to preliminarily assess environmental impact compared to fuels currently in use. The R-8 fuel was evaluated both neat and as a 50/50 volume percent blend with JP-8 at idle and cruise engine conditions to investigate any difference in emissions properties at varying power settings. All emission characteristics were compared to baseline operation with neat JP-8. Properties evaluated included aerosol emissions (total particle count and particle size distribution), particulate matter (PM) mass and composition, smoke number and gaseous emissions. The results presented within this draft report indicate significant reductions in the aerosol and PM emissions during operation with neat and blended R-8 fuels with comparable gaseous emissions to operation with JP-8.

Instrumentation and Sampling System

Gaseous and particulate emissions were extracted from the exhaust using probes located at the engine exit plane. A total of 3 probes were used during the sample collection. A particulate probe that allows dilution of the sample directly at the probe tip with nitrogen was used for characterization of the aerosol emissions. Dilution of sample is necessary to prevent saturation of the instrumentation and to quench further reaction/condensation of the particles. Undiluted samples were collected for measurement of the smoke number and gaseous emissions, and analysis of particulate soot sample composition and mass. All samples were transported 75 feet via heated lines (75°C for diluted; 150°C for undiluted) to instrumentation located in the TERTEL (Turbine Engine Research Transportable Emissions Laboratory) adjacent to the T-63 engine cell.

Particle size distributions (PSD) were quantified using a TSI 3936 SMPS (scanning mobility particle sizer) consisting of a 3080 ESC (electrostatic classifier), 3085 nano-DMA (differential mobility analyzer) and a 3025A CPC (condensation particle counter). The particle count (particles per volume of sample gas) was obtained using a TSI 3022A CPC. Gaseous emissions were measured using an FTIR based MKS Multigas 2030 analyzer. Total PM mass emissions were measured using an R&P 1105 Tapered Element Oscillating Microbalance (TEOM) while filter samples were collected using an in house fabricated smoke sampler. Off-line analysis of the filter samples included measurement of engine smoke number (paper filters) and estimation of PM mass and volatile composition (quartz filters).

Results & Discussion

<u>Aerosol Emissions</u>

The aerosol emissions were characterized for the total particle number (particle count) and particle size distribution. The particle count was corrected for dilution ratio and normalized to the fuel usage while the size distributions were only corrected for dilution. The total particle number emissions are shown in Figure G-1, with percent reductions displayed in Table G-1. As shown, a significant reduction was observed during operation with the R-8 fuel and blend. These reductions are similar to that observed during previous testing with an FT-derived SPK produced by Syntroleum (Corporan et al., 2007). The particle size distributions for testing at both idle and cruise conditions are shown in Figures G-2 and G-3. The reduction in the particle size distributions is consistent with the total particle number trends. The mean particle diameter was reduced relative to neat JP-8 during testing: approximately 10% and 20% at idle and 42% and 44% at cruise for the R-8 blend and neat fuel, respectively. This trend is similar to that observed during testing with S-8.

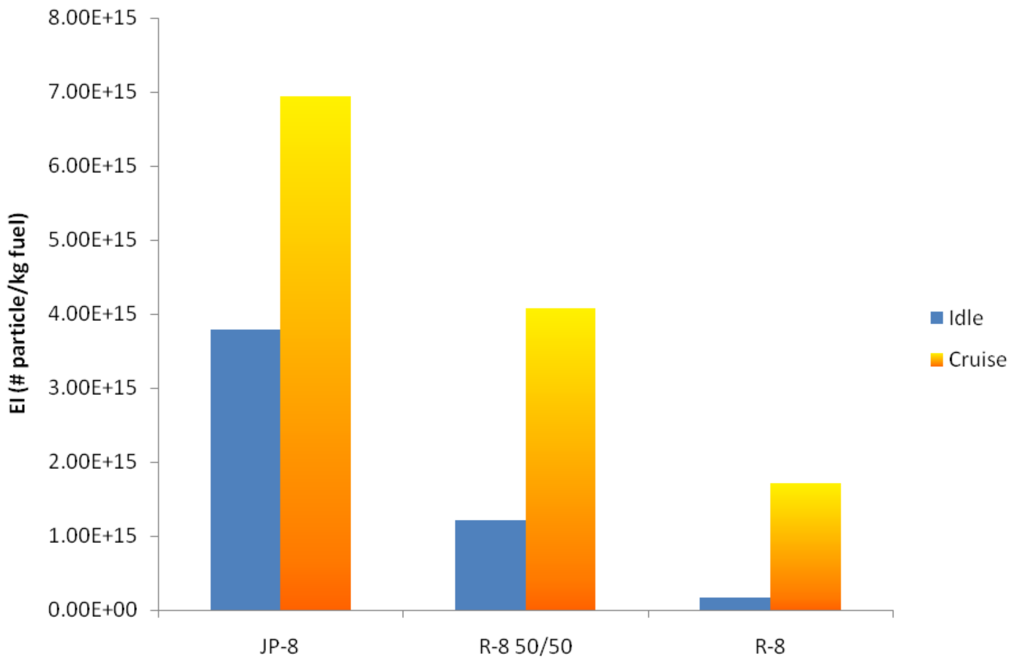


Figure G-1. Total Particle Number Emission Indice (EI) (Particles/kg of Fuel) as a Function of Fuel and Engine Condition

APPENDIX G
Preliminary Evaluation of Aerosol and Gaseous Emissions of Neat R-8 and a 50/50 Volume Percent Blend of R-8/JP-8 Compared to Specification JP-8

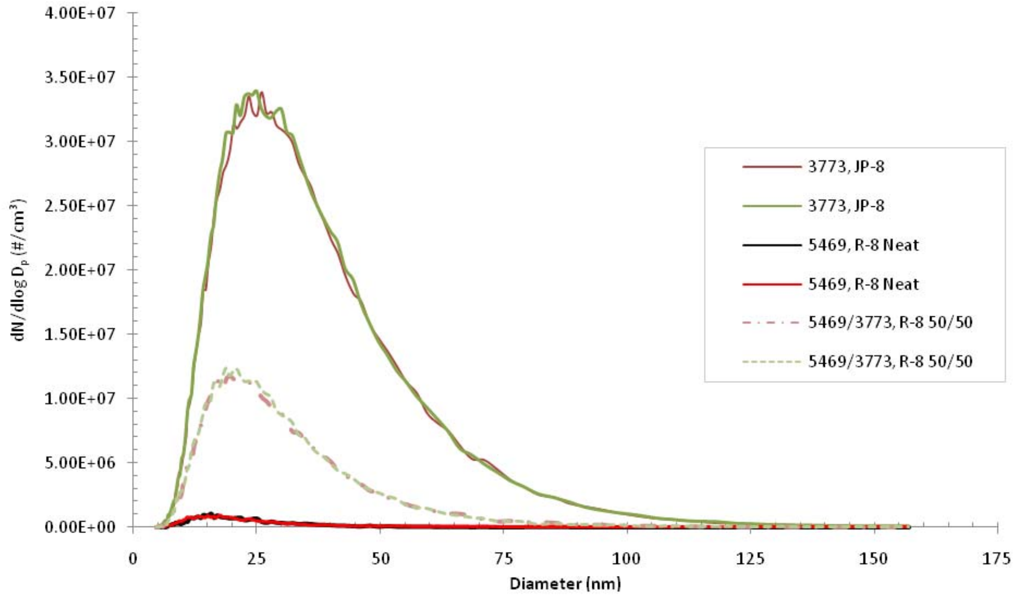


Figure G-2. Corrected Particle Size Distribution as a Function of Fuel at Engine Idle

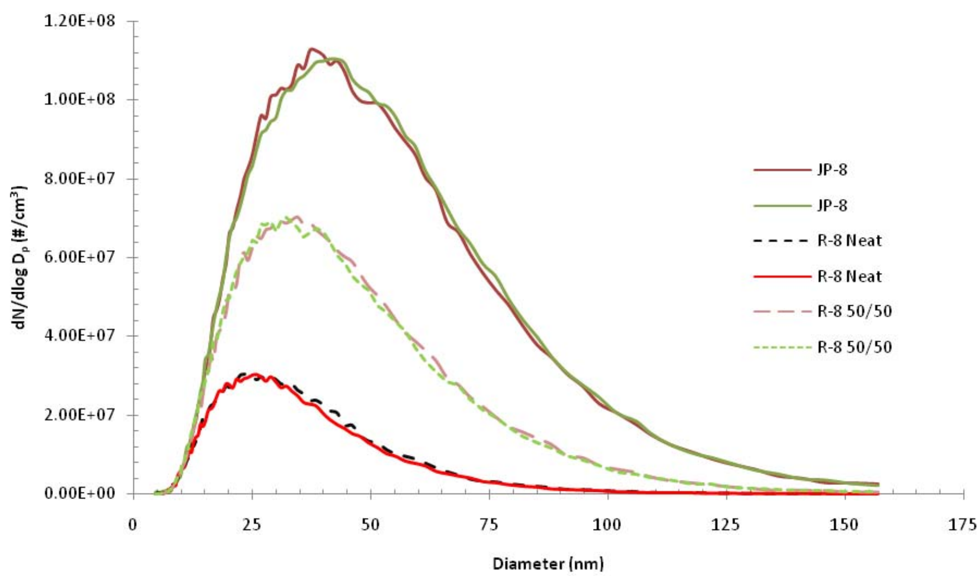


Figure G-3. Corrected Particle Size Distribution as a Function of Fuel at Engine Cruise

APPENDIX G

Preliminary Evaluation of Aerosol and Gaseous Emissions of Neat R-8 and a 50/50 Volume Percent Blend of R-8/JP-8 Compared to Specification JP-8

Table G-1. Percent Reduction in Total Particle Count as a Function of Fuel and Engine Condition

% Reduction Relative to JP-8		
Fuel	**Idle**	**Cruise**
R-8 (50-50)	**68%**	**41%**
R-8	**95%**	**75%**

Particle Matter Mass and Composition

<u>On-Line Mass Measurement</u>

Particulate mass was quantified on-line using a TEOM (Tapered Element Oscillating Microbalance). The mass emissions from testing with JP-8 were observed to decrease by 58% and 90% for the fuel blend and neat R-8 for testing at cruise power. These reductions are consistent with those previously observed during testing with blends of S-8. The idle engine condition mass results are not reported as they were below the sensitivity of the instrument.

<u>Off-Line Mass Measurement and Composition</u>

An undiluted sample volume of 2.0 ft^3 was collected on quartz filters using the smoke machine and analyzed using a LECO multiphase carbon determinator. A temperature-programmed oxidation scheme was used where the carbon deposited on the quartz sample is burned off in the presence of excess oxygen. Carbonaceous compounds which oxidize at lower temperatures (< 325°C) are considered volatile organic species while species that oxidize at higher temperatures are considered elemental carbon. Figure G-4 shows the total carbon mass concentration determined via LECO analysis and Figure G-5 displays the estimated volatile carbon percentage. The samples showed a significant reduction in the measured PM mass emissions with the addition of R-8, which is consistent with the TEOM results. The mass trend was less prevalent at the engine idle condition, which may be due to reduced efficiency of sample collection due to increased volatile percentage (see Figure G-5). As shown in Figure G-5, the volatile percentage of the PM significantly increased with the addition of R-8; this is most likely due to a reduced rate of pyrolysis and PM growth reactions with the addition of the paraffinic R-8 fuel.

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Preliminary Evaluation of Aerosol and Gaseous Emissions of Neat R-8 and a 50/50 Volume Percent Blend of R-8/JP-8 Compared to Specification JP-8

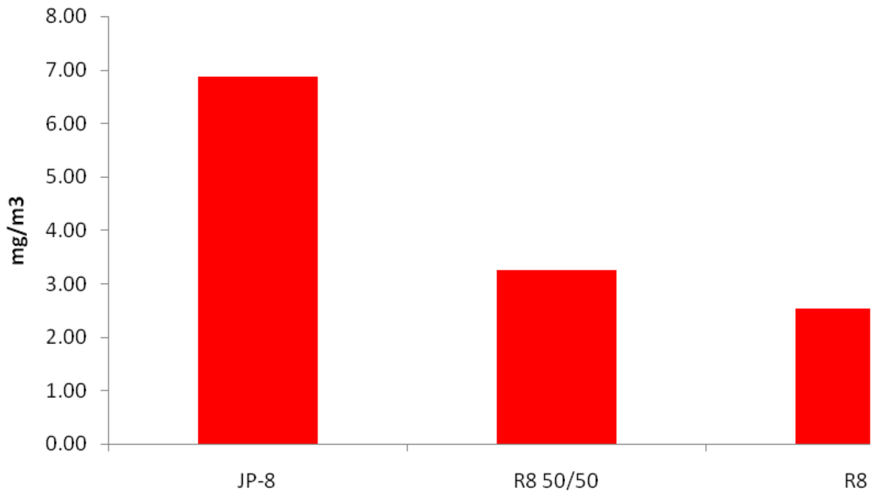

Figure G-4. Total Carbon Mass Concentration From LECO Analysis as a Function of Fuel at Engine Cruise

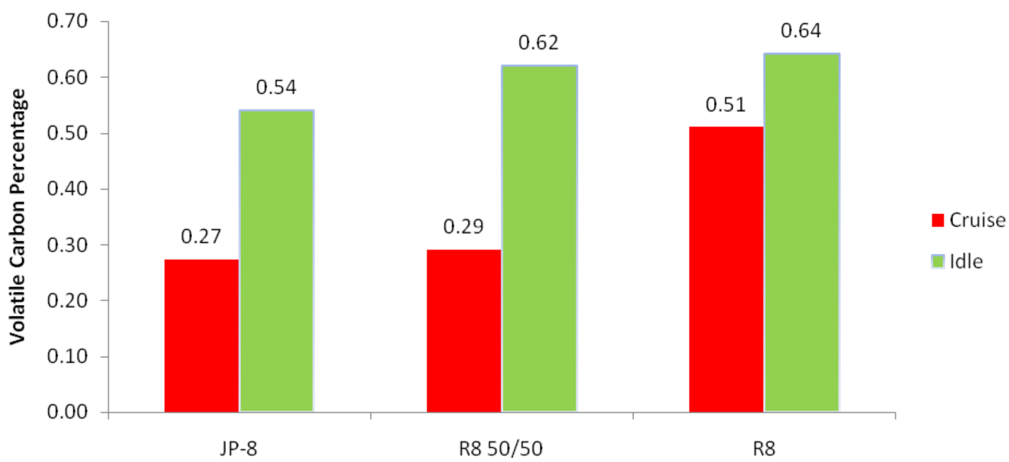

Figure G-5. Average Volatile Carbon Percentage as a Function of Fuel and Engine Condition Using Temperature Programmed Oxidation

APPENDIX G

Preliminary Evaluation of Aerosol and Gaseous Emissions of Neat R-8 and a 50/50 Volume Percent Blend of R-8/JP-8 Compared to Specification JP-8

Smoke Number Results

Smoke number measurements for each engine condition were obtained; this is determined by passing a known volume (0.25 scf) of engine exhaust through a paper filter, and the change in filter optical reflectance is correlated to the quantity of PM. Table G-2 displays the results of the smoke number testing of JP-8, R-8, and R-8 blended fuel. Table G-2 shows a significant reduction of particle emissions and supports the particle number and TEOM data trends. The smoke number for the idle condition was below the detection limits of the smoke meter.

Table G-2. Average Smoke Number Results for Cruise Condition

Fuel	Smoke Number
JP-8	**15**
R-8 (50-50)	**9**
R-8 Neat	**3**

Gaseous Emissions

Gaseous emissions were measured using an FTIR based MKS Multigas 2030 analyzer. Undiluted samples were obtained hot and wet (150°C). Samples were measured at 8 second intervals and averaged over 20 minutes at each engine operating condition. The averages of these selected compounds are reported in Table G-3 and show a slight reduction of carbon monoxide for the R-8 and R-8 blend.

Table G-3. Average Gaseous Emissions as a Function of Fuel and Engine Condition

Fuel	Condition	CO (ppm)	CO_2 (%)
JP-8	Idle	1155	2.1
R-8 (50-50)	Idle	1106	2.1
R-8	Idle	1003	2.1
JP-8	Cruise	271	4
R-8 (50-50)	Cruise	235	4
R-8	Cruise	231	4

APPENDIX G

Preliminary Evaluation of Aerosol and Gaseous Emissions of Neat R-8 and a 50/50 Volume Percent Blend of R-8/JP-8 Compared to Specification JP-8

Summary

Preliminary testing of the emission propensity of an alternatively-derived fuel supplied by Syntroleum (termed R-8) was performed using a T63 turbo shaft helicopter engine. Exhaust samples were collected at the engine exit plane and were analyzed for aerosol, gaseous and PM emissions. Testing with neat R-8 and a 50/50 volume percent R-8/JP-8 fuel blend showed a significant reduction in aerosol and PM emissions; these trends were similar to previous testing with an F-T derived SPK produced by Syntroleum (S-8). Gaseous emissions were minimally impacted, with only slight reductions in carbon monoxide observed. A more detailed overview of this testing will be included in subsequent reporting.

Reference

Corporan, E., DeWitt, M.J., Belovich, V. Pawlik, R., Lynch, A.C., Gord, J.R., and T.R. Meyer, "Emissions Characteristics of a Turbine Engine and Research Combustor Burning a Fischer-Tropsch Jet Fuel," *Energy & Fuels*, 21, pp2615-2626, **2007**.

APPENDIX H
R-8 HRJ Fit-for-Purpose Evaluations
APPENDIX H-1: Southwest Research Institute Report #13283

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February 19, 2010

Michele L. Puterbaugh
UTC Program Manager
Universal Technology Corporation
1270 N. Fairfield Road
Dayton, OH 45432-2600

SUBJECT: Final Report for Southwest Research Institute® Project No. 08.13283.01.001, *"Research of Renewable IPK Alternative Jet Fuel"*

Dear Ms. Puterbaugh:

Southwest Research Institute® (SwRI®) is pleased to inform you that the R-8 material shows every indication of being very suitable as a blending stock for producing aviation turbine fuel. We provided you with this service in response to your original Statement of Work asking that we conduct the following evaluation:

- Conduct of specification testing:
    - Particulates
    - Kinematic viscosity at -20ºC
    - Copper Strip corrosion
    - Aromatic carbon
    - Total sulfur
    - Net heat of combustion per ASTM D 4809
    - Hydrogen content
    - Smoke point
- Thermal Stability
- Product acidity
- Residual gums and residual fats/particulates
- Water separation & small scale filtration
- Additive compatibility
- Lubricity/pumpability

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APPENDIX H

R-8 HRJ Fit-for-Purpose Evaluations

APPENDIX H-1: Southwest Research Institute Report #13283

Following are the results of our testing.

Conduct of Specification Testing

The specification tests were conducted by the methods referenced in MIL-DTL-83133E (or current version at time of testing). Besides running the testing by the methods, we inspected the data in reference to the expected values for these quantities and discuss those results in the following data table.

Table H-1-1. Test Results

Test	Method		AF-6778
Particulates	D5452	mg/L	0.20
Kinematic viscosity at -20ºC	D445	cSt	5.45
Copper Strip corrosion	D130	rating	1A
FIA	D1319		
Aromatics		vol%	0.9
Olefins		vol%	0.8
Saturates		vol%	98.3
Total sulfur	D5453	ppm	0.6
Net heat of combustion	D4809	BTU/lb	18862.7
Hydrogen content	D3701	mass%	15.27
Smoke point	D1322		20
Thermal Stability	D3241	Breakpoint	>340°C
Product acidity	D3242	mg/L	0.003
MSEP	D3948	rating	100
Residual Gums and Fatty Acids			
-Fatty Acids	SwRI/GC		<10ppm
-Residual Gums			
-Neat Particle Count	ISO 4406	Total	71
-Filtered Particle Count	ISO 4406	Total	137
-Existent Gum	D381	mg/dl	1.9
-Reconsituted Particle Count	ISO 4406	Total	1373
Water Separation and Small Scale Filtration	SAE J1488		Pass
Additive Compatibility			Pass
Lubricity/Pumpablity			
- Pump Rig		hours	25
- BOCLE	D5001	mm	0.86
- HFRR	D6079	µm	575

Thermal Stability

We evaluated the relative thermal stability of this proposed fuel by determining its Breakpoint, as defined in Appendix X2 of ASTM D3241. While both the military and commercial specifications set this limit at 260°C, recent studies have shown the median stability to be approximately 285°C. In the case of R-8, the stability far exceeds the requirements for a specification fuel. In a recently concluded ASTM meeting, the Aviation Fuel Subcommittee agreed to set the JFTOT test requirement for Fischer Tropsch derived synthetic paraffinic Kerosenes (FT SPK) at 325°C. R-8 meets this requirement.

Residual Gums and Residual Fats/Particulates

We did the standard particulate evaluation as part of the specification testing, and the results were well within specification requirements. Your additional interest in particulates generated in the residue process called for alternative techniques. We used a modified version of ISO 4406. While this method is primarily intended for hydraulic oil, we have used it in the past for the evaluation of turbine fuels. In doing so, we have routinely seen significant differences between fuels. To evaluate residue generated particulate, we generated the residue using the standard ASTM D381 existent gum tests, reconstituted it into a solvent, and measured the particulate. Before doing this, we will measure the particulate in the neat fuel and after filtration with a 0.45µm filter.

The method provides a cumulative value for all particles 4µm and larger. In our experience with jet fuel in this method, we have routinely seen cumulative values in the thousands. The cumulative value of 71 for the unfiltered fuel is extremely low. It is so low that it appears the shear stress of passing through the filter dislodged slight traces of filter material and resulted in a similar particulate level of 137. As could reasonably be anticipated, reconstituting the residue deposit resulted in a significant increase in particulates. The value, 1373 cumulative, would not be disturbing if measured on a typical refined jet fuel.

There is no standard test for measuring the residual fats in an aviation turbine fuel because fats are not normally expected to be present. There are techniques being developed to allow evaluation of biodiesel contamination in middle distillates, but they are not ready yet. Even if they were ready, it is uncertain how they would respond to the non-esterified acid. Our efforts in this matter showed there were no detectable free fatty acids in the sample. This analysis is reinforced by the results of the BOCLE test. With a WSD of 0.86 mm, it shows there are essentially no fatty acids present.

Water Separation & Small Scale Filtration

Water separation is a critical property for an aviation fuel because there are just so many opportunities for fuel to come into contact with water in the transportation system. From years of experience we have found that for aviation applications, the standard ASTM D3948 Microseparometer test has proven effective for predicting the water separation characteristics of aviation fuel. JP-8, however, is not used solely for aviation purposes. It is also used by the Army for ground vehicles as part of the DOD “Single Fuel Forward” policy.

The evaluation of water separation characteristics for automotive applications is much more complicated than for aviation. Experience has shown that ground vehicles have to deal with a lot more water than do aircraft. To evaluate this issue we used the methodology embodied in SAE J1488. This operation is, in fact, a small-scale filtration system that duplicates the kind of coalescing system one would find on a diesel-powered system. While relatively small in volume, this device works on the same principles as a full-scale filter separator system, and the passing results indicate the R-8 will have no adverse effect on fuel water separation.

Table H-1-2. Filter Separator Test Results

Test Description	SAE J1488	**Test No**	#1
Test Engineer	Gary Bessee	**Filter ID**	Kaydon
Test Fluid	UTC R8 BioFuel	**Test Date**	11/4/2008
Vacuum/ Pressure	Pressure	**Test Temperature, C**	26.6
Test Fluid Flow Rate (lpm)	7.57	**Water Saturation**	58

Fuel/Water Interfacial Tension (mN/m)	
Before	33
MSEP	
Before	100

Sample ID	**Test Time (minutes)**	**Upstream**	**Downstream Water Content (ppm)**		**Pressure Drop (kPa)**	**Water Drained from Test filter (ml)**
1	10	1650	75	17	9.67	5
2	30	1910	46	0	10.98	350
3	50	2790	69	11	11.55	405
4	70	2590	81	23	12.64	470
5	90	1990	78	20	12.99	460
6	110	2190	83	25	13.43	475
7	130	2450	70	12	14.21	500
8	150	2650	76	18	14.4	480
		2277.5				3145

Average Water Content, ppm	2278
Time Weighted Average Water Removal Efficiency(%)	99.4
Total Water from Test Housing(ml)	3235
Water from Cleanup filters(ml)	trace

APPENDIX H
R-8 HRJ Fit-for-Purpose Evaluations
APPENDIX H-1: Southwest Research Institute Report #13283

Additive Compatibility

Additive compatibility is a relatively simple evaluation. We blended in the five standard additives at 4X the maximum allowable concentration (individual samples per additive), divided them, and placed one half in cold storage and one half in hot storage. After 24 hours the samples were evaluated by observation to ensure there were no issues with the physical compatibility of the additives. Now that it passed the basic compatibility testing the next step was to assess additive performance.

Lubricity/Pumpability

Aviation lubricity has been predicted successfully for over two decades by the use of ASTM D5001 Ball On Cylinder Lubricity Evaluation Test. The results on this test exceed the limits for a 50% blend of FT SPK allowed in MIL-DTL-83133F. We also evaluated the R-8 for use in ground vehicles by evaluating the pumpablity of the fuel in the standard 500-hour endurance test program. In preparation we tested the material using the automotive industry preferred D6079 HFRR test. The fuel had a wear scar in excess of the recommended max of 525µm. This suggested the likelihood of poor performance, but it is not a 100% reliable arbiter so the test was performed as planned.

The endurance tests were performed using a motorized pump stand to define the effects of the candidate fuel composition on full-scale fuel injection equipment durability. The test series determined the level of fuel injection system degradation due to wear and failure of the boundary film in candidate fuel. A 500-hour pump operating procedure was utilized. Discussions with Stanadyne Automotive have indicated 500 hours was the duration they utilized to verify pump performance. Manufacturers have previously indicated fuel injectors wear very little on test stands because the injectors are not thermally stressed. However, manufacturers in the past have indicated that with insufficient lubricity fuels, a decrease in fuel injector performance could occur in 500-hours. The test fuel injection system was of Stanadyne design.

As perhaps would be expected from the BOCLE and HFRR results, the R-8 performed poorly. The standard test protocol calls for an extensive report, and that report is included as Annex 1. In short, the test was stopped at 25 hours. The units were not taken to destruction, as it was felt the data on the wear was too valuable to risk to catastrophic failure. As noted in the attached report, this type of problem is often associated with the very hard nature of synthetic paraffinic Kerosenes. The real question will be if the material will respond to blending and additization. Since the R-8 material, in other regards, looks so much like the FT SPKs, which do well blended and additized, we anticipate R-8 will perform likewise.

General Test Remarks

Overall the R-8 looks like a very good SPK candidate, despite the anticipated poor lubricity. This was seen early in the test program, and we have already recommended moving forward with the complete analysis of the Fit for Purpose properties of the R-8 and blends thereof (refer to SwRI Proposal No. 08-48951D, "Fuel Property Tests on R-8 HRJ SPK"). The aviation industry, in general has seen enough data on synthetic Kerosenes from hydroprocessed renewable feedstocks (HRJ SPK) to preliminarily assess that a test program similar to that done for the FT SPKs would be the next step for HRJ SPK like R-8. The R-8 data will provide a valuable link into generating a collective approval for renewable kerosene blend stocks.

Thank you for the opportunity to provide this service. If you have any technical questions please contact George Wilson by e-mail (gwilson@swri.org) or by phone (210-522-2587).

Sincerely,

Approved by:

George R. Wilson, III, Sr. Research Scientist
Fuels, Lubricants, & Fluids Applications

Edwin A. Frame, Manager
Fuels, Lubricants, & Fluids Applications

GRW/rae
r:\working\13283\final_19dec2008.doc
Attachment [63 pages]
cc: J. Klein (AFRL/PRTG)
S. Marty, E. Frame, Record Copy B (SwRI)

APPENDIX H
R-8 HRJ Fit-for-Purpose Evaluations
APPENDIX H-2: Excerpt From Southwest Research Institute Report #14406
Additional R-8 HRJ Fit-for-Purpose Evaluations

Analysis of R-8 HRJ

(1) The purpose of this effort is to evaluate the R-8 HRJ and 50/50 R-8/JP-8 blend for the following properties. Current results for this task are shown in Table H-2-1. Evaluations include:

- Dielectric Constant vs. temperature (-40°C to 80°C)
- E659 Autoignition Temperature
- Trace Materials (metals and organics)
- Minimum Ignition Energy
- Upper/Lower Explosion Limits
- Hot Surface Ignition Temperature
- Fit-For-Purpose tests

Analysis of R-8X HRJ

(2) The purpose of this effort is to evaluate R-8X for selected properties. Current results for this task are shown in Table H-2-2.

APPENDIX H
R-8 HRJ Fit-for-Purpose Evaluations
APPENDIX H-2: Excerpt From Southwest Research Institute Report #14406
Additional R-8 HRJ Fit-for-Purpose Evaluations

Table H-2-1. Results for R-8 HRJ

SwRI Sample Code			CL09-00324	CL09-00325
Test	**Method**	**Units**	**R-8**	**50/50 R-8/Jet-A**
Surface tension	D1331A			
-10ºC		mN/m	26.8	*N/A*
23ºC		mN/m	24.4	*N/A*
40ºC		mN/m	23.0	*N/A*
Freeze Point (manual)	D2386	ºC	-49.0	*N/A*
Hydrocarbon Types by Mass Spec	D2425			
Paraffins		mass%	90.20	*N/A*
Monocycloparaffins		mass%	8.90	*N/A*
Dicycloparaffins		mass%	0.00	*N/A*
Tricycloparaffins		mass%	0.00	*N/A*
Alkylbenzenes		mass%	0.90	*N/A*
Electrical Conductivity vs. SDA Concentration	D2624			
0 mg/L		pS/m	10	0
1 mg/L		pS/m	320	300
2 mg/L		pS/m	580	590
3 mg/L		pS/m	1690	830
4 mg/L		pS/m	3200	1050
Copper by AA	D3237M	ppm	0.013	*N/A*
JFTOT Breakpoint	D3241BP			
Test Temperature		ºC	>340	*N/A*
ASTM Code		rating	>2	*N/A*
Maximum Pressure Drop		mm Hg	0.1	*N/A*
JFTOT deposit thickness	D3241BP			
280ºC		nm	15.52	*N/A*
300ºC		nm	19.26	*N/A*
320ºC		nm	20.77	*N/A*
330ºC		nm	21.67	*N/A*
340ºC		nm	24.36	*N/A*
Acid Number	D3242	mg KOH/g	0.004	*N/A*
Storage Stability - Peroxides @65ºC	D3703			
0 week		mg/kg	3.2	*N/A*
1 week		mg/kg	5.6	*N/A*
2 week		mg/kg	7.2	*N/A*
3 week		mg/kg	1.6	*N/A*
6 week		mg/kg	6.7	*N/A*
Density	D4052			
0ºC		g/mL	0.7742	0.7984

APPENDIX H

R-8 HRJ Fit-for-Purpose Evaluations

APPENDIX H-2: Excerpt From Southwest Research Institute Report #14406

Additional R-8 HRJ Fit-for-Purpose Evaluations

Table H-2-1. Results for R-8 HRJ

SwRI Sample Code			CL09-00324	CL09-00325
Test	**Method**	**Units**	**R-8**	**50/50 R-8/Jet-A**
15ºC		g/mL	0.7632	0.7872
40ºC		g/mL	0.7449	0.7685
60ºC		g/mL	0.7322	0.7564
80ºC		g/mL	0.7182	0.7424
Kinematic Viscosity	D445			
-40ºC		cSt	12.59	11.29
20ºC		cSt	2.30	2.11
40ºC		cSt	1.49	1.45
Nitrogen Content	D4629	mg/kg	0.10	*N/A*
Lubricity (BOCLE) vs. CI/LI Concentration	D5001			
0 mg/L		mm	0.90	*N/A*
5 mg/L		mm	0.59	*N/A*
10 mg/L		mm	0.57	*N/A*
15 mg/L		mm	0.54	*N/A*
20 mg/L		mm	0.54	*N/A*
Vapor Pressure (Triple Expansion)	D6378			
0ºC		psia	0.16	0.22
10ºC		psia	0.20	0.26
20ºC		psia	0.24	0.31
30ºC		psia	0.27	0.36
40ºC		psia	0.32	0.47
50ºC		psia	0.39	0.55
60ºC		psia	0.50	0.69
70ºC		psia	0.65	0.88
80ºC		psia	0.87	1.14
90ºC		psia	1.17	1.51
100ºC		psia	1.58	1.98
110ºC		psia	2.12	2.60
120ºC		psia	2.87	3.45
Carbon/Hydrogen	D5291			
Carbon		%	86.32	*N/A*
Hydrogen		%	14.12	*N/A*
Storage Stability – Potential Gums	D5304			
16 hours		mg/100mL	0.40	*N/A*
Freeze Point	D5972	ºC	-49.1	-57.8
Isothermal Tangent Bulk Modulus, 30ºC	D6793			
0 psi		psi	193859	*N/A*

Table H-2-1. Results for R-8 HRJ

SwRI Sample Code			CL09-00324	CL09-00325
Test	**Method**	**Units**	**R-8**	**50/50 R-8/Jet-A**
1000 psi		psi	203786	*N/A*
2000 psi		psi	213958	*N/A*
3000 psi		psi	224376	*N/A*
4000 psi		psi	235039	*N/A*
5000 psi		psi	245948	*N/A*
6000 psi		psi	257102	*N/A*
7000 psi		psi	268501	*N/A*
8000 psi		psi	280146	*N/A*
9000 psi		psi	292036	*N/A*
10000 psi		psi	304171	*N/A*
Isothermal Tangent Bulk Modulus, 60ºC	D6793			
0 psi		psi	165137	*N/A*
1000 psi		psi	175779	*N/A*
2000 psi		psi	186750	*N/A*
3000 psi		psi	198051	*N/A*
4000 psi		psi	209680	*N/A*
5000 psi		psi	221640	*N/A*
6000 psi		psi	233928	*N/A*
7000 psi		psi	246546	*N/A*
8000 psi		psi	259493	*N/A*
9000 psi		psi	272770	*N/A*
10000 psi		psi	286375	*N/A*
Elemental Analysis	D7111			
Al		ppb	101.00	*N/A*
Ba		ppb	<100	*N/A*
Ca		ppb	<100	*N/A*
Cr		ppb	<100	*N/A*
Cu		ppb	<100	*N/A*
Fe		ppb	<100	*N/A*
Li		ppb	<100	*N/A*
Pb		ppb	<100	*N/A*
Mg		ppb	<100	*N/A*
Mn		ppb	<100	*N/A*
Mo		ppb	<100	*N/A*
Ni		ppb	<100	*N/A*
K		ppm	<1	*N/A*
Na		ppm	1.3	*N/A*

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R-8 HRJ Fit-for-Purpose Evaluations

APPENDIX H-2: Excerpt From Southwest Research Institute Report #14406

Additional R-8 HRJ Fit-for-Purpose Evaluations

Table H-2-1. Results for R-8 HRJ

SwRI Sample Code			CL09-00324	CL09-00325
Test	**Method**	**Units**	**R-8**	**50/50 R-8/Jet-A**
Si		ppb	<100	*N/A*
Ag		ppb	<100	*N/A*
Ti		ppb	<100	*N/A*
V		ppb	<100	*N/A*
Zn		ppb	<100	*N/A*
Distillation	D86			
IBP		ºC	67.8	*N/A*
5%		ºC	150.7	*N/A*
10%		ºC	164.2	*N/A*
15%		ºC	170.3	*N/A*
20%		ºC	176.9	*N/A*
30%		ºC	188.1	*N/A*
40%		ºC	199.4	*N/A*
50%		ºC	210.2	*N/A*
60%		ºC	222.5	*N/A*
70%		ºC	234.8	*N/A*
80%		ºC	247.4	*N/A*
90%		ºC	260.9	*N/A*
95%		ºC	269.1	*N/A*
FBP		ºC	270.9	*N/A*
Residue		%	1.5	*N/A*
Loss		%	1.3	*N/A*
Distillation Slope	D86			
T50-T10		ºC	39.8	*N/A*
T90-T10		ºC	85.3	*N/A*
Calculated Cetane Index	D976	--	67.2	*N/A*
Calculated Cetane Index	D4737 Proc A	--	72.4	*N/A*
Specific Heat	E1269	kJ/kg.K	*See* **Error! Reference source not found.**	*N/A*
Minimum Ignition Energy	E582	mJ	0.63	*N/A*
Autoignition temperature	E659			
Hot Flame Autoignition Temperature		ºC	222	227
Hot Flame Lag Time		seconds	6.0	163.0
Cool Flame Autoignition Temperature		ºC	*N/A*	224
Cool Flame Lag Time		seconds	*N/A*	216.0
Barometric Pressure		mm Hg	740.3	736.4
Reaction Threshold Temperature		ºC	201	213

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R-8 HRJ Fit-for-Purpose Evaluations
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Additional R-8 HRJ Fit-for-Purpose Evaluations

Table H-2-1. Results for R-8 HRJ

SwRI Sample Code			CL09-00324	CL09-00325
Test	**Method**	**Units**	**R-8**	**50/50 R-8/Jet-A**
Upper Explosion Limit (UEL), @150ºC	E681	%	4.3	*N/A*
Lower Explosion Limit (LEL)	E681			
@100ºC		%	0.4	*N/A*
@ 150ºC		%	0.3	*N/A*
Carbonyls, Alcohols, Esters, Phenols				
Alcohols	EPA 8015B	ppm	<5	*N/A*
Carbonyls, Esters	EPA 8260B	ppb	<1	*N/A*
Phenols	EPA 8270C	ppm	<50	*N/A*
Hot surface ignition	FTM 791-6053	ºF	1250	*N/A*
Elastomer Compatibility (O-Ring Tests)	various		*See* **Error! Reference source not found.** *and* **Error! Reference source not found.**	*N/A*
Dielectric Constant 400Hz)	SwRI			
-31.2ºC		--	2.0894	*N/A*
-20.1ºC		--	2.0760	*N/A*
-4ºC		--	2.0562	*N/A*
17.9ºC		--	2.0299	*N/A*
49.2ºC		--	1.9946	*N/A*
81ºC		--	1.9578	*N/A*
Dielectric Constant 400Hz)	SwRI			
-37.9ºC		--	*N/A*	2.1512
-18ºC		--	*N/A*	2.1244
1.2ºC		--	*N/A*	2.0992
20.2ºC		--	*N/A*	2.0743
50.8ºC		--	*N/A*	2.0374
81ºC		--	*N/A*	1.9999
Thermal Conductivity	SwRI			
23.7ºC		W/m.K	***IC***	*N/A*
50.9ºC		W/m.K	***IC***	*N/A*
80ºC		W/m.K	***IC***	*N/A*
Aromatic Content	D5186			
Total Aromatics		mass%	1.0	*N/A*
Mononuclear Aromatics		mass%	0.9	*N/A*
Polynuclear Aromatics		mass%	0.1	*N/A*

Specific Heat Results for R-8 HRJ SPK

SwRI Sample Code	CL09-00324
Temperature (°C)	**Specific Heat (kJ/kg.K)**
-40	1.655
-35	1.655
-30	1.677
-25	1.700
-20	1.715
-15	1.744
-10	1.767
-5	1.774
0	1.794
5	1.805
10	1.829
15	1.846
20	1.863
25	1.880
30	1.893
35	1.910
40	1.923
45	1.938
50	1.952
55	1.966
60	1.984
65	1.929
70	2.004
75	2.044
80	2.064
85	2.075
90	2.085
95	2.101
100	2.114
105	2.126
110	2.141
115	2.155
120	2.172
125	2.180
130	2.196
135	2.214
140	2.224
145	2.219
150	2.246

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SwRI Sample Code	CL09-00324
Temperature (°C)	**Specific Heat (kJ/kg.K)**
155	2.252
160	2.258
165	2.282
170	2.281
175	2.300
180	2.319
185	2.252
190	2.129
195	2.222
200	2.316

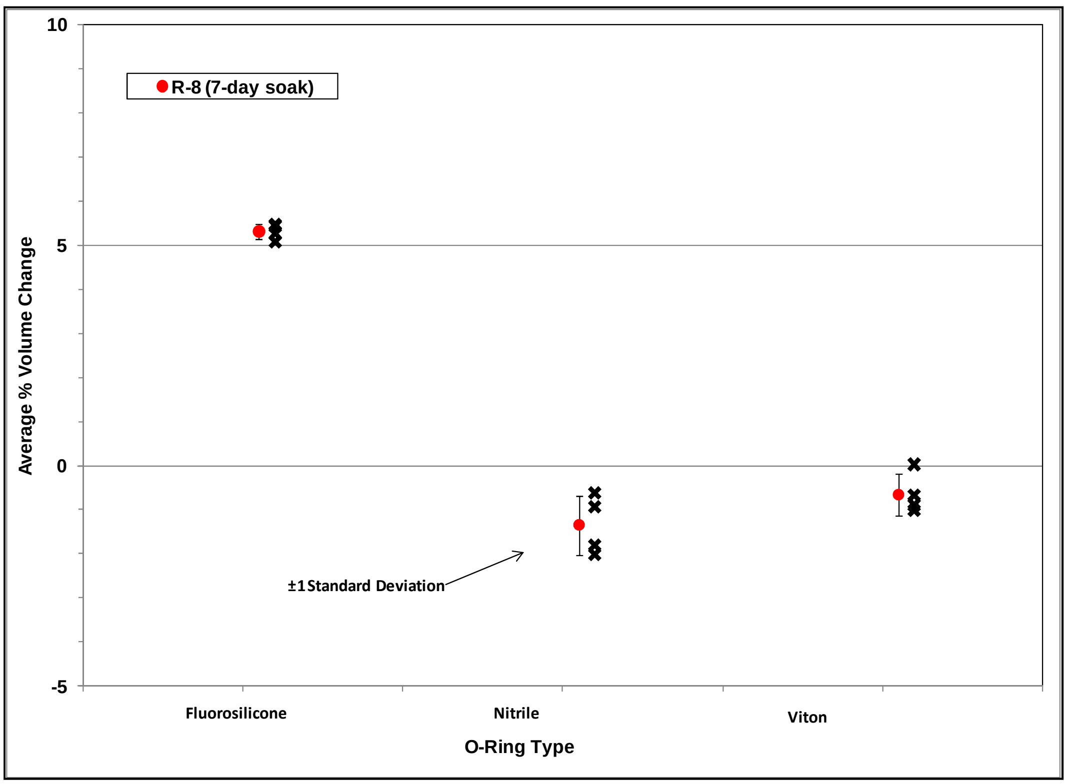

Figure H-2-1. O-Ring Swell Test – R-8

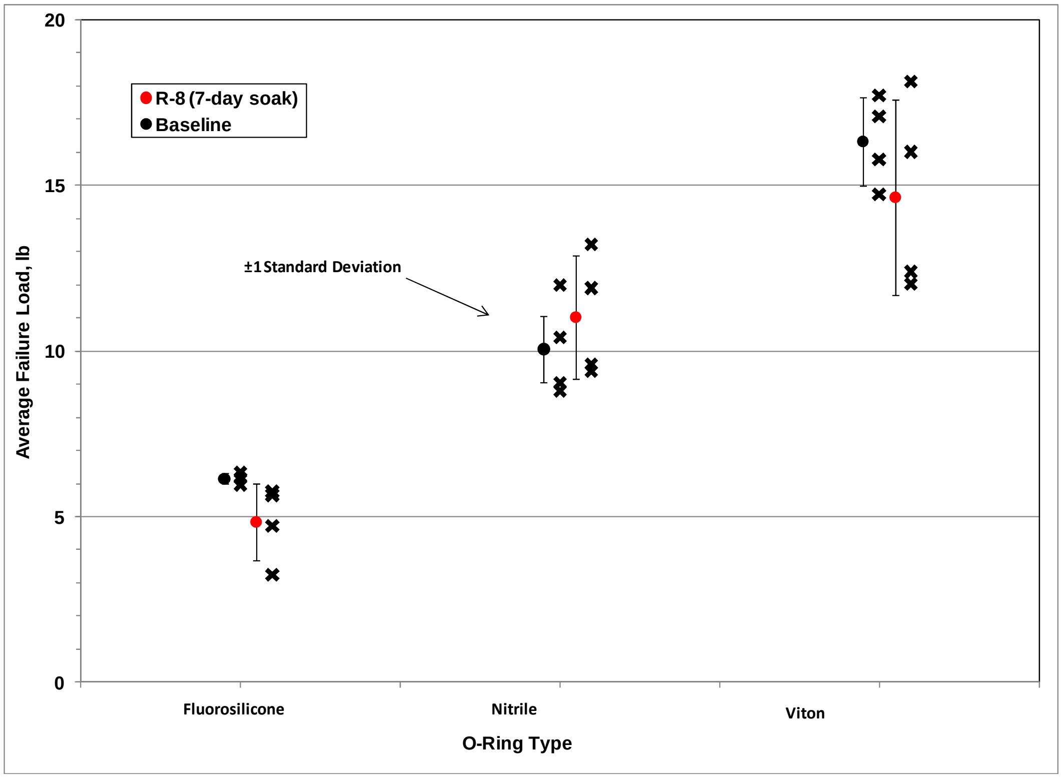

Figure H-2-2. O-Ring Tensile Strength – R-8

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R-8 HRJ Fit-for-Purpose Evaluations
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Additional R-8 HRJ Fit-for-Purpose Evaluations

Table H-2-2. Results for R-8X (POSF5470)

SwRI Sample Code			**CL09-00636**
Test	**Method**	**Units**	**R-8X (POSF 5470)**
Water Reaction	D1094		
Aqueous layer volume change		mL	1.0
Interface Rating		rating	1
Degree of Separation		rating	1
Copper Strip Corrosion (2 hrs @ 100ºC)	D130	rating	1A
Aromatic Content	D1319		
Aromatics		vol%	0.7
Olefins		vol%	0.5
Saturates		vol%	98.80
Smoke Point	D1322	mm	41.0
Surface tension	D1331A		
-10ºC		mN/m	26.1
22ºC		mN/m	23.8
40ºC		mN/m	22.3
Saybolt Color	D156	rating	+30
Naphthalene Content	D1840	vol%	0.33
Freeze Point (manual)	D2386	ºC	-56.0
Hydrocarbon Types by Mass Spec	D2425		
Paraffins		mass%	87.9
Monocycloparaffins		mass%	11.2
Dicycloparaffins		mass%	0.0
Tricycloparaffins		mass%	0.0
Alkylbenzenes		mass%	0.9
Sulfur - Mercaptan	D3227	mass%	<0.0003
JFTOT	D3241		
Test Temperature		ºC	260
ASTM Code		rating	2A
Maximum Pressure Drop		mm Hg	0
JFTOT deposit thickness	D3241		

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Table H-2-2. Results for R-8X (POSF5470)

SwRI Sample Code			CL09-00636
Test	**Method**	**Units**	**R-8X (POSF 5470)**
260ºC		nm	30.17
Acid Number	D3242	mg KOH/g	0.006
Specific Energy (calculated, sulfur corrected)	D3338	MJ/kg	44.078
Hydrogen Content (NMR)	D3701	mass%	15.24
Storage Stability - Peroxides @65ºC	D3703		
0 week		mg/kg	0.0
1 week		mg/kg	5.6
2 week		mg/kg	14.3
3 week		mg/kg	7.2
6 week		mg/kg	6.3
Existent Gums	D381		
Washed		mg/100mL	<0.5
Unwashed		mg/100mL	<0.5
MSEP	D3948	rating	99
Density	D4052		
0ºC		g/mL	0.7719
15ºC		g/mL	0.7607
40ºC		g/mL	0.7424
60ºC		g/mL	0.7276
80ºC		g/mL	0.7126
Kinematic Viscosity	D445		
-20ºC		cSt	5.08
0ºC		cSt	2.89
40ºC		cSt	1.34
100ºC		cSt	0.74
Specific Energy (calculated, sulfur corrected)	D4529	MJ/kg	44.088
Nitrogen Content	D4629	mg/kg	<1
Heat of Combustion	D4809		
BTUHeat_Gross		BTU/lb	20281.6

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Table H-2-2. Results for R-8X (POSF5470)

SwRI Sample Code			CL09-00636
Test	**Method**	**Units**	**R-8X (POSF 5470)**
BTUHeat_Net		BTU/lb	18883.1
MJHeat_Gross		MJ/kg	47.17
MJHeat_Net		MJ/kg	43.91
Lubricity (BOCLE) vs. CI/LI Concentration	D5001		
0 mg/L		mm	0.94
5 mg/L		mm	0.85
10 mg/L		mm	0.72
15 mg/L		mm	0.64
20 mg/L		mm	0.60
Vapor pressure	D6378		
0ºC		psia	0.17
10ºC		Psia	0.20
20ºC		psia	0.24
30ºC		psia	0.28
40ºC		psia	0.34
50ºC		psia	0.41
60ºC		psia	0.53
70ºC		psia	0.71
80ºC		psia	0.96
90ºC		psia	1.30
100ºC		psia	1.77
110ºC		psia	2.37
120ºC		psia	3.20
Carbon/Hydrogen	D5291		
Carbon		%	84.86
Hydrogen		%	15.33
Storage Stability – Potential Gums	D5304		
16 hours		mg/100mL	1
Sulfur Content - (Antek)	D5453	ppm	0.6

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R-8 HRJ Fit-for-Purpose Evaluations

APPENDIX H-2: Excerpt From Southwest Research Institute Report #14406

Additional R-8 HRJ Fit-for-Purpose Evaluations

Table H-2-2. Results for R-8X (POSF5470)

SwRI Sample Code			CL09-00636
Test	**Method**	**Units**	**R-8X (POSF 5470)**
Freeze Point	D5972	ºC	-52.3
Aniline Point	D611	ºC	82.4
Isothermal Tangent Bulk Modulus, 30ºC	D6793		
0 psi		psi	*IC*
1000 psi		psi	*IC*
2000 psi		psi	*IC*
3000 psi		psi	*IC*
4000 psi		psi	*IC*
5000 psi		psi	*IC*
6000 psi		psi	*IC*
7000 psi		psi	*IC*
8000 psi		psi	*IC*
9000 psi		psi	*IC*
10000 psi		psi	*IC*
Isothermal Tangent Bulk Modulus, 60ºC	D6793		
0 psi		psi	*IC*
1000 psi		psi	*IC*
2000 psi		psi	*IC*
3000 psi		psi	*IC*
4000 psi		psi	*IC*
5000 psi		psi	*IC*
6000 psi		psi	*IC*
7000 psi		psi	*IC*
8000 psi		psi	*IC*
9000 psi		psi	*IC*
10000 psi		psi	*IC*
Distillation	D86		
IBP		ºC	154.1
5%		ºC	167.1

APPENDIX H
R-8 HRJ Fit-for-Purpose Evaluations
APPENDIX H-2: Excerpt From Southwest Research Institute Report #14406
Additional R-8 HRJ Fit-for-Purpose Evaluations

Table H-2-2. Results for R-8X (POSF5470)

SwRI Sample Code			CL09-00636
Test	**Method**	**Units**	**R-8X (POSF 5470)**
10%		ºC	170.7
15%		ºC	175.9
20%		ºC	180.3
30%		ºC	188.6
40%		ºC	198.3
50%		ºC	208.2
60%		ºC	218.0
70%		ºC	228.3
80%		ºC	239.9
90%		ºC	253.9
95%		ºC	263.3
FBP		ºC	267.9
Residue		%	1.5
Loss		%	1.1
Distillation Slope	D86		
T50-T10		ºC	37.5
T90-T10		ºC	83.2
Flash Point - Pensky-Martens Closed Cup	D93	ºC	47
Calculated Cetane Index	D976	--	65.0
Specific Heat	E1269	kJ/kg.K	*See* **Error! Reference source not found.**
Carbonyls, Alcohols, Esters, Phenols			
Alcohols	EPA 8015B	ppm	<5
Carbonyls, Esters	EPA 8260B	ppb	<1
Phenols	EPA 8270C	ppm	<50
Thermal Conductivity	SwRI		
23.8ºC		W/m.K	***IC***
50.8ºC		W/m.K	***IC***
81.5ºC		W/m.K	***IC***

Table H-2-2. Results for R-8X (POSF5470)

SwRI Sample Code			CL09-00636
Test	**Method**	**Units**	**R-8X (POSF 5470)**
Aromatic Content	D5186		
Total Aromatics		mass%	1.1
Mononuclear Aromatics		mass%	1.1
Polynuclear Aromatics		mass%	0.0

APPENDIX H

R-8 HRJ Fit-for-Purpose Evaluations

APPENDIX H-2: Excerpt From Southwest Research Institute Report #14406

Additional R-8 HRJ Fit-for-Purpose Evaluations

Specific Heat (E1269) Results for F-8x (POSF5470)

Temperature (°C)	Specific Heat (kJ/kg.K)
-40	1.722
-35	1.721
-30	1.697
-25	1.714
-20	1.726
-15	1.748
-10	1.761
-5	1.772
0	1.787
5	1.798
10	1.812
15	1.821
20	1.833
25	1.850
30	1.865
35	1.881
40	1.897
45	1.912
50	1.928
55	1.948
60	1.920
65	1.969
70	2.004
75	2.024
80	2.039
85	2.054
90	2.070
95	2.085
100	2.105
105	2.122
110	2.135
115	2.151
120	2.167
125	2.182
130	2.196
135	2.209
140	2.220
145	2.230
150	2.240
155	2.250

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Temperature (°C)	Specific Heat (kJ/kg.K)
160	2.260
165	2.271
170	2.283
175	2.295
180	2.301
185	2.282
190	2.161
195	2.128
200	2.259

APPENDIX I
R-8 Pump Evaluations
APPENDIX I-1: R-8 HRJ Pump Test Stand Evaluations, SwRI Report #13283

A. Rotary Pump Test Procedure

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5209, for a General Engine Products 6.5L engine application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure I-1-1.

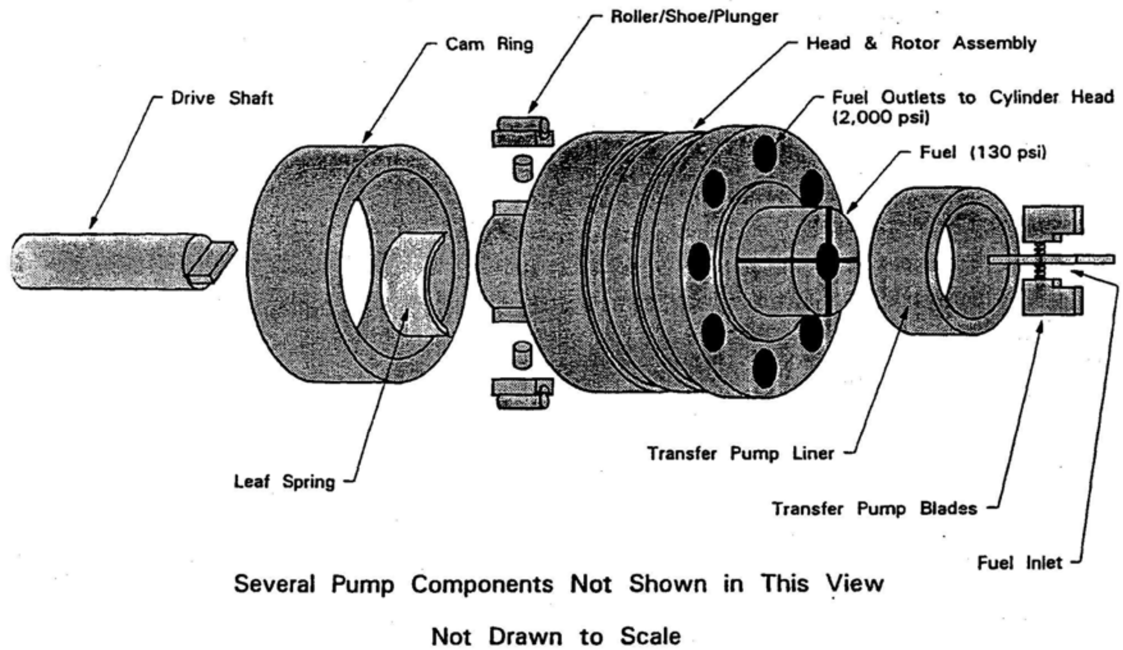

Figure I-1-1. Schematic Diagram of Principal Pump Components

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade heights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5209 model. The specification calls for a roller-to-roller dimension setting of 1.962 inches ± .0005 inches. All pumps were set prior to testing inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent benchmark for the effects of fuel lubricity.

The pumps were reassembled and pre-test performance evaluations were conducted. The pumps were then mounted on the test stand and operated at 1800 RPM, with the fuel levers in the wide open throttle position (WOT) for targeted 500-hour increments (or less). Fuel flow, fuel inlet and outlet temperatures, transfer pump, pump housing pressures, and RPM were tracked and recorded. Flow meter readings reflect the injected fuel from the eight fuel injectors in each collection canister. Any wear in the fuel injection pump metering section was reflected as an increased or reduced flow reading. The fuel inlet temperature control target was 40°C. Inlet temperature variations directly affect the fuel return temperature, which is a function of accelerated pump wear. The transfer pump pressure is the regulated pressure the metal blade transfer pump supplies to the pump metering section. With low lubricity fuels, wear is likely to occur in the transfer pump blades, blade slot, and eccentric liner. Wear in these areas generally causes the transfer pump pressure to decrease. However, because the transfer pump has a pressure regulator, significant wear needs to occur in the transfer pump before the fuel pressure drops to below the operating range allowed in the pump specification. The housing pressure is the regulated pressure in the pump body that affects fuel metering and timing. With low lubricity fuel, wear occurs in high fuel pressure generating opposed plungers and bores, and between the hydraulic head and rotor. Leakage from the increased diametrical clearances of the plunger bores and the hydraulic head and rotor, results in increased housing pressures. Increased housing pressure reduces metered fuel and retards injection timing.

B. Pump Test Stand

The rotary pumps were tested on a drive stand with a common fuel supply. To insure a realistic test environment, the mounting arrangement and drive gear duplicate that of the 6.5L engine. The fuel was maintained in a 55-gallon drum and continuously recirculated throughout the duration of each test. A gear pump provided a positive head of 3 psig at the inlet to the test pumps. A cartridge filter rated was used to remove wear debris and particulate contamination. Finally, a 5-kW Chromalox explosion-resistant circulation heater produced the required fuel inlet temperature.

The high-pressure outlets from the pumps were connected to eight Bosch Model O432217104 fuel injectors for a 6.5L engine and assembled in a collection canister. Fuel from both canisters was then returned to the 55-gallon drum. A separate line was used to return excess fuel from the governor housing to the fuel supply. Fuel-to-water heat exchangers on both the return lines from the injector canisters and the governor housing were used to cool the fuel. The fuel system used for the tests is depicted in Figure I-1-2 and the test stand with pumps mounted is shown in Figures I-1-3 through I-1-5.

APPENDIX I
R-8 Pump Evaluations
APPENDIX I-1: R-8 HRJ Pump Test Stand Evaluations, SwRI Report #13283

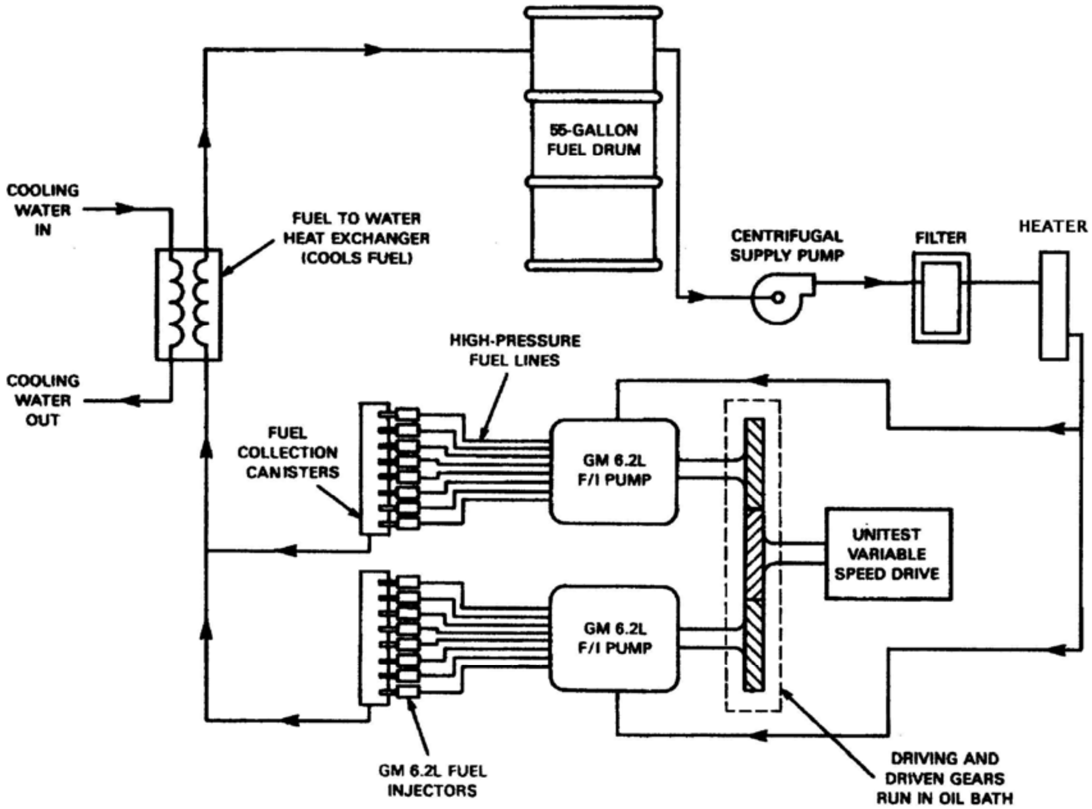

Figure I-1-2. Fuel System Schematic

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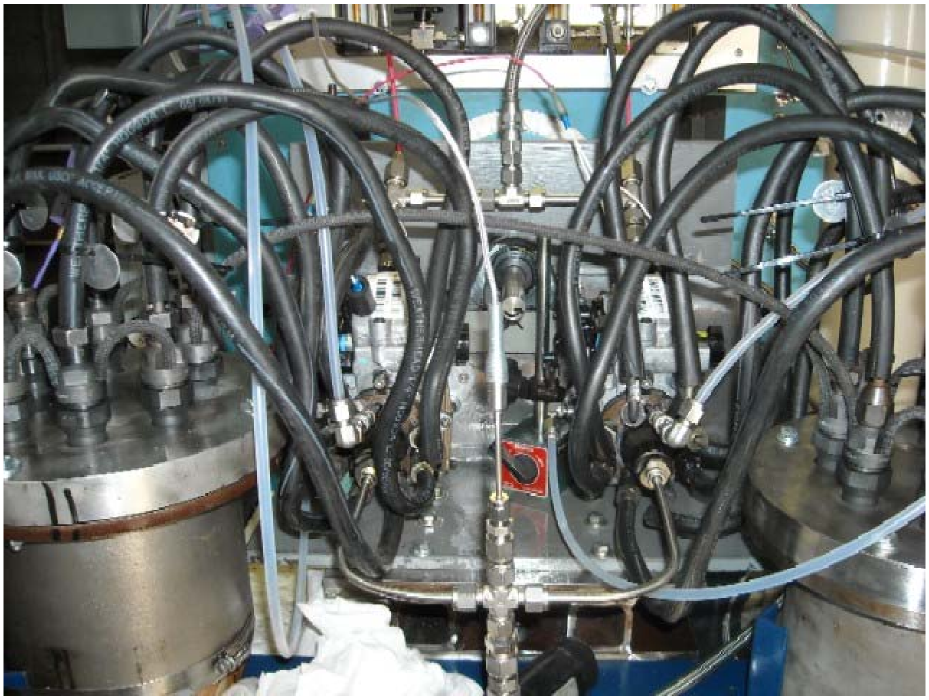

Figure I-1-3. Both R-8 Stanadyne Rotary Fuel Injection Pumps Mounted on Stand with Fuel Injectors

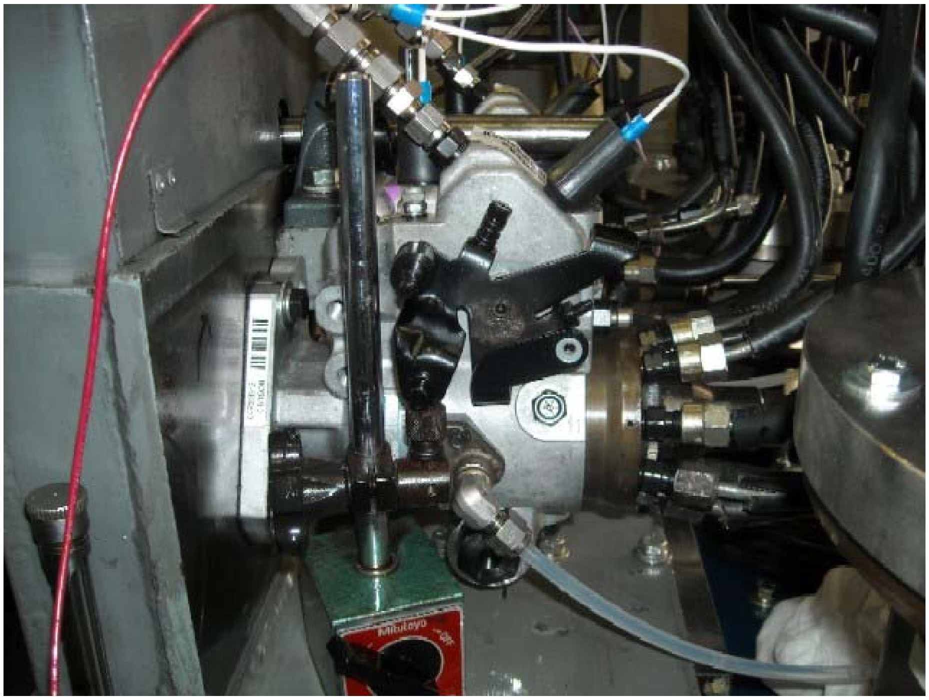

Figure I-1-4. R-8 Stanadyne Rotary Fuel Injection Pump SN:14193135 Mounted on Left Side Drive

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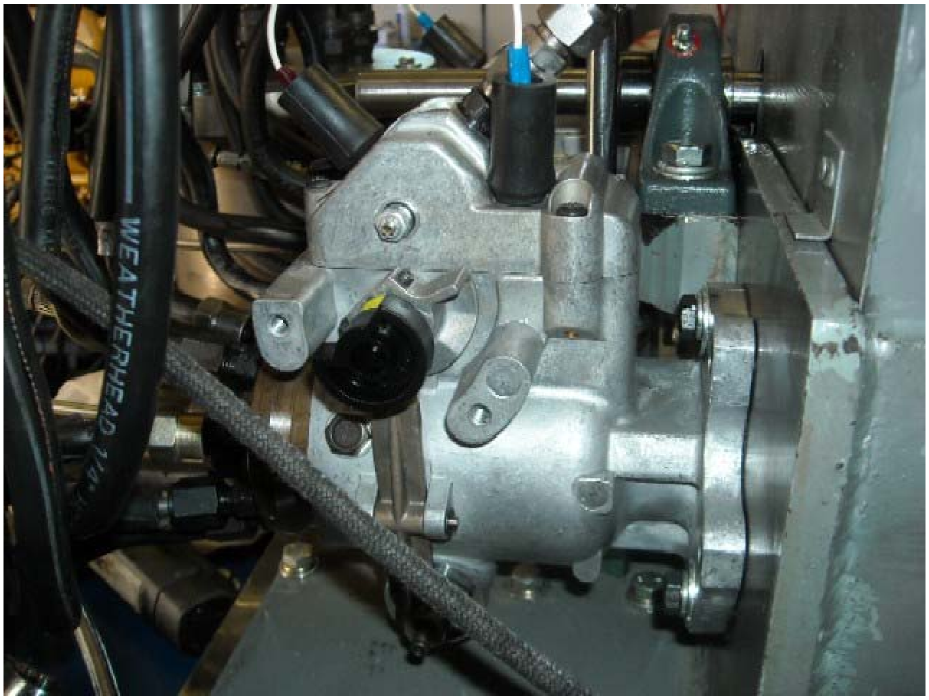

Figure I-1-5. R-8 Stanadyne Rotary Fuel Injection Pump SN:14193181 Mounted on Right Side Drive

A data acquisition and control system recorded pump stand RPM, fuel inlet pressure, fuel inlet and return temperature, transfer pump, pump housing pressures, and fuel flow readings. The entire rig was equipped with safety shutdowns that would turn off the drive motor in the event of low fluid level in the supply drum, high inlet and return fuel temperature (70º C), or low or high transfer pump and housing pressure. Since high-return fuel temperature is a precursor of accelerated wear, this failsafe feature reduced the possibility of head and rotor seizure.

VI. ROTARY PUMP EVALUATIONS AND RESULTS

A. Rotary Pump R-8 Fuel Test

The Stanadyne model DB2831-5209 rotary fuel injection pumps were received from a supplier and the pumps appeared to have been dropped on the advance piston housing during handling. Inspection of the pumps indicated they were functioning properly and the dinged housings were cosmetic. The calibration shop ran the pumps for an extended time on a Viscor calibration fluid to verify proper functionality and to determine there was not any leakage around the advance piston.

The fuel injection pumps were installed on the test stand and the pumps were operated for an hour to validate their operation, and to run-in the components with a good lubricity fuel. The fuel used was a Jet -A fuel treated with 22.5-ppm CI/LI additive. The pumps were run for 30-minutes at 1200-RPM pump speed, with a half-rack fuel flow setting. For the final 30-minutes of the run-in the pumps were operated at the test condition of 1800-RPM pump speed, with a full-rack fuel flow setting.

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The test bench and pumps were flushed with Iso-octane to attempt to remove any remaining run-in fuel and CI/LI additive. The Iso-octane was forced through the fuel injection pumps with pressure, the pumps were not run with Iso-octane in them. Following the Iso-octane flush, an un-additized synthetic Iso-Paraffinic Kerosene was used to flush the test stand and pumps prior to fuelling with the R-8 test fuel. The R-8 was introduced into the test stand and the stand was operated at an idle condition until 2L of fuel was flushed through each set of eight injectors.

The testing with R-8 was initiated and control issues developed with the fuel inlet temperature. The temperature in the fuel drum was changing due to solar gain, and the temperature stratification in the test fuel drum caused the fuel inlet temperature controller to go unstable, with brief excursions to 50ºC fuel inlet temperature. Eventually the plumbing of the fuel drum return and pickup was modified, a drum shade cover was constructed, and the testing commenced with good fuel inlet temperature control. After nine-hours of operation the injected flow of both of the pumps was increasing, this increase has been seen previously when wear between the roller shoe and the leaf spring that limits the plunger travel occurs. The temperature and flow histories of the fuel injection pumps are shown in Figure I-1-6.

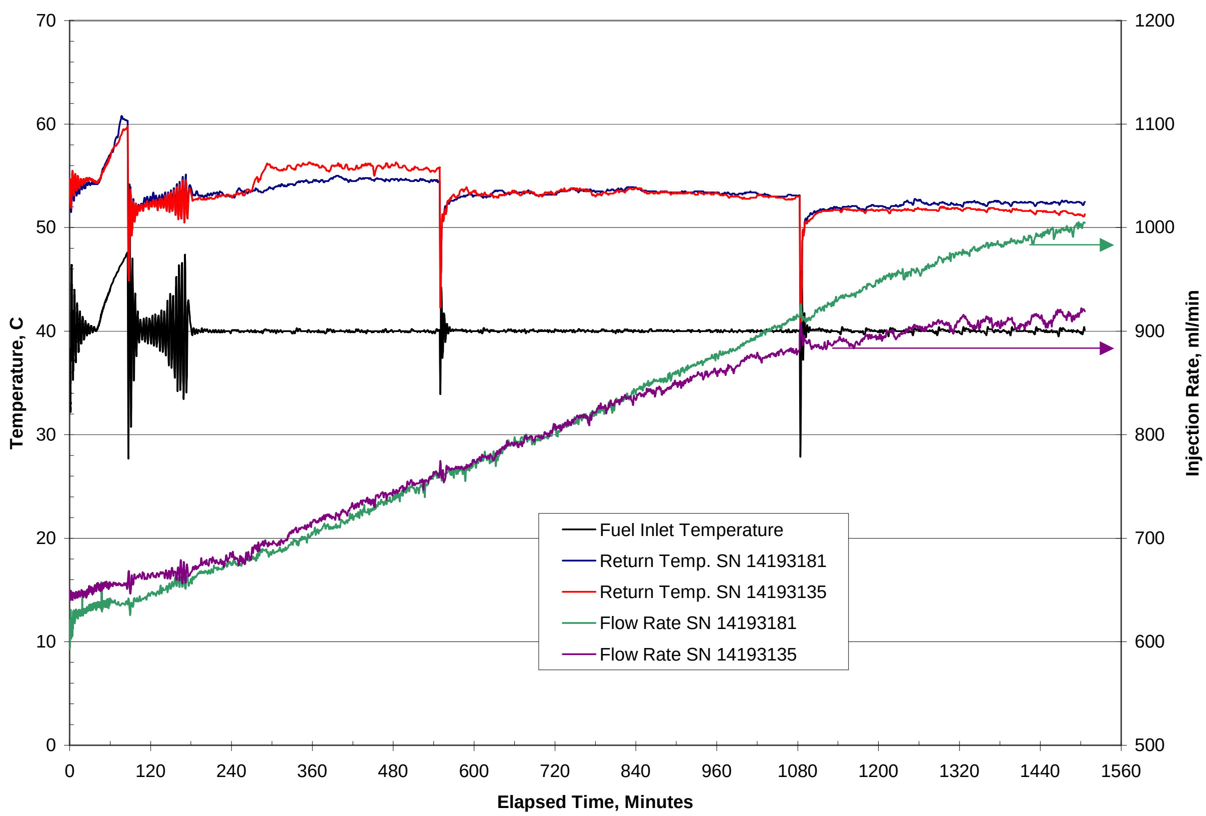

Figure I-1-6. Fuel Inlet, Fuel Return Temperatures and Fuel Flow Rate Histories for 25-Hours on R-8 Fuel

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An increase in transfer pump pressure was noted on pump SN:14193135, that usually means the regulator function may be compromised. The return fuel temperatures for both pumps were creeping up gradually, but were still 15ºC from the shutdown limit at nine hours.

The pump stand was operated on the R-8 fuel until 25-test hours. At that time it was noted a minor leak had occurred around one of the collection reservoirs. For safety, and to conserve the R-8 fuel, the stand was shut down to investigate the leakage. At that time a review of the logged data had indicated an over 150% increase in injected fuel flow for the fuel injection pumps. During an investigation into the condition of the pumps by removing the top cover, there was noted a highly unusual dark brown deposition in both fuel injection pumps. Usually with low lubricity fuels, a light golden color is seen in the pump after several hundred hours of operation. Figures I-1-6 and I-1-7 for pump SN:14193135 show the brown deposition in the pump top cover and housing governor cavity. Likewise, Figures I-1-8 and I-1-9 for pump SN:14193181 show the brown deposition in the pump top cover and housing governor cavity also. Furthermore, in the pictures of the components with the solenoids, wear debris can be seen on the magnetized parts of the solenoids.

A check in the side of one of the pumps indicates the pump rollers appear dark and dull (instead of bright and shiny), which usually indicates wear. Even though the fuel injection pumps were vigorously delivering fuel, it is likely the injection timing has dramatically changed, and the pumps were likely to catastrophically fail soon. It should be noted that the pumps had become very noisy on start-up until they were completely warmed up, an indication that there were excessive tolerances in the pumps. At this point it was decided to remove the end of the fuel injection pump to check the transfer pump condition. Note, the transfer pump can be inspected without changing the functional performance or calibration of the pump while it is still on the stand. During the inspection severe transfer pump liner wear was noted and the test was terminated at 25-hours of operation. The fuel injection pumps and fuel injectors were removed from the test stand and checked for performance, calibration, and disassembled for component condition documentation.

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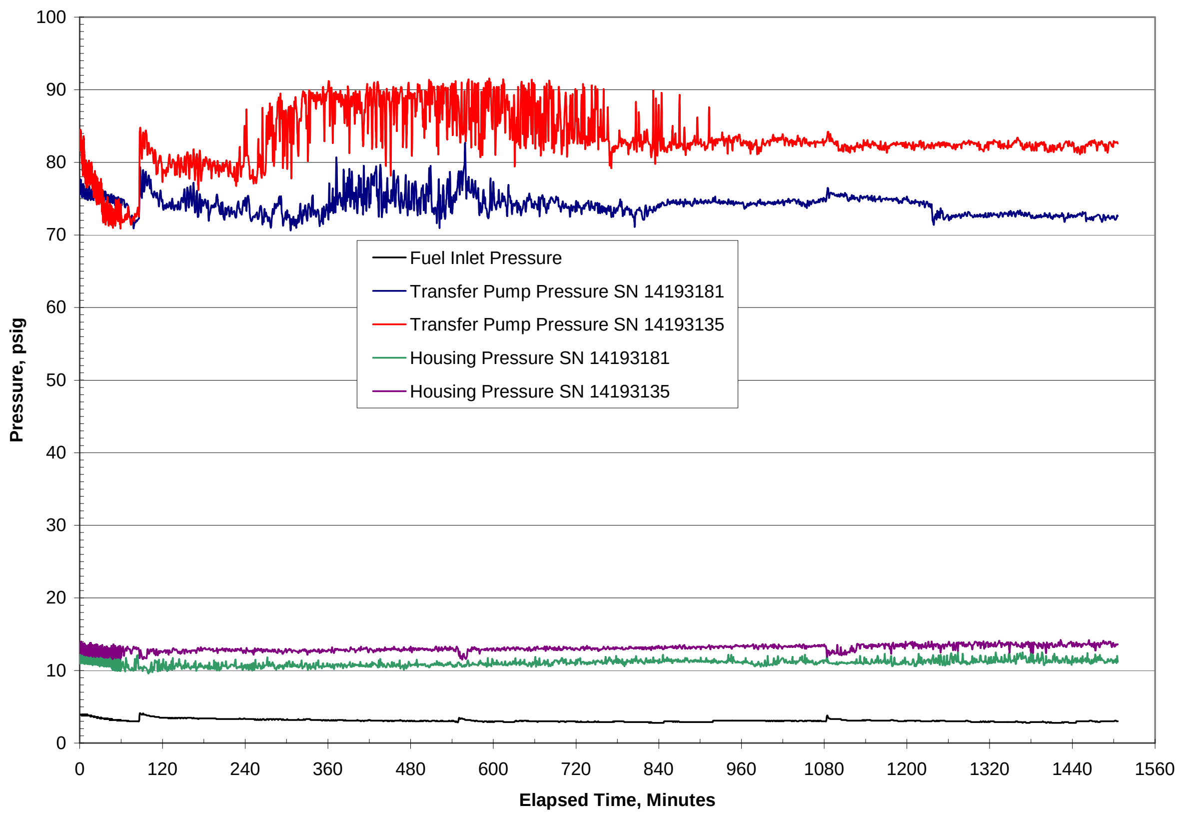

Figure I-1-7. Fuel Inlet, Transfer Pump, and Housing Pressure Histories for 25-Hours on R-8 Fuel

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APPENDIX I-1: R-8 HRJ Pump Test Stand Evaluations, SwRI Report #13283

Figure I-1-8. Injection Pump SN:14193135 Top Cover with Disposition and Wear Debris

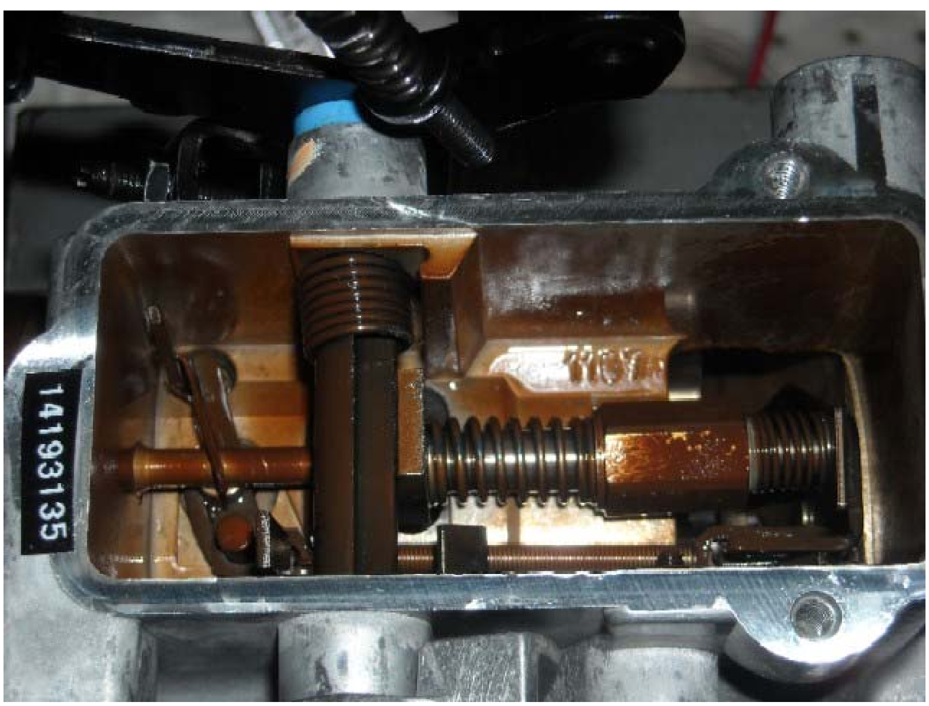

Figure I-1-9. Injection Pump SN:14193135 Housing with Deposition and Wear Debris

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Figure I-1-10. Injection Pump SN:14193181 Top Cover with Deposition and Wear Debris

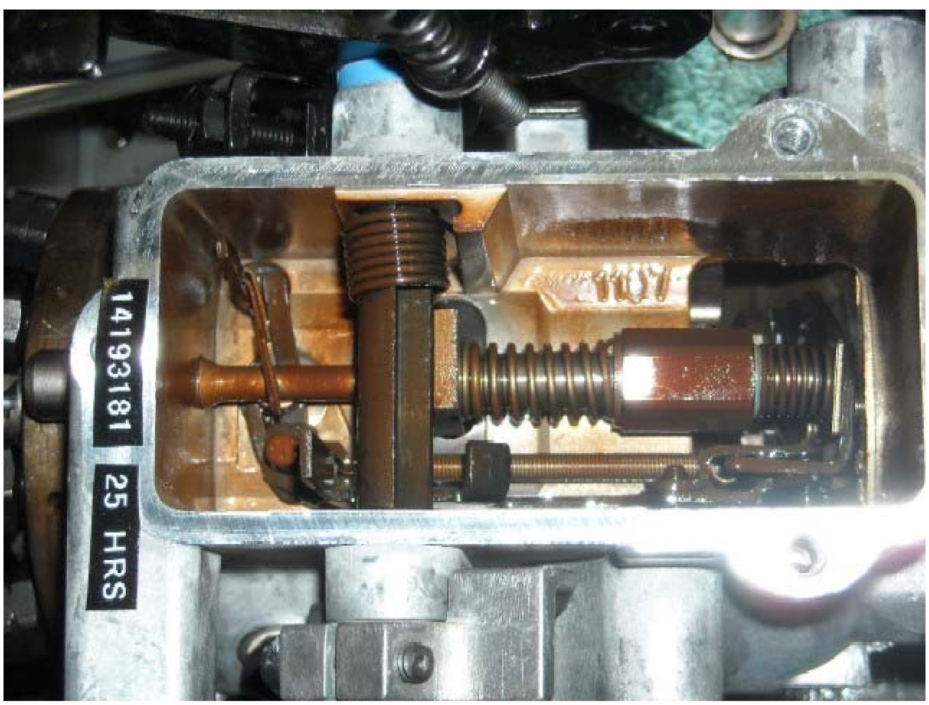

Figure I-1-11. Injection Pump SN:14193181 Housing with Deposition and Wear Debris

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B. Rotary Pump Performance Measurements

Prior to durability testing the fuel injection pumps were run on an injection pump calibration stand to verify their performance with respect to their model number and application specification sheet. Although the pumps come from the factory set to meet their designated specification, because SwRI disassembles the pumps to take transfer pump blade measurements and roller-to-roller dimensions the fuel injection pumps performance is validated. At the conclusion of testing the fuel injection pumps are installed on the calibration stand and checked for performance changes due to the test fuel. There are not any adjustments made to the fuel injection pumps by the calibration personnel.

The Pre- and Post-Test performance curves for fuel injection pump SN:14193135 is included as Table I-1-1. Items in bold characters in Table I-1-1 are values that fall outside of the specification for the fuel injection pump model. It should be noted that the fuel injection pump was delivering a large quantity of fuel at several check conditions, however the specification only reflects a minimum delivery value. This pump exceeded transfer pump pressure and delivery specifications at 1000-RPM pump speed, which is around the peak torque speed of the engine and would result in heavy smoke. At low idle, 350-RPM, the SN:14193135 pump was below the minimum delivery value that would result in a rough engine idle. At 1750-RPM both quantity and timing are out of specification which could lead to rough running, smoke, and high gaseous exhaust emissions. The results at 2025-RPM suggest the governor operation had not been compromised for the SN:14193135 pump on R-8 fuel. Although the minimum delivery values at 200-RPM and 75-RPM are met, these conditions are significant for start-up; the high fuel delivery values post-test may result in an over-rich condition that could affect starting ability, white smoke, and run-up to idle. The air timing is a value that is critical for operation on the engine, and a change of 4-degrees is significant considering the short duration of the R-8 fuel test. All parameter changes evident are significant due to the short length of the testing with R-8 fuel.

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APPENDIX I-1: R-8 HRJ Pump Test Stand Evaluations, SwRI Report #13283

Table I-1-1. Performance Parameters for SN:14193135 After Operation on R-8 Fuel

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831- 5209 (arctic)	**SN: 14193135**
Test condition : 25 Hours R8 Fuel, 1800 rpm, 40*C	**AF: 6778**

PUMP RPM	***Description***	***Spec.***	***Before***	***After***	***Change***
1000	Transfer pump psi.	60-62 psi	62	**65**	3
	Return Fuel	225-375 cc	301	306	5
	Fuel Delivery	51.5 cc. Max.	50	**75**	25
350	Low Idle	12-16 cc	14	**8**	-6
	Housing psi.	8-12 psi	11	11.5	0.5
	Cold Advance Solenoid	0-1 psi	1	1	0
1750	Fuel Delivery	44.5 - 47.5 cc	44	**72**	28
	Advance	3.75 - 4.75 deg.	4	**1.75**	-2.25
1900	Fuel Delivery	31.5 cc min.	36	51	15
1600	Face Cam Fuel delivery	21.5 - 23.5 cc	22	22	0
	Advance	4 - 6 deg.	5.25	5.5	0.25
1800	Fuel Delivery	44 cc min.	45	68	23
	Transfer pump psi.	Record	90	86	-4
	Housing psi.	Record	9	11	2
2025	High Idle	15 cc max.	2	0.5	-1.5
	Transfer pump psi.	125 psi max.	115	107	-8
200	Fuel Delivery	40 cc min.	43	73	30
	Shut-Off	4 cc max.	0.5	0.5	0
75	Fuel Delivery	26 cc min.	32	60	28
	Transfer pump psi.	16 psi min.	26	20	-6
	Air Timing	-1 deg. (+/-.5)	-1	**3**	4
	Fluid Temp. Deg. C				
	Date		10/30/2008	12/3/2008	

Notes : Post test air timing very erratic and inconsistant.

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APPENDIX I-1: R-8 HRJ Pump Test Stand Evaluations, SwRI Report #13283

The Pre- and Post-Test performance curves for fuel injection pump SN:14193181 is included as Table 2. Items in bold characters in Table 2 are values that fall outside of the specification for the fuel injection pump model. It should be noted that the fuel injection pump was delivering a large quantity of fuel at several check conditions, however the specification only reflects a minimum delivery value. This pump delivered a low transfer pump pressure and exceeded delivery specifications at 1000-RPM pump speed, which is around the peak torque speed of the engine and would result in heavy smoke. At low idle, 350-RPM, the SN:14193181 pump was above the maximum delivery value that could result in poor idle stability. At 1750-RPM both quantity and timing are out of specification which could lead to rough running, smoke, and high gaseous exhaust emissions. The results at 2025-RPM suggest the governor operation had not been compromised for the SN:14193181 pump on R-8 fuel. Although the minimum delivery values at 200-RPM and 75-RPM are met, these conditions are significant for start-up; the high fuel delivery values post-test may result in an over-rich condition that could affect starting ability, white smoke, and run-up to idle. The air timing is a value that is critical for operation on the engine, and a change of 5-degrees is significant considering the short duration of the R-8 fuel test. All parameter changes evident are significant due to the short length of the testing with R-8 fuel.

C. Rotary Pump Wear Measurements

The transfer pump and plunger assemblies are integral to the fuel-metering system in the Stanadyne rotary pump, and by function are the most affected with low lubricity fuel. Accelerated wear in either the transfer pump blades or the roller-to-roller dimension results in a change of fueling condition that jeopardizes the quantity of fuel injected into the hydraulic head assembly. Wear in the transfer pump blades limits the amount of pressure necessary to maintain the proper amount of fuel in the chamber where opposing plungers, actuated by the rollers and cam, inject the metered fuel into the hydraulic head assembly. Roller-to-roller dimension variations alter the travel distance of the plungers, effectively changing metered fuel, injector pressure, and injection timing.

Table I-1-2. Performance Parameters for SN:14193181 After Operation on R-8 Fuel

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831- 5209 (arctic)	**SN: 14193181**
Test condition : 25 Hours R8 Fuel, 1800 rpm, 40*C	**AF: 6778**

PUMP RPM	***Description***	***Spec.***	***Before***	***After***	***Change***
1000	Transfer pump psi.	60-62 psi	63	**55**	-8
	Return Fuel	225-375 cc	320	304	-16
	Fuel Delivery	51.5 cc. Max.	49	**79**	30
350	Low Idle	12-16 cc	16	**19**	3
	Housing psi.	8-12 psi	11	11	0
	Cold Advance Solenoid	0-1 psi	1	0	-1
1750	Fuel Delivery	44.5 - 47.5 cc	45	**75**	30
	Advance	3.75 - 4.75 deg.	4.25	**1**	-3.25
1900	Fuel Delivery	31.5 cc min.	39	55	16
1600	Face Cam Fuel delivery	21.5 - 23.5 cc	22	22	0
	Advance	4 - 6 deg.	4.5	5.25	0.75
1800	Fuel Delivery	44 cc min.	45	75	30
	Transfer pump psi.	Record	90	76	-14
	Housing psi.	Record	10	10	0
2025	High Idle	15 cc max.	1	0.5	-0.5
	Transfer pump psi.	125 psi max.	107	100	-7
200	Fuel Delivery	40 cc min.	43	77	34
	Shut-Off	4 cc max.	0.5	0.5	0
75	Fuel Delivery	26 cc min.	34	65	31
	Transfer pump psi.	16 psi min.	25	16	-9
	Air Timing	-1 deg. (+/-.5)	-1	**-6**	-5
	Fluid Temp. Deg. C				
	Date		10/31/2008	12/3/2008	

Notes : Post test air timing very erratic and inconsistant.

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APPENDIX I-1: R-8 HRJ Pump Test Stand Evaluations, SwRI Report #13283

Tables I-1-3 and I-1-4 present the transfer pump blade and roller-to-roller dimension measurement results for the two fuel injection pumps. There were no out-of-specification transfer blade measurements based on the dimension length C; the width of the blades changed dramatically, approaching 0.191-inches on one blade, and the blades thickness all decreased on the order of 0.020-inch. Both pump roller-to-roller dimensions changed substantially more than the ± 0.0005-inch assembly specification tolerance. The roller-to-roller eccentricity specification is 0.008-inch maximum, of which pump SN:14193181 exceeded the value after testing with R-8 Fuel. In general all transfer pump blades were in poor condition, and the roller-to-roller dimensions changes reflect the performance changes seen on the calibration stand.

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required.

New Bosch Model O432217104 injectors were used for the test. The injector performance tests and rating results are shown in Table I-1-5.

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R-8 Pump Evaluations

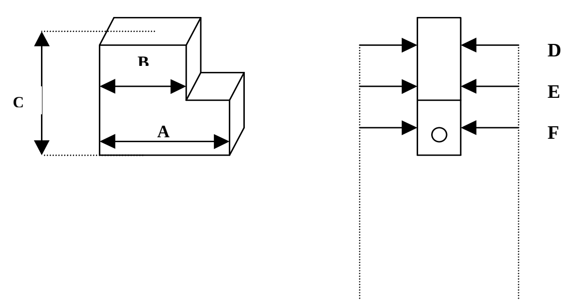
APPENDIX I-1: R-8 HRJ Pump Test Stand Evaluations, SwRI Report #13283

Table I-1-3. Wear Measurements for SN:1413135 After Operation on R-8 Fuel

Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5209		SN:14193135	Test Number : 1	
Fuel description : 25 Hours R8 Fuel (AF-6778)				
		10/27/2008	12/5/2008	
Dimensional Measurements (mm)		***0 hrs.***	***25***	***Change***
Transfer Pump Blade #1	Dimension A	13.790	13.605	-0.185
	Dimension B	10.050	9.940	-0.110
	Dimension C	12.676	12.667	-0.009
	Dimension D	3.132	3.112	-0.020
	Dimension E	3.132	3.113	-0.019
	Dimension F	3.132	3.110	-0.022
Transfer Pump Blade #2	Dimension A	13.810	13.619	-0.191
	Dimension B	10.070	9.968	-0.102
	Dimension C	12.676	12.667	-0.009
	Dimension D	3.132	3.112	-0.020
	Dimension E	3.132	3.112	-0.020
	Dimension F	3.132	3.114	-0.018
Transfer Pump Blade #3	Dimension A	13.795	13.640	-0.155
	Dimension B	10.080	9.949	-0.131
	Dimension C	12.680	12.670	-0.010
	Dimension D	3.132	3.112	-0.020
	Dimension E	3.132	3.112	-0.020
	Dimension F	3.132	3.110	-0.022
Transfer Pump Blade #4	Dimension A	13.805	13.662	-0.143
	Dimension B	10.090	9.971	-0.119
	Dimension C	12.680	12.667	-0.013
	Dimension D	3.133	3.109	-0.024
	Dimension E	3.133	3.111	-0.022
	Dimension F	3.133	3.109	-0.024
	Roller to Roller (in)	1.9620	1.9840	0.022
	Eccentricity (in.)	0.0035	0.0075	0.004
	Drive Backlash (In)	0.0040	0.0075	0.0035

	MIN - HEIGHT (C)	MAX - HEIGHT (C)
Millimeters	12.6644	12.6822



- A- Blade length approximately 13.77mm
- B- Blade length approximately 9.95mm
- C- Blade height approximately 12.66mm

Blade Thickness / width approximately 3.11mm

1

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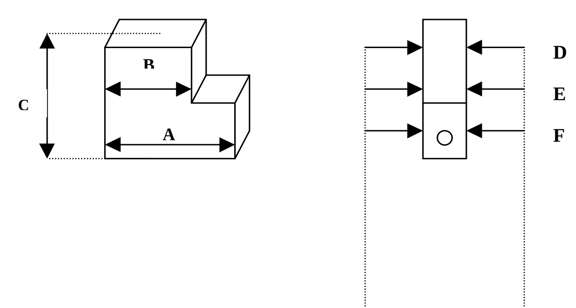
Table I-1-4. Wear Measurements for SN:14193181 After Operation on R-8 Fuel Blade

Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5209	SN:14193181	Test Number : 1
Fuel description : 25 Hours R8 Fuel (AF-6778)		

Dimensional Measurements (mm)		10/28/2008 *0 hrs.*	12/5/2008 *25*	*Change*
Transfer Pump Blade #1	Dimension A	13.800	13.668	-0.132
	Dimension B	10.099	10.027	-0.072
	Dimension C	12.676	12.665	-0.011
	Dimension D	3.131	3.113	-0.018
	Dimension E	3.131	3.113	-0.018
	Dimension F	3.131	3.113	-0.018
Transfer Pump Blade #2	Dimension A	13.790	13.645	-0.145
	Dimension B	10.056	9.972	-0.084
	Dimension C	12.678	12.668	-0.010
	Dimension D	3.132	3.113	-0.019
	Dimension E	3.131	3.113	-0.018
	Dimension F	3.131	3.113	-0.018
Transfer Pump Blade #3	Dimension A	13.790	13.657	-0.133
	Dimension B	10.075	9.973	-0.102
	Dimension C	12.676	12.665	-0.011
	Dimension D	3.131	3.113	-0.018
	Dimension E	3.131	3.113	-0.018
	Dimension F	3.131	3.113	-0.018
Transfer Pump Blade #4	Dimension A	13.788	13.660	-0.128
	Dimension B	10.051	9.960	-0.091
	Dimension C	12.676	12.668	-0.008
	Dimension D	3.131	3.112	-0.019
	Dimension E	3.131	3.112	-0.019
	Dimension F	3.131	3.112	-0.019
	Roller to Roller (in)	1.9621	1.9880	0.0259
	Eccentricity (in.)	0.0035	0.0100	0.0065
	Drive Backlash (In)	0.0045	0.0085	0.0040

	MIN - HEIGHT (C)	MAX - HEIGHT (C)
Millimeters	12.6644	12.6822



- A- Blade length approximately 13.77mm
- B- Blade length approximately 9.95mm
- C- Blade height approximately 12.66mm

Blade Thickness / width approximately 3.11mm

1

Data subject to restrictions on cover and notice page.

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APPENDIX I-1: R-8 HRJ Pump Test Stand Evaluations, SwRI Report #13283

Table I-1-5. Fuel Injector Performance Evaluations After R-8 Fuel Usage

Stanadyne Rotary Pump Lubricity Evaluation

6.5L Fuel Injector Test Inspection

Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure	Tip Leakage	Chatter	Spray pattern	Assy. Leakage	Pintle cond.	Lapped Surface	Date	Hrs.
				Pre / Post	Pre / Post	Pre / Post	Pre / Post				Pre / Post	
1	SN: 14193135	AF-6778 (R8)	1-08	1900 / 1700	None / None	Good / Fair	Good / Fair	None / None			10/29/08 / 12/11/08	25
			2-08	1900 / 1700	None / None	Good / Good	Good / Good	None / None			10/29/08 / 12/11/08	25
			3-08	1875 / 1700	None / None	Good / Good	Good / Good	None / None			10/29/08 / 12/11/08	25
			4-08	1900 / 1700	None / None	Good / Good	Good / Good	None / None			10/29/08 / 12/11/08	25
			5-08	1900 / 1700	None / None	Good / Good	Good / Good	None / None			10/29/08 / 12/11/08	25
			6-08	1900 / 1725	None / None	Good / Good	Good / Good	None / None			10/29/08 / 12/11/08	25
			7-08	1925 / 1725	None / None	Good / Good	Good / Good	None / None	Sticky		10/29/08 / 12/11/08	25
			8-08	1975 / 1750	None / None	Good / Good	Good / Good	None / None			10/29/08 / 12/11/08	25
1	SN: 14193181	AF-6778 (R8)	9-08	1925 / 1825	None / None	Good / Good	Good / Good	None / None			10/29/08 / 12/11/08	25
			10-08	1900 / 1700	None / None	Good / Good	Good / Good	None / None			10/29/08 / 12/11/08	25
			11-08	1925 / 1700	None / None	Good / Good	Good / Good	None / None			10/29/08 / 12/11/08	25
			12-08	1900 / 1775	None / None	Good / Good	Good / Good	None / None			10/29/08 / 12/11/08	25
			13-08	1900 / 1700	None / None	Good / Good	Good / Good	None / None			10/29/08 / 12/11/08	25
			14-08	1875 / 1675	None / None	Good / Good	Good / Good	None / None			10/29/08 / 12/11/08	25
			15-08	1900 / 1700	None / None	Good / Good	Good / Good	None / None			10/29/08 / 12/11/08	25
			16-08	1975 / 1750	None / None	Good / Good	Good / Good	None / None			10/29/08 / 12/11/08	25
			Spec. :	1500psig min	no drop off in 10sec. @ 1400	chatter	fine mist	dry, no seepage	shiny, no scratches	report		

Injectors 1-16 PN :0 432 217 104 127 Bar (1842psi)

Comments : ***# 1-08 Has high return - post test***

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All the fuel injectors passed the post-test evaluations, primarily due to the low number of hours of operation. An injector with decreased opening pressure will probably "fail' the chatter test and more than likely "fail" the spray pattern test. In a typical vehicle application, this condition could cause erratic engine operation, increased smoke emission or decreased power, which may actually go unnoticed depending on the severity of the condition. Likewise, a leakage test failure would cause increased smoke emission upon engine start.

Rotary Pump Component Wear Evaluations

After the fuel injection pump calibration and functional performance checks, the fuel injection pumps are disassembled and the components critical to pump operation are evaluated for parts conditions. The parts conditions and subjective wear ratings for fuel injection pump SN:14193135 are summarized in Table I-1-6. A technician with over twenty years experience rebuilding, servicing, and testing Stanadyne fuel injection pumps performs the subjective wear rating. Images of the wear seen on the components of fuel injection pump SN:14193135 are shown in Figures I-1-12 through I-1-32. Figures I-1-12, I-1-13, and I-1-14 show the condition of the injection pump rotor that carries the plungers and distributes the compressed fuel. Figure I-1-12 of the drive tang (hardened) and Figure I-1-13 of the discharge ports are in good condition. Figure I-1-14 of the roller shoe slots reveals chipping on the slot edges that are unusual, more so because the chips did not cause a catastrophic seizure failure. It is expected the increased roller-to-roller dimensions and increased fuel delivery allowed the roller shoes to have more contact with the slot in the rotor. Wear on the injection pump delivery valve is seen in Figure I-1-15; the delivery valve effects injection timing and reduces secondary injections.

Figure I-1-16 and Figure I-1-17 are the Pre-Test and Post-Test conditions of fuel injection pump SN:14193135 Roller Shoe and Roller conditions. Of note is the lack of a wear scar at the roller shoe leaf spring contact and the shiny, bright rollers shown in Figure I-1-16. Figure I-1-17 reveals severe scars on the roller shoe from the leaf spring contact, and pitted and discolored rollers. The rollers tend to discolor when combination rolling-sliding action occurs as the rollers follow the injection cam profile. Figure I-1-18 shows one of the roller shoe contact areas of the leaf spring, and Figure I-1-19 shows the roller shoes without the rollers. The dimpled scars on the roller shoes seen in Figure I-1-20 are from the plunger contacts, with the plungers shown in Figure I-1-21.

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Table I-1-6. Pump SN:14193135 Component Parts Wear Evaluations

Stanadyne Pump Parts Evaluations

Pump Type:	DB2831-5209	**SN:**	14193135
Test Condition:	25-Hours, R8 Fuel, 40C, 1800 RPM	**Fuel:**	AF-6778

Part Name	Condition of Part	Rating: 0 = No Wear 5 = Failed
Transfer Pump Blades	Medium to Heavy wear at Liner contact and Rotor Blade Slots	4.5
Blade Springs	Look Good	0
Transfer Pump Liner	Very Worn, Heavy scarring over 100% of Area	5
Transfer Pump Regulator	Some Wear Caused by Blades, Heavy in Spots	3.5
Regulator Piston	Two Small Wear Spots _ Looks Good	1
Rotor	Very Light Wear at Discharge Ports - Looks Good Unusual Chipping at Roller Shoe Slots	Ports: 1 Shoe Slots: 5
Rotor Retainers	Worn From Rotor Contact - Likely to not effect Pump Performnce	3
Delivery Valve	Light Polishing Wear	1
Plungers	Left: Light Scuffing Wear Right: Polishing Wear	Left: 3 Right: 1
Roller Shoes	Both have Dimples Worn from Plungers, 0.010-inch Worn at each Leaf Spring Contact, Scarring at Roller Contact	5
Rollers	Both Look Pitted and Discolored, Early Stages of Flaking	4
Leaf Spring	Worn from Roller Shoe Contact - Left-side Worn Most	4
Cam Ring	Pitting at the Foot of Some of the Lobes	3.5
Thrust Washer	Polishing Wear, with a few Very Light Scratches from Governor Weights	2
Thrust Sleeve	Brown Coating, Light Wear at Governor Arm Slots	1
Governor Weights	Brown Coating, Some Wear on the Foot and Thrust Washer Contact	2
Link Hook	Brown Coating, Light Wear on Arm Fingers	1
Metering Valve	Brown Coating, Light Wear at Helix	1
Drive Shaft Tang	Very Light Polishing Wear	1
Drive Shaft Seals	Good	1
Cam Pin	Light Polishing Wear	1
Advance Piston	Scuffing Wear, Top Right Side	3
Housing	Brown Coating	1

	Pre-Test Setting (inches)	Post-Test Measured (inches)	Roller-to-Roller Change (inches)
Roller-to-Roller Dimension	1.962	1.984	0.022
Eccentricity	0.0035	0.0075	0.004

Figure I-1-12. Injection Pump SN:14193135 Rotor Drive Tang with Minimal Wear

Figure I-1-13. Injection Pump SN:14193135 Rotor Discharge Ports with Minimal Wear

Figure I-1-14. Injection Pump SN:141931335 Drive Shaft with Unusual Chipping in Shoe Slot

Figure I-1-15. Injection Pump SN:14193135 Delivery Valve Wear Scar

Figure I-1-16. Injection Pump SN:14193135 Pre-Test Roller Shoes and Rollers

Figure I-1-17. Injection Pump SN:14193135 25-Hour R-8 Fuel Roller Shoes and Rollers

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Figure I-1-18. Injection Pump SN:14193135 Leaf Spring/Roller Shoe Wear Contact

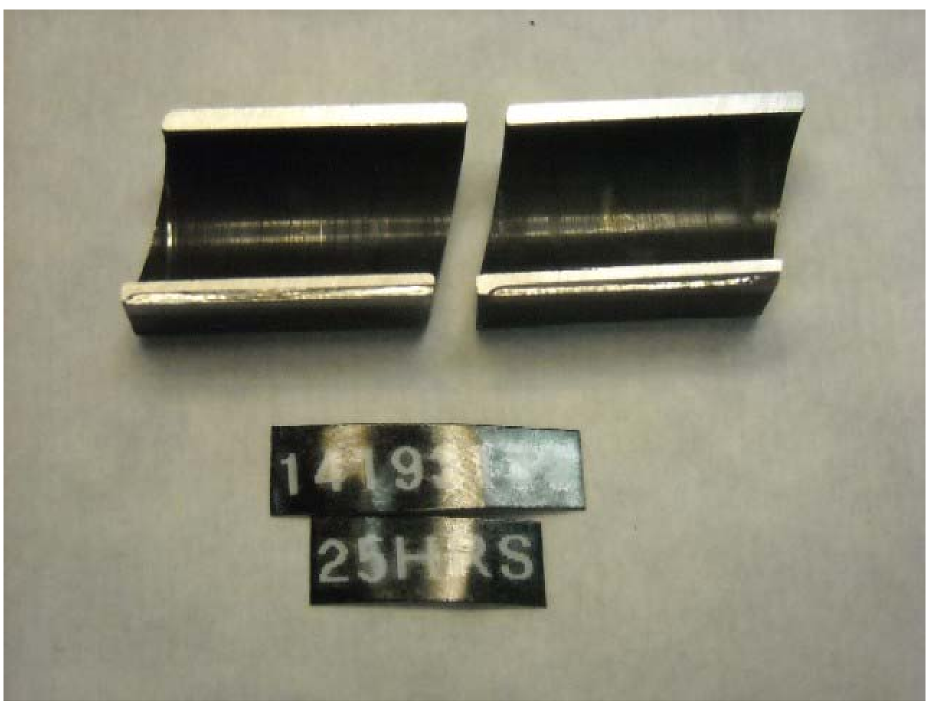

Figure I-1-19. Injection Pump SN:14193135 25-Hour R-8 Fuel Roller Shoes

Figure I-1-20. Injection Pump SN:14193135 Roller Shoe Plunger Contacts

Figure I-1-21. Injection Pump SN:14193135 Plungers

The governor weight shown in Figure I-1-22 has evidence of the dark brown deposit seen in the pump, along with wear seen on the thrust washer contact area. The subsequent wear on the thrust washer is seen in Figure I-1-23. The advance piston from pump SN:14193135 in Figure I-1-24 reveals a fretting type wear pattern that indicates the advance piston may have been chattering in its bore. The advance piston has fuel pressure on one end, offset by spring pressure on the other end, with the spring pressure being a function of the throttle position cam. With the throttle position fixed during testing, the wear on the advance piston suggests the fuel pressure may have been fluctuating in that area of the fuel injection pumps housing. The metering valve shown in Figure I-1-25 regulates the pressure to the rotor fill ports. The pressure is regulated by the action of the helix changing the outlet area of an orifice. Due to WOT operation a polished area shows at one location on the helix. These wear on these components is unique considering the short duration of testing, save the advance piston wear, the wear on the other components would not have effected pump operation.

Figure I-1-26 and I-1-27 illustrate dramatically the level of wear seen in the transfer pump section of fuel injection pump SN:14193135. Figure I-1-26 shows the surface condition of the transfer pump liner prior to testing and Figure I-1-27 shows the surface with 100% area scuffed after 25-hours of operation on the R-8 fuel. Also illustrative of the transfer pump section wear are the transfer pump blade conditions shown in Figure I-1-28 and Figure I-1-29. The edge scuffing shown in Figure I-1-28 correspond to the surface on the transfer pump blades that contact the transfer pump liner. The side scuffing shown in Figure I-1-29 reflect wear from the transfer pump blade slots on the injection pump rotor. The rotor retainer of Figure I-1-30 and the transfer pump regulator of Figure I-1-31 act as thrust surfaces for the rotor and the transfer pump. The circumferential wear scars on the components of Figures I-1-30 and I-1-31 are from the edges of the transfer pump blades, and any thrust forces from the rotor. The final component from the transfer pump section of injection pump SN:14193135 is the transfer pump pressure regulator piston shown in Figure I-1-32. The wear scar seen on the piston may have inhibited the regulator action, thus allowing the transfer pump pressure to increase during testing with injection pump SN:14193135.

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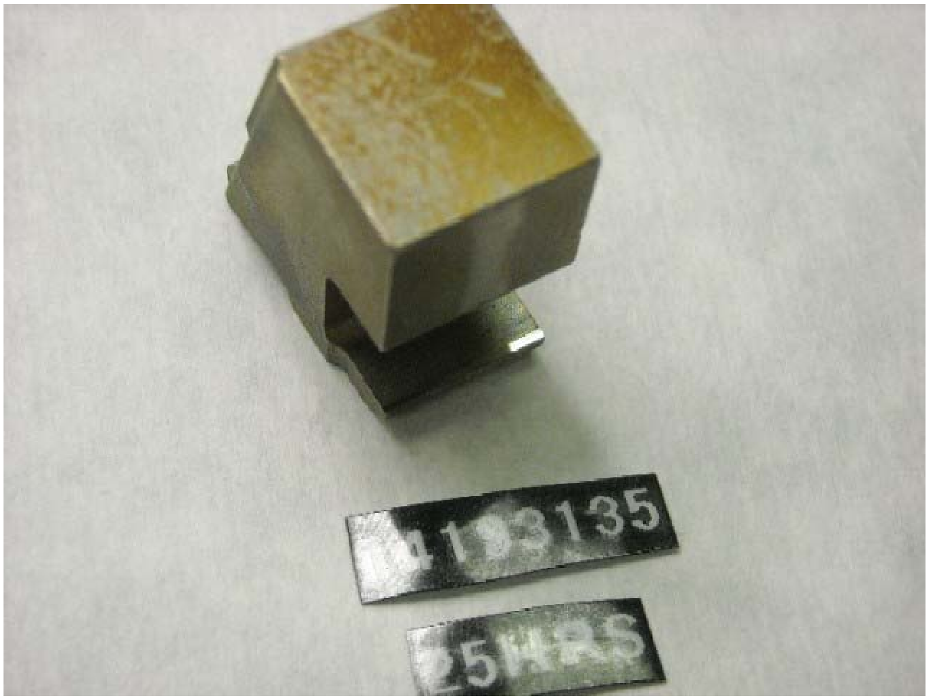

Figure I-1-22. Injection Pump SN:14193135 Governor Weight

Figure I-1-23. Injection Pump SN:14193135 Governor Weight Thrust Washer

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Figure I-1-24. Injection Pump SN:14193135 Advance Piston Wear

Figure I-1-25. Injection Pump SN:14193135 Metering Valve Wear

Figure I-1-26. Injection Pump SN:14193135 Transfer Pump Liner Pre-Test Condition

Figure I-1-27. Injection Pump SN:14193135 Transfer Pump Liner Wear

Figure I-1-28. Injection Pump SN:14193135 Transfer Pump Blade Edge Wear

Figure I-1-29. Injection Pump SN:14193135 Transfer Pump Blade Side Wear

Figure I-1-30. Injection Pump SN:14193135 Rotor Retainer Wear

Figure I-1-31. Injection Pump SN:14193135 Transfer Pump Regulator Wear

Figure I-1-32. Injection Pump SN:14193135 Transfer Pump Pressure Regulator Piston Wear

The parts conditions and subjective wear ratings for fuel injection pump SN:14193181 are summarized in Table I-1-7. Images of the wear seen on the components of fuel injection pump SN:14193181 are shown in Figures I-1-33 through I-1-53. Figures I-1-33, I-1-34, and I-1-35 show the condition of the injection pump rotor that carries the plungers and distributes the compressed fuel. Figure I-1-33 of the drive tang (hardened) and Figure I-1-34 of the discharge ports are in good condition. Figure I-1-35 of the roller shoe slots reveals unusual chipping on the slot edges. The increased roller-to-roller dimensions and increased fuel delivery may have allowed the roller shoes to have more contact with the slot in the rotor. Wear on the injection pump delivery valve is seen in Figure I-1-36.

Figure I-1-37 and Figure I-1-38 are the Pre-Test and Post-Test conditions of fuel injection pump SN:14193181 Roller Shoe and Roller conditions. Of note is the lack of a wear scar at the roller shoe leaf spring contact and the shiny, bright rollers shown in Figure I-1-37. Figure I-1-38 reveals severe scars on the roller shoe from the leaf spring contact, and pitted and discolored rollers. Figure I-1-39 shows one of the roller shoe contact areas of the leaf spring, and Figure I-1-40 shows the roller shoes without the rollers. The dimpled scars on the roller shoes seen in Figure I-1-41 are from the plunger contacts, with the plungers shown in Figure I-1-42.

The governor weight shown in Figure I-1-43 has evidence of the dark brown deposit seen in the pump, along with wear seen on the thrust washer contact area. The subsequent wear on the thrust washer is seen in Figure I-1-44. In Figure I-1-45 the advance piston from pump SN:14193181 reveals a fretting type wear pattern that indicates the advance piston may have been chattering in its bore. The metering valve shown in Figure I-1-46 regulates the pressure to the rotor fill ports. These wear on these components is unique considering the short duration of testing, save the advance piston wear, the wear on the other components would not have impacted pump operation.

Figure I-1-47 and I-1-48 illustrate dramatically the level of wear seen in the transfer pump section of fuel injection pump SN:14193181. Figure I-1-47 shows the surface condition of the transfer pump liner prior to testing and Figure I-1-48 shows the surface with 100% area scuffed after 25-hours of operation on the R-8 fuel. Also illustrative of the transfer pump section wear are the transfer pump blade conditions shown in Figure I-1-49 and Figure I-1-50. The edge scuffing shown in Figure I-1-49 correspond to the surface on the transfer pump blades that contact the transfer pump liner. The side scuffing shown in Figure I-1-50 reflect wear from the transfer pump blade slots on the injection pump rotor. The rotor retainer of Figure I-1-51 and the transfer pump regulator of Figure I-1-52 act as thrust surfaces for the rotor and the transfer pump. He circumferential wear scars on the components of Figures I-1-51 and I-1-52 are from the edges of the transfer pump blades, and any thrust forces from the rotor. The final component from the transfer pump section of injection pump SN:14193181 is the transfer pump pressure regulator piston shown in Figure I-1-53. The wear scar seen on the piston may have inhibited the regulator action, thus allowing the transfer pump pressure to increase during testing with injection pump SN:14193181.

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Table I-1-7. Pump SN:14193181 Component Parts Wear Evaluations

Stanadyne Pump Parts Evaluations

Pump Type:	DB2831-5209	**SN:**	14193181
Test Condition:	25-Hours, R8 Fuel, 40C, 1800 RPM	**Fuel:**	AF-6778

Part Name	Condition of Part	Rating: 0 = No Wear 5 = Failed
Transfer Pump Blades	Medium to Heavy wear at Liner contact and Rotor Blade Slots	4.5
Blade Springs	Look Good	0
Transfer Pump Liner	Very Worn, Heavy scarring over 100% of Area	5
Transfer Pump Regulator	Some Scuffing and Polishing Wear Caused by Blades	3.5
Regulator Piston	Three Small Wear Spots _ Looks Good	1
Rotor	Very Light Wear at Discharge Ports - Looks Good Unusual Chipping at Roller Shoe Slots	Ports: 1 Shoe Slots: 5
Rotor Retainers	Scuffing Wear from Rotor Contact	3
Delivery Valve	Very Light Polishing Wear	0.5
Plungers	Left: Light Scuffing Wear Right: Polishing Wear	Left: 3 Right: 1
Roller Shoes	Both have Dimples Worn from Plungers, Worn at each Leaf Spring Contact	5
Rollers	Both are Discolored, with Light Pitting	4
Leaf Spring	Worn from Roller Shoe Contact - Left-side Worn Most	4
Cam Ring	Looks Good, Light Wear	1.5
Thrust Washer	Polishing Wear, but Looks Good	1
Thrust Sleeve	Brown Coating, Light Polishing Wear at Governor Arm Slots	1
Governor Weights	Brown Coating, Some Light Wear at Washer Contact	1.5
Link Hook	Brown Coating, Light Wear on Arm Fingers	1
Metering Valve	Brown Coating, Light Wear at Helix	1.5
Drive Shaft Tang	Very Light Polishing Wear	1
Drive Shaft Seals	Good	1
Cam Pin	Light Polishing Wear	1
Advance Piston	Scuffing Wear, Top Right Side	3.5
Housing	Brown Coating	1

	Pre-Test Setting (inches)	Post-Test Measured (inches)	Roller-to-Roller Change (inches)
Roller-to-Roller Dimension	1.962	1.988	0.026
Eccentricity	0.0035	0.010	0.0065

Figure I-1-33. Injection Pump SN:14193181 Rotor Drive Tang with Minimal Wear

Figure I-1-34. Injection Pump SN:14193181 Rotor Discharge Ports with Minimal Wear

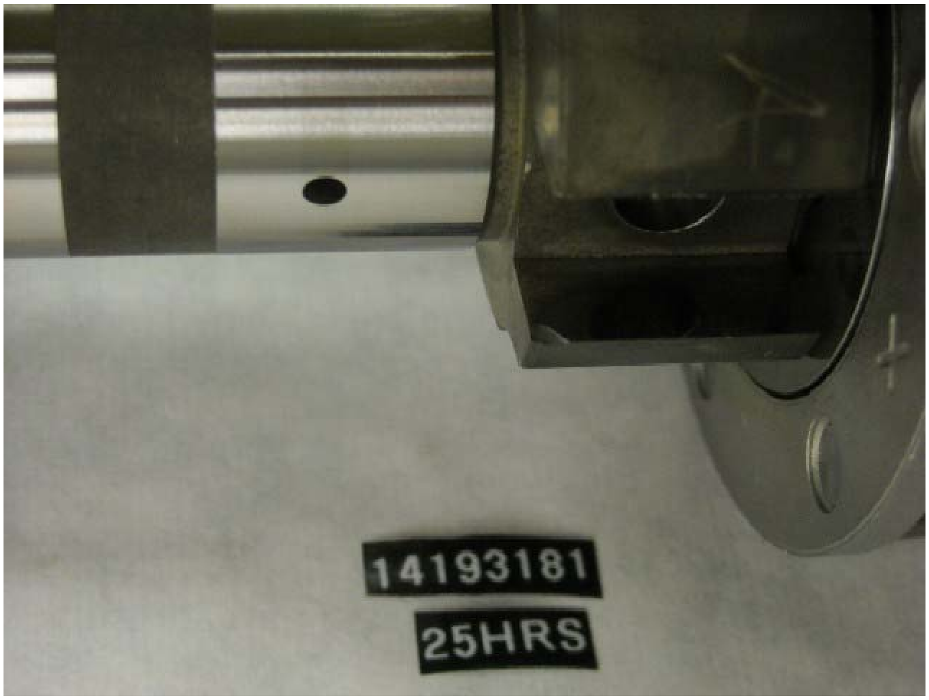

Figure I-1-35. Injection Pump SN:14193181 Drive Shaft with Unusual Chipping in Shoe Slot

Figure I-1-36. Injection Pump SN:14193181 Delivery Valve Wear Scar

Figure I-1-37. Injection Pump SN:14193181 Pre-Test Roller Shoes and Rollers

Figure I-1-38. Injection Pump SN:14193181 25-Hour R-8 Fuel Roller Shoes and Rollers

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Figure I-1-39. Injection Pump SN:14193181 Leaf Spring/Roller Shoe Wear Contact

Figure I-1-40. Injection Pump SN:14193181 25-Hour R-8 Fuel Roller Shoes

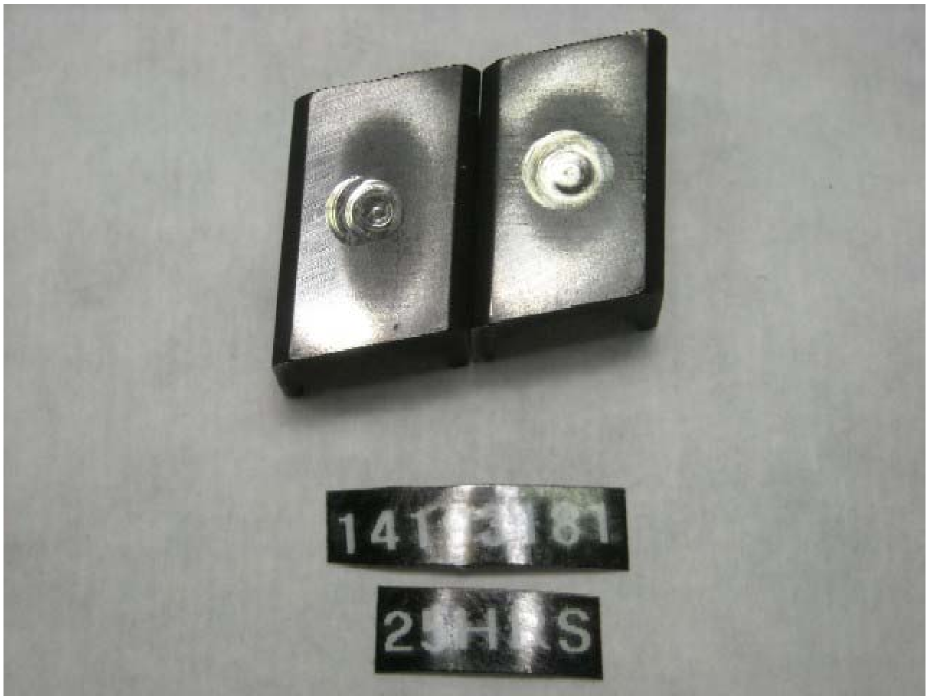

Figure I-1-41. Injection Pump SN:14193181 Roller Shoe Plunger Contacts

Figure I-1-42. Injection Pump SN:14193181 Plungers

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Figure I-1-43. Injection Pump SN:14193181 Governor Weight

Figure I-1-44. Injection Pump SN:14193181 Governor Weight Thrust Washer

Figure I-1-45. Injection Pump SN:14193181 Advance Piston Wear

Figure I-1-46. Injection Pump SN:14193181 Metering Valve Wear

Figure I-1-47. Injection Pump SN:14193181 Transfer Pump Liner Pre-Test Condition

Figure I-1-48. Injection Pump SN:14193181 Transfer Pump Liner Wear

Figure I-1-49. Injection Pump SN:14193181 Transfer Pump Liner Blade Edge Wear

Figure I-1-50. Injection Pump SN:14193181 Transfer Pump Blade Side Wear

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Figure I-1-51. Injection Pump SN:14193181 Rotor Retainer Wear

Figure I-1-52. Injection Pump SN:14193181 Transfer Pump Regulator Wear

Figure I-1-53. Injection Pump SN:14193181 Transfer Pump Regulator Piston Wear

VII. DISCUSSION OF RESULTS

In summary, the effect of synthetic R-8 on the durability of the Stanadyne arctic rotary injection pump that contains hardened parts was examined. This fuel injection pump is found on the HMMWV. In conducting the R-8 pump stand test, it was found that the tests had to be stopped prematurely for the following reasons:

- Excessive Fuel Delivery
- Wear debris was observed
- Increased Transfer pump pressure

The most frequent out of specification parameters during the post-test pump performance checks were:

- Change of Injection Timing
- Increased fuel flow at various speeds

For a results comparison to the R-8 fuel, a prior test program had been performed on a synthetic kerosene grade S-5. (1) The results section for the neat S-5 pump performance test of reference 1 is include as Appendix I-1A to this report. The pumps used in the S-5 testing had a different model designation (thus calibration), however the critical components are basically the same. Similar wear patterns were seen with the neat S-5 fuel, however the neat S-5 fuel did operate longer in the fuel injection pumps (95.6-hours and 150.7-hours). The neat S-5 pumps showed a similar performance degradation pattern as the R-8 pumps, an increase in delivery and transfer pump pressure during the first 24-hours of operation. The neat S-5 pumps did not do as much damage to the transfer pump liner as the R-8 fuelled pumps, likely due to the increased viscosity of an S-5 grade fuel versus the R-8 fuel. It is likely if the neat R-8 fuelled pumps were run longer some form of catastrophic damage would have occurred.

On a positive note, reference 1 also performed tests with CI/LI additives in S-5 fuel that showed a substantial improvement if rotary fuel injection pump durability with synthetic fuel.

One item of significant difference between the R-8 and S-5 fuel injection pumps at the conclusion of testing was the level of brown fuel deposition in the pump housing. When the top covers of the injection pumps were removed on the stand for the R-8 pumps heavy, brown deposition was noted. Likewise the images of the S-5 pumps with their top covers removed (shown in Appendix I-1A) do not show the heavy, brown deposition.

VIII. CONCLUSIONS

The following conclusions are drawn from this project:

1. In conducting the R-8 pump stand test, it was found that the test had to be stopped prematurely for the following reasons:
    - Excessive Fuel Delivery
    - Wear debris was observed
    - Increased Transfer pump pressure
2. The most frequent out of specification parameters during the post-test pump performance checks were:
    - Change of Injection Timing
    - Increased fuel flow at various speeds
3. Neat R-8 fuel severely impacts rotary fuel injection pump life and should not be used.
4. Due to short duration of testing, the impact of neat R-8 fuel on fuel injectors could not be determined.
5. Unusual heavy, brown deposition occurred with neat R-8 fuel.

IX. RECOMMENDATIONS

The technical feasibility of using neat R-8 fuel in rotary fuel injection equipment has been investigated:

1. It is NOT recommended to use Neat R-8 fuel in diesel rotary fuel injection equipment.
2. The source/composition of the unusual heavy, brown deposits seen with neat R-8 fuel.
3. The impact of fuel lubricity additives on R-8 fuel wear in diesel rotary fuel injection equipment should be investigated.
4. The impact of blending R-8 fuel with a MIL-T-83133 kerosene should be investigated.

X. REFERENCES

"Synthetic Fuel Lubricity Evaluations", Interim Report TFLRF No. 367, E.A. Frame and R.A. Alvarez, U.S. Army TARDEC Fuels and Lubricants Research Facility (SwRI), Southwest Research Institute, September 2003, ADA 421822.

APPENDIX I

R-8 Pump Evaluations

APPENDIX I-1: R-8 HRJ Pump Test Stand Evaluations, SwRI Report #13283

APPENDIX I-1A: Synthetic Kerosene Grade S-5 Rotary Fuel Injection Pump Testing Excerpted From TFRLF Interim Report No. 367 (Orig. Figures Renumbered)

The following excerpt comes from Interim Report TFLRF No. 367, "Synthetic Fuel Lubricity Evaluations", E.A. Frame and R.A. Alvarez, U.S. Army TARDEC Fuels and Lubricants Research Facility (SwRI), Southwest Research Institute, September 2003, ADA 421822. The excerpt discusses the results of a rotary pump test with a neat synthetic kerosene grade S-5 fuel. Original figures have been renumbered, but content remain the same.

B. Rotary Pump Tests

1. Test 1 Neat S-5 Fuel (Pumps 1 & 2)

Two new arctic pumps were mounted on pump stand Rigs 3 and 4, and the test stand was slowly ramped to 1000 RPM and operated for five minutes. For the next five minutes the test stand was then incrementally ramped to 1800 RPM until the inlet fuel temperature reached the specified temperature of 104ºF, and the first temperature, flow, and pressure readings were recorded.

Early into the test, the pump outlet temperatures increased slightly, and a corresponding rise in rotameter flows was noted, which indicated accelerated wear. Twenty-four hours into the test, rotameter flows increased from 81.5 to 100cc on Pump 1 and from 77.5 to 90cc on Pump 2. As the fuel flow increased, the inlet pressure fell to 0 psi and was adjusted back to 3 psi.

Approximately 46 hours into the test, recorded data revealed that the inlet fuel pressure on Pump 1 increased to 11 psi and fuel flow decreased to 43cc, indicating that some event was causing extreme accelerated wear. Fuel flow continued to increase on Pump 2, indicating accelerated wear on this pump also. All other parameters remained at normal ranges; however, in order to preclude a complete seizure of the head and rotor assembly on Pump 1, the test stand was shut down at 95.6 hours of testing. The top cover on Pump 1 was removed for inspection. Slight metal debris was observed in the top chamber of the pump (Figure I-1A-1). Metal debris was also found in the top cover electric shut-off solenoid (Figure I-1A-2). Pump 1 was removed from the test stand, and testing resumed with Pump 2.

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APPENDIX I-1A: Synthetic Kerosene Grade S-5 Rotary Fuel Injection Pump Testing Excerpted From TFRLF Interim Report No. 367 (Orig. Figures Renumbered)

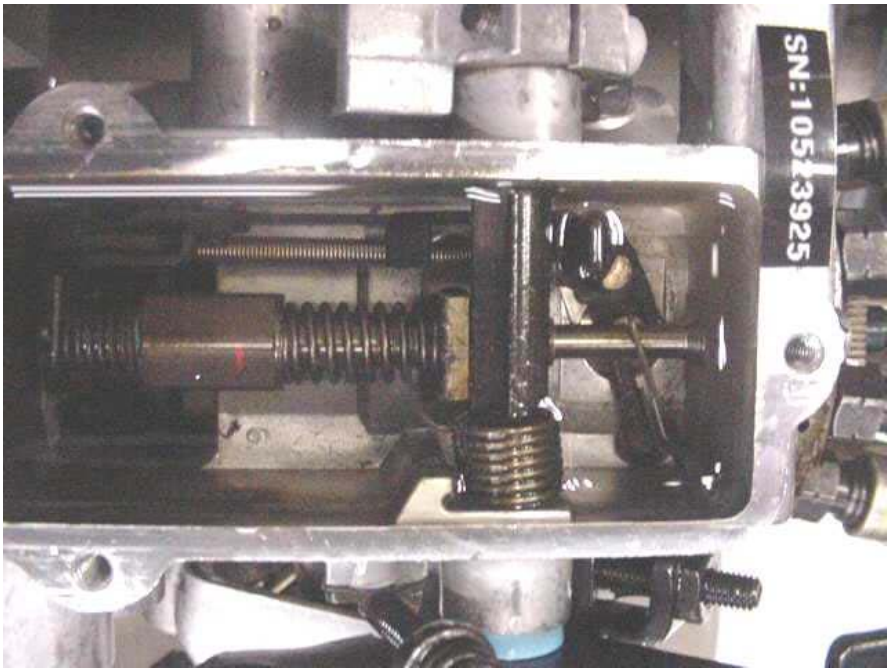

Figure I-1A-1. Test 1 Pump 1: Pump Chamber Wear Debris

Figure I-1A-2. Test 1 Pump 1: Metal Shavings on Solenoid

The test progressed until the test stand shut down after 151 hours. Logged data revealed that increased fuel outlet temperature triggered the automatic shutdown of the test stand solenoid, which is used to prevent imminent seizure of the head and rotor assembly. The top cover was removed from Pump 2; however, there was no evidence of wear debris in the chamber or the electric shut-off solenoid (Figures I-1A-3 and I-1A-4).

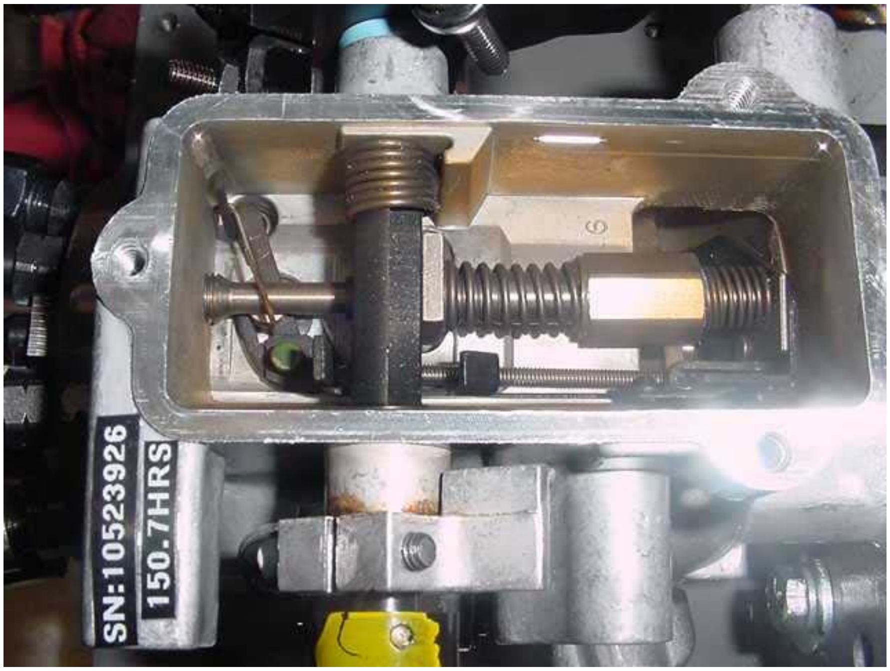

Figure I-1A-3. Test 1 Pump 2: Debris Free Pump Chamber

Figure I-1A-4. Test 1 Pump 2: Debris Free Solenoid

Test stand parameter plots in Appendix I-1B (Figures I-1B-1 through I-1B-4) show that both pumps exhibited a marked increase in rotameter fuel flow readings and a corresponding increase of fuel-return temperatures at the onset of the test. These parameters are precursors in accelerated pump wear. Pump 1 shows a significant increase in transfer pump pressure when the rotameter fuel flow decreases.

Pump 2 was removed from the test stand, rinsed, and prepared for post-test performance evaluations. Results of these evaluations are shown in Table I-1A-1. Differences occurred between pre- and post- test results on 9 of 18 performance sequences for Pump 1. Decreased fuel delivery at 750, 1800, 200, and 75 RPM were the most critical of the out-of-specification performance checks. This pump would not be expected to perform adequately in a typical vehicle application. The very low fuel flow delivered at cranking speed would probably not be sufficient to start the engine. Pump 2 exhibited an increase in fuel flow at 1000 and 1750 RPM; in a typical vehicle application, rough idle and visible smoke emissions would be expected.

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APPENDIX I-1A: Synthetic Kerosene Grade S-5 Rotary Fuel Injection Pump Testing Excerpted From TFRLF Interim Report No. 367 (Orig. Figures Renumbered)

Table I-1A-1. Rotary Pump Performance Checks Test 1

Pump Model: DB2829-4879 Arctic	**Test Fuel: S-5 AL-26943**	**Pump No.1 Rig 3 SN10523925**			**Pump No. 2 Rig 4 SN10523926**		
		Date: 04/07/03		**Hours: 95.6**	**Date: 4/10/03**		**Hours: 150.7**
RPM	**Specification**	**Pre-Test**	**Post-Test**	**Change**	**Pre-Test**	**Post-Test**	**Change**
1000	Trans Pump Pres. 60-62 psi	61	**66**	5	61	60	-1
	Return Fuel 225-375 cc	325	**395**	70	225	275	50
	Fuel Delivery 56 cc max.	50.2	34	-16.2	50.4	**78.5**	28.1
325	Low Idle 12-16 cc	14	14.1	0.1	13.5	14.9	1.4
	Housing Pres. 8-12 psi	8	8	0	8	**7.75**	-0.25
	C.A.S. 0-1 Degree	0	0	0	0	0	0
1750	Fuel Delivery 48-53 cc	50	**35**	-15	49	**70.7**	21.7
	Advance 1.25-5.25 Degrees	4.5	**6.5**	2	4.5	4	-0.5
750	F.C. 21.5-23.5 cc	22	**31.4**	9.4	22.1	21.5	-0.6
	Advance 1.25-3.75 Degrees	2.2	**0**	-2.2	2	2.25	0.25
1800	Fuel Delivery 48 cc min.	49	**34.8**	-14.2	48.7	67.4	18.7
	Transfer Pump Pressure	90	94	4	89	85	-4
	Housing Pressure psi.	6	5	-1	6.5	7	0.5
1900	Fuel Delivery 33 cc min.	42	34.8	-7.2	36	59.6	23.6
2025	High Idle 15 cc max.	1.2	2.6	1.4	1.4	2.5	1.1
	Trans. Pump Pres.125psi max.	116	116	0	117	120	3
200	Fuel Delivery 45 cc min.	45	**21.6**	-23.4	46	74.7	28.7
	Shut-Off 4 cc max.	0	0	0	0	0	0
75	Fuel Delivery 28 cc min.	28	**8.8**	-19.2	37.2	52.8	15.6
	Trans. Pump Pres. 12 psi min	19	18	-1	20	20	0
Bold Values are out of specification							

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R-8 Pump Evaluations

APPENDIX I-1: R-8 HRJ Pump Test Stand Evaluations, SwRI Report #13283

APPENDIX I-1A: Synthetic Kerosene Grade S-5 Rotary Fuel Injection Pump Testing Excerpted From TFRLF Interim Report No. 367 (Orig. Figures Renumbered)

Post-test inspection of Pumps 1 and 2 revealed that the transfer pump blades had light wear at the liner contact and that each had a broken blade spring. The transfer pump liner had slight wear on 5 to 10% of the contact surface area for Pump 1 and 30% for Pump 2. Both liners were functional. The rotor shafts on both pumps exhibited varying degrees of scarring from the broken transfer pump blade springs.

Shoe and roller assemblies were excessively worn at the contact point with the leaf spring. The surface where the rollers make contact in the shoe assemblies on both pumps showed a galled surface, and the rollers were pitted and abraded. The back of the shoes (where the plunger contacts) showed excessive wear. One of the shoes on Pump 1 wore so excessively at the contact point with the leaf spring that it traveled away from the holder until it made contact with the cam ring assembly, causing a piece to chip off the end of the shoe.

Normally a metal chip would create a binding condition, which would immediately seize the head and rotor assembly and shear the drive shaft. However in this instance, the metal chip pulverized, creating highly accelerated wear throughout the pump that ultimately caused the right plunger to seize and to chronically reduce the fuel flow to the transfer pump.

Figures I-1A-5 through I-1A-10 show the shoe and roller assemblies, the back of the shoe holders, and the fuel plunger assemblies. The chipped shoe assembly can be seen in Figure I-1A-5 while the seized plunger is shown in Figure I-1A-9. Figure I-1A-11 shows deep scarring at the upper ports of the rotor shaft on Pump 1, and light scarring can be seen at the bottom of the rotor shaft in Figure I-1A-12.

Figure I-1A-5. Test 1 Pump 1: Chipped Shoe Wear

Figure I-1A-6. Test 1 Pump 2: Shoe and Roller Wear

Figure I-1A-7. Test 1 Pump 1: Shoe Back and Roller Wear

Figure I-1A-8. Test 1 Pump 2: Shoe Back and Roller Wear

Figure I-1A-9. Test 1 Pump 1: Plunger Assembly Wear

Figure I-1A-10. Test 1 Pump 2: Plunger Assembly Wear

Figure I-1A-11. Test 1 Pump 1: Rotor Shaft Wear

Figure I-1A-12. Test 1 Pump 2: Rotor Shaft Wear

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R-8 Pump Evaluations

APPENDIX I-1: R-8 HRJ Pump Test Stand Evaluations, SwRI Report #13283

APPENDIX I-1B: Pump Performance Plots Excerpted From TFLRP Interim Report No. 367 (Orig. Figures Renumbered)

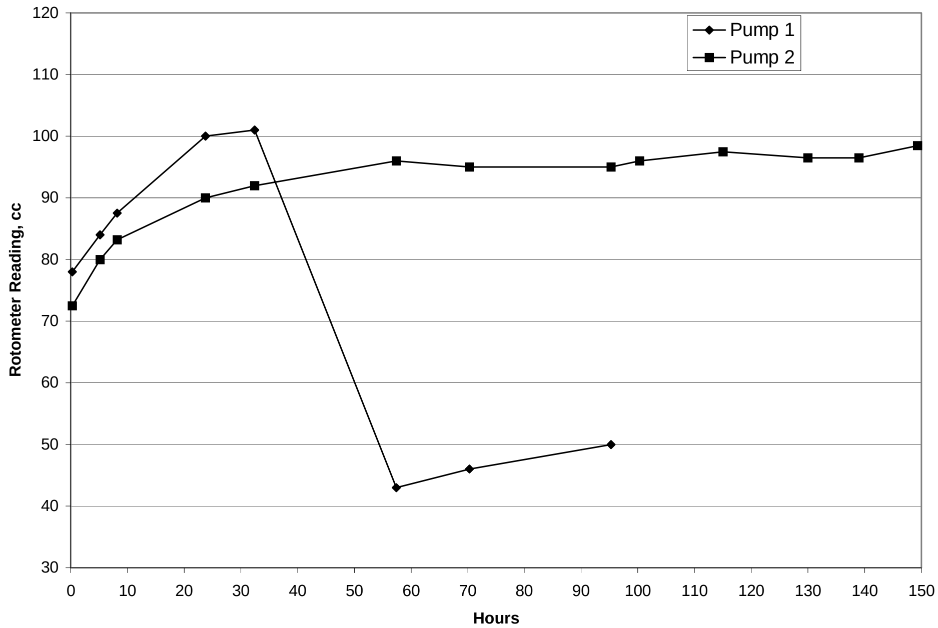

Figure I-1B-1. Test 1 – Rotameter Readings

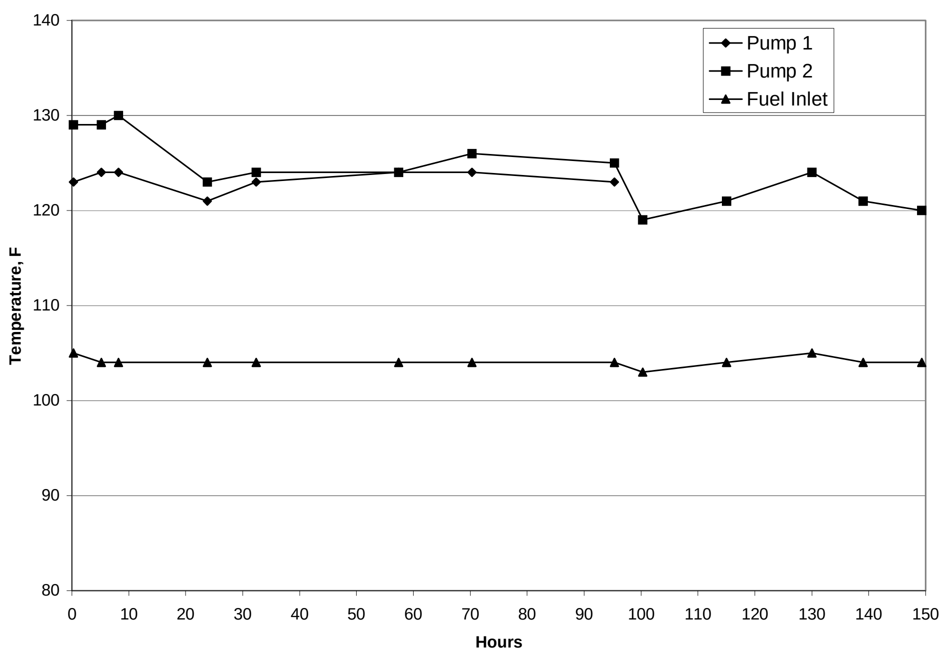

Figure I-1B-2. Test 1 – Fuel Return and Inlet Temperatures

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APPENDIX I-1B: Pump Performance Plots Excerpted From TFLRP Interim Report No. 367 (Orig. Figures Renumbered)

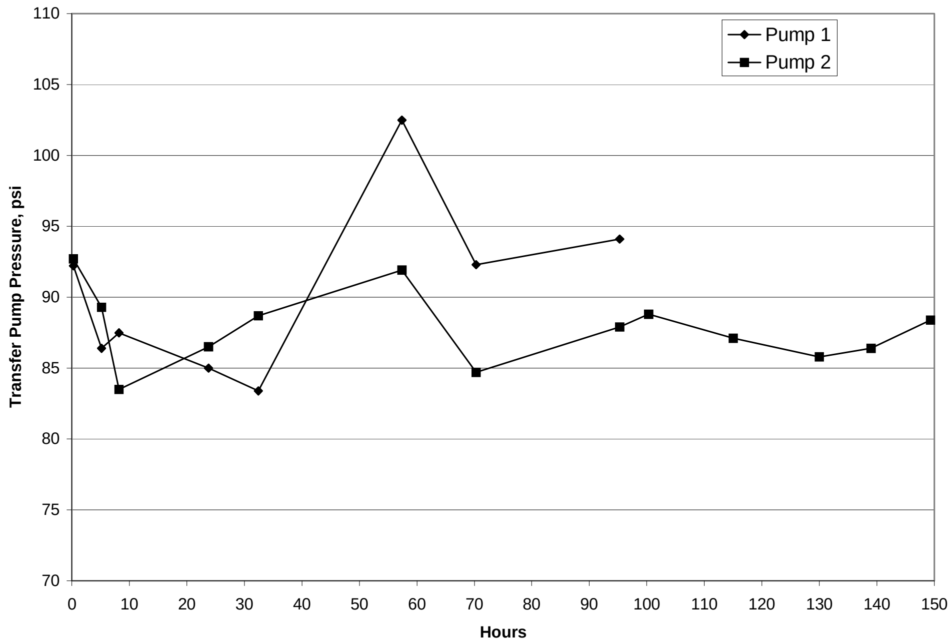

Figure I-1B-3. Test 1 – Transfer Pump Pressures

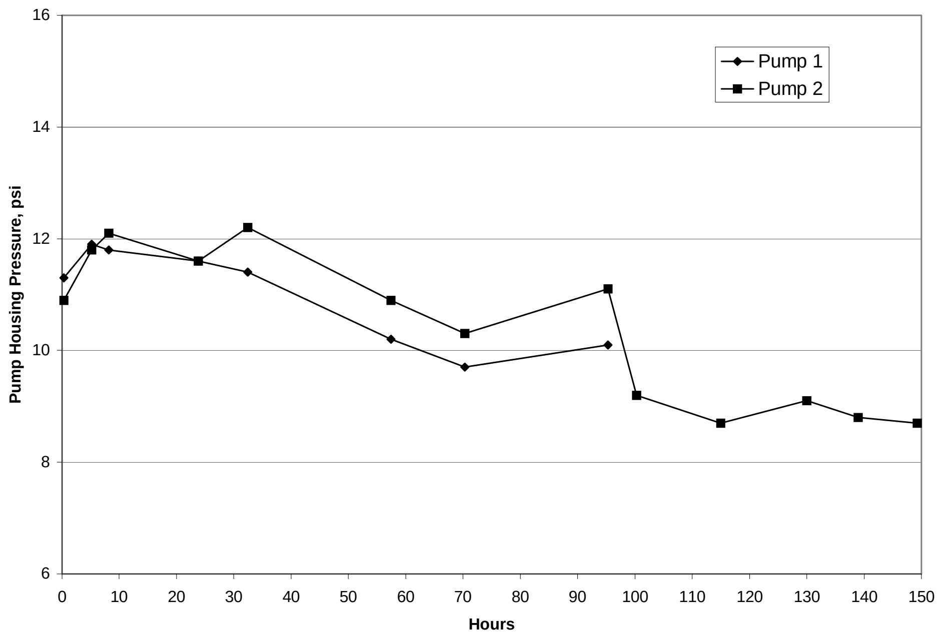

Figure I-1B-4. Test 1 – Pump Housing Pressures

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R-8 Pump Evaluations
APPENDIX I-2: R-8 HRJ Follow-on Pump Evaluations, SwRI Report #14406

R8 ROTARY FUEL INJECTION PUMP WEAR TESTING

FINAL REPORT
SwRI® Project No. 08.14406.03

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1.0 BACKGROUND & OBJECTIVE

Initial tests with an R8 Synthetic Paraffinic Kerosene (SPK) fuel revealed severe wear and extreme life reduction of rotary fuel injection pumps for diesel engines. The untreated R8 (SPK) fuel caused performance degrading wear on the rotary fuel injection pumps within 25-hours of operation on the untreated fuel. However, the wear seen with the untreated R8 (SPK) fuel was not dissimilar to wear observed with untreated S8 or untreated S5 fuels in the same type of diesel fuel injection equipment. Previous work with S8/S5 fuels showed that those fuels responded well to the addition of a Corrosion Inhibitor/Lubricity Improver (CI/LI) additive to extend the life of the rotary fuel injection equipment. In addition, it is likely the R8 (SPK) fuel will be used as a blending component in the blend with petroleum JP-8 fuel (at a maximum of 50-percent) in order to maintain the blend fuel density above the JP-8 specification minimum. The objective of the study was to look at the effectiveness of a CI/LI additive at maximum treat rate in extending rotary fuel injection equipment durability while operating on an R8 (SPK) fuel and an R8 (SPK)/Jet-A fuel blend.

2.0 APPROACH

Endurance tests were performed using a motorized pump stand to define the effects of fuel and fuel additives on full-scale fuel injection equipment durability. The test series will attempt to determine the level of fuel injection system degradation due to wear and failure of the boundary film in R8 (SPK) fuels. A 500-hour pump operating procedure will be utilized.

3.0 SCOPE OF WORK

3.1 FUELS

The initial test fuel was the same R8 (SPK) fuel evaluated in a previous study (1) after being clay filtered and filtered to remove any wear particles from the prior testing. After clay filtering, the R8 (SPK) fuel was treated with a fuel lubricity additive. The fuel lubricity additive was a QPL-25017 product, DCI-4A, used at the maximum treat rate.

The second test fuel was a fifty-percent blend of the R8 (SPK) and fifty-percent Jet-A fuels. The R8 (SPK) fraction was clay filtered before blending with the Jet-A fuel fraction. Jet-A was used so that the final blend could be treated to the maximum treat rate from QPL-25017 for the DCI-4A additive.

3.2 FUELS INJECTION SYSTEM

3.2.1 Stanadyne

The test articles were opposed-piston, rotary distributor, fuel injection pumps used on HMMWV engines. Rotary distributor fuel injection pumps are fuel lubricated, thus sensitive to fuel lubricity. Highly refined, low sulfur, and low aromatic fuels can cause substantial performance degradation with these pumps. Wear seen in the Stanadyne pumps could be interpolated to rotary distributor pumps of other manufacturers.

3.3 PUMP TEST PROCEDURE

Full-scale equipment tests were performed using new injection pumps and fuel injectors with each test fuel. The pump tests were performed in duplicate in order to obtain average wear results. Two fifty-five gallon drums of the appropriate test fuel are normally required for each 500-hour pump tests. Due to the limited supply of R8 (SPK) fuel, one 55-gallon drum was utilized for testing, with the drum of fuel clay filtered at the 250-hour interval. After clay filtering, the R8 (SPK) fuel was treated again with the DCI-4A additive for the next 250-hours of operation. The 500-hour tests were performed under steady state conditions at maximum fuel delivery for the test pump, as summarized in Table 1. The tests were occasionally halted and restarted as necessary due to scheduling requirements or technical reasons. The pumps were started gradually to prevent seizure due to thermal shock. To further reduce the risk of seizure due to differential expansion, the fuel was not preheated prior to starting the pumps.

Table 1 - Pump Operating Conditions

Parameter:	Value:
Duration, Hrs	500
Speed, RPM	1800
Fuel Inlet Temperature, °C	40
Throttle Position	Full
Fuel-Drum Temperature, °C	<30

The test stand includes injection flow and pump return pipes, lift pumps, filters, flow meters, a fuel pre-heater, and a heat exchanger to reduce the temperature of the fuel before returning to the storage tank. A schematic diagram of the fuel supply system proposed for the pump stand is shown in Figure 1. The temperature of the incoming fuel to each pump, was controlled to 40°C.

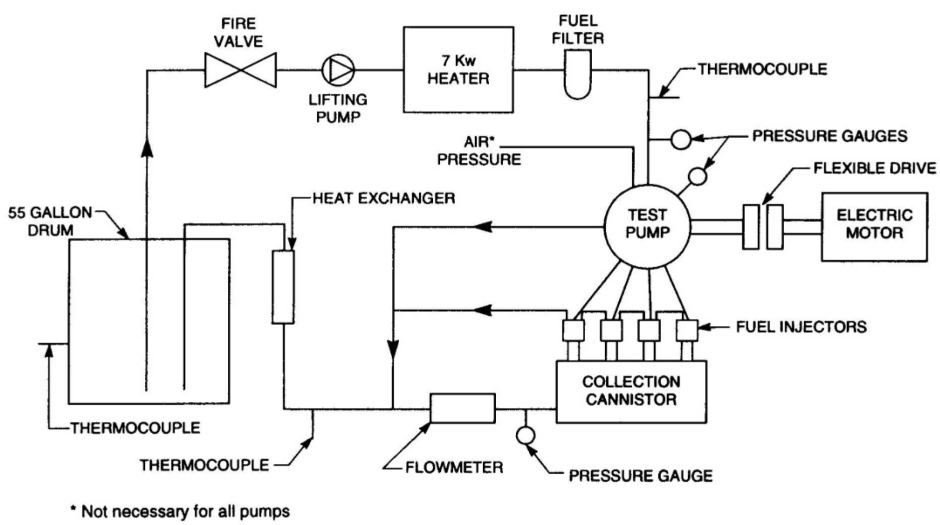

Figure 1 - Schematic Diagram of Fuel Delivery System

The high-pressure outlets from the pumps were connected to fuel injectors assembled in a collection canister.

3.4 LABORATORY SCALE WEAR TESTS

Stanadyne has indicated the lubricity of the test fuel should be determined prior to testing. Stanadyne recommends measuring the fuel when the test fuel is changed at 250-hour intervals. The laboratory scale wear performed on the test fuels was the Ball on Cylinder Lubricity Evaluator (BOCLE) procedure described in ASTM D-5001, because that procedure is called out for aviation kerosene fuels and additives.

3.5 EVALUATION OF THE PUMPS USING A CALIBRATED TEST STAND

Prior to and following each 500-hour pump test, the performance of the Stanadyne pumps, were evaluated using a calibrated test stand. The objective of the calibration stand evaluation is to define the effect of the durability testing on pump performance. The calibration stand evaluations were performed at an authorized pump distributor. No adjustments were made to any of the pumps to achieve the manufacturer's specifications, either before, during or following the 500-hour pump stand tests.

The appropriate inspection and test procedures for determining fuel injector performance were followed prior to, and after each fuel evaluation.

3.6 PUMP DISASSEMBLY AND WEAR EVALUATION

The pumps and fuel injectors were disassembled at SwRI® following completion of the 500-hour durability test and the subsequent evaluation using the calibrated test stand. A SwRI disassembly and rating procedure was originally developed for the U.S. Army for use with Stanadyne equipment. Each sliding contact within the pump is rated on a scale from 0 to 5, with 0 corresponding to no wear and 5 corresponding to severe wear and failure. The wear scars on components throughout the pump are evaluated visually and quantitative measurements of wear volume will be made on critical pump components. The SwRI procedure looks at all wear contacts within the pump and injectors, which are lubricated by the fuel.

4.0 PUMP TEST STAND EVALUATIONS

4.1 ROTARY PUMP TEST PROCEDURE

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5209, for a General Motors Engine Products 6.5L engine application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure 2.

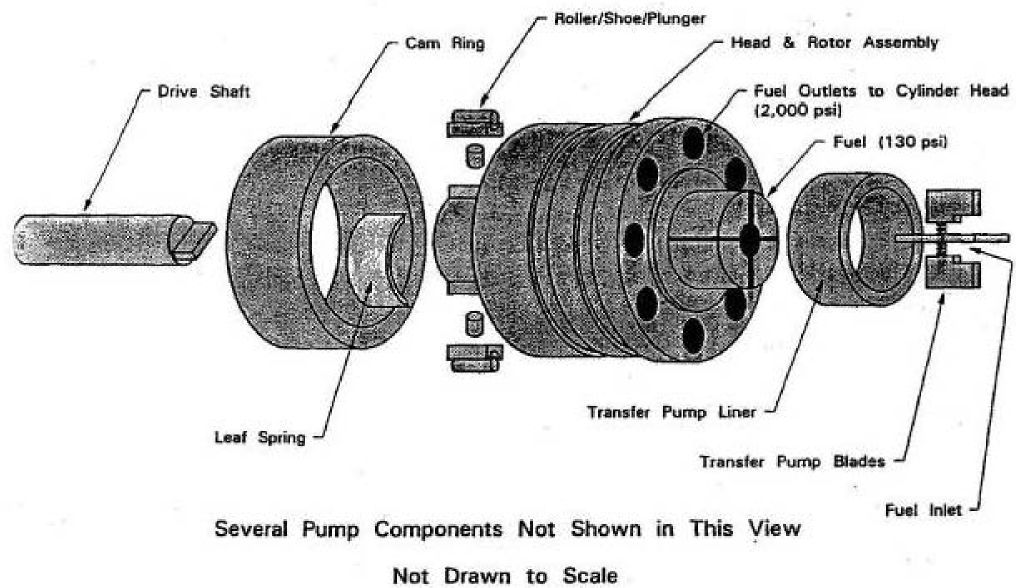

Figure 2 - Schematic Diagram of Principal Pump Components

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade heights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5209 model. The specification calls for a roller-to-roller dimension setting of 1.962 inches ± .0005 inches. All pumps were set prior to testing with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured.

Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent benchmark for the effects of fuel lubricity.

The pumps were reassembled and pre-test performance evaluations were conducted. The pumps were then mounted on the test stand and operated at 1800 RPM, with the fuel levers in the wide open throttle position (WOT) for targeted 500-hour increments (or less). Fuel flow, fuel inlet and outlet temperatures, transfer pump, pump housing pressures, and RPM were tracked and recorded. Flow meter readings reflect the injected fuel from the eight fuel injectors in each collection canister. Any wear in the fuel injection pump metering section was reflected as an increased or reduced flow reading. The fuel inlet temperature control target was 40°C. Inlet temperature variations directly affect the fuel return temperature, which is a function of accelerated pump wear. The transfer pump pressure is the regulated pressure the metal blade transfer pump supplies to the pump metering section. With low lubricity fuels, wear is likely to occur in the transfer pump blades, blade slot, and eccentric liner. Wear in these areas generally causes the transfer pump pressure to decrease. However, because the transfer pump has a pressure regulator, significant wear needs to occur in the transfer pump before the fuel pressure drops to below the operating range allowed in the pump specification. The housing pressure is the regulated pressure in the pump body that affects fuel metering and timing. With low lubricity fuel, wear occurs in high fuel pressure generating opposed plungers and bores, and between the hydraulic head and rotor. Leakage from the increased diametrical clearances of the plunger bores and the hydraulic head and rotor, results in increased housing pressures. Increased housing pressure reduces metered fuel and retards injection timing.

4.2 PUMP TEST STAND

The rotary pumps were tested on a drive stand with a common fuel supply. To insure a realistic test environment, the mounting arrangement and drive gear duplicate that of the 6.5L engine. The fuel was maintained in a 55-gallon drum and continuously re-circulated throughout the duration of each test. A gear pump provided a positive head of 3 psig at the inlet to the test pumps. A cartridge filter rated at 4-μm (c) was used to remove wear debris and particulate contamination. Finally, a 5-kW Chromalox explosion-resistant circulation heater produced the required fuel inlet temperature.

The high-pressure outlets from the pumps were connected to eight Bosch Model O432217104 fuel injectors for a 6.5L engine and assembled in a collection canister. Fuel from both canisters was then returned to the 55-gallon drum. A separate line was used to return excess fuel from the governor housing to the fuel supply. Fuel-to-water heat exchangers on both the return lines from the injector canisters and the governor housing were used to cool the fuel. The test stand with pumps mounted is shown in Figure 3.

Figure 3 - Dual Stanadyne Rotary Fuel Injection Pumps Mounted on Stand with Fuel Injectors

A data acquisition and control system recorded pump stand RPM, fuel inlet pressure, fuel inlet and return temperature, transfer pump, pump housing pressures, and fuel flow readings. The entire rig was equipped with safety shutdowns that would turn off the drive motor in the event of low fluid level in the supply drum, high inlet and return fuel temperature (70° C), or low or high transfer pump and housing pressure. Since high-return fuel temperature is a precursor of accelerated wear, this failsafe feature reduced the possibility of head and rotor seizure.

5.0 ROTARY FUEL INJECTION PUMP EVALUATIONS AND RESULTS

5.1 ROTARY FUEL INJECTION PUMPS WITH R8 FUEL BLENDS

5.1.1 R8 Fuel with 22.5-ppm DCI-4A CI/LI Additive

The Stanadyne model DB2831-5209 rotary fuel injection pumps were received from a supplier and the pumps appeared to be in good condition. The fuel injection pumps were installed on the test stand and the pumps were operated for an hour to validate their operation and to run-in the components with a good lubricity fuel, a Jet -A fuel treated with 22.5-ppm CI/LI additive. The pumps were run for 30-minutes at 1200-RPM pump speed, with a half-rack fuel flow setting. For the final 30-minutes of the run-in the pumps were operated at the test condition of 1800-RPM pump speed, with a full-rack fuel flow setting.

The test bench and pumps were flushed with isooctane to attempt to remove any remaining run-in fuel and CI/LI additive. The isooctane was forced through the fuel injection pumps with pressure; the pumps were not run with isooctane in them. Following the isooctane flush, untreated synthetic Iso-Paraffinic Kerosene was used to flush the test stand and pumps prior to fuelling with the additive treated R8 test fuel. The treated R8 was introduced into the test stand and the stand was operated at an idle condition until 2L of fuel was flushed through each set of eight injectors.

The 55-gallon drum of test fuel from the prior test was clay filtered and checked for lubricity with the ASTM D 5001 BOCLE. The test fuel after clay-filtering revealed a 0.9mm BOCLE wear scar diameter, which was close to the original BOCLE value for the fuel. The test fuel was then treated with 22-ppm DCI-4A and revealed a BOCLE value of 0.55mm. At 250-hours of pump stand operation the drum of R8 fuel was clay-treated again and treated with 22-ppm of DCI-4A and the BOCLE value was measured to be 0.53-mm.

The testing with the treated R8 was initiated and the fuel injection pumps and stand control system appeared to function properly. The temperature and flow histories of the fuel injection pumps are shown in Figure 4. At the start of a day of testing (around 75-hours), the control system reverted to a higher set point for fuel inlet temperature, however the stand was shutdown and the startup/shutdown procedures and set point values were modified so that the fuel inlet temperature would always default to 40°C. The fuel return temperatures were very consistent after 100-hours of operation, which indicated there was not any unusual wear in the fuel injection pumps.

Both pumps completed 250-hours of operation with a small decrease in delivery, 5-10 percent. Fuel injection pump SN: 14833394 appeared to have a more erratic delivery. At 342-hours of testing the tops of both fuel injection pumps were removed for inspection. Fuel injection pump SN: 14833394 revealed a small amount of metallic debris, likely due to internal wear. Fuel injection pump SN: 14828532 did not reveal any wear debris. Both fuel injection pumps were free of the brown deposition that had previously been seen with the neat R8 fuel.

Fuel injection pump SN: 14828532 revealed a steady slight decrease in fuel delivery with an increase in housing pressure. Figure 5 shows the pressure histories for the test with the R8 + 22.5-ppm DCI-4A fuel. Housing pressure usually increases in these pumps when an excessive amount of high-pressure fuel leaks past the pumping plungers, indicating an increase of the plunger-to-bore clearance. Fuel injection pump SN: 14833394 revealed a consistent housing pressure and erratic delivery characteristics, with a larger drop-off in delivery that was eventually recovered. Erratic delivery in these pumps could be due to metering valve wear or governor linkage wear. At 500-hours of testing the tops of both fuel injection pumps were removed for inspection. Fuel injection pump SN: 14833394 revealed a small amount of metallic debris, likely due to internal wear that was previously reported when inspected at 342-hours of operation. Fuel injection pump SN: 14828532 did not reveal any wear debris. Both fuel injection pumps were free of the brown deposition that had previously been seen with the neat R8 fuel. Both fuel injection pumps appeared to be functioning normally at 500-hours on the test stand.

5.1.2 Blend of R8 and Jet-A Fuels with 22.5-ppm DCI-4A CI/LI Additive

Two Stanadyne model DB2831-5209 fuel injection pumps were installed on the test stand and the pumps were operated for an hour to validate their operation and to run-in the components with a good lubricity fuel, a Jet -A fuel treated with 22.5-ppm CI/LI additive. The pumps were run for 30-minutes at 1200-RPM pump speed, with a half-rack fuel flow setting. For the final 30-minutes of the run-in the pumps were operated at the test condition of 1800-RPM pump speed, with a full-rack fuel flow setting.

The test bench and pumps were flushed with isooctane. The isooctane was forced through the fuel injection pumps with pressure; the pumps were not run with isooctane in them. Following the isooctane flush, untreated synthetic Iso-Paraffinic Kerosene was used to flush the test stand and pumps prior to fuelling with the additive treated R8/Jet-A test fuel blend.

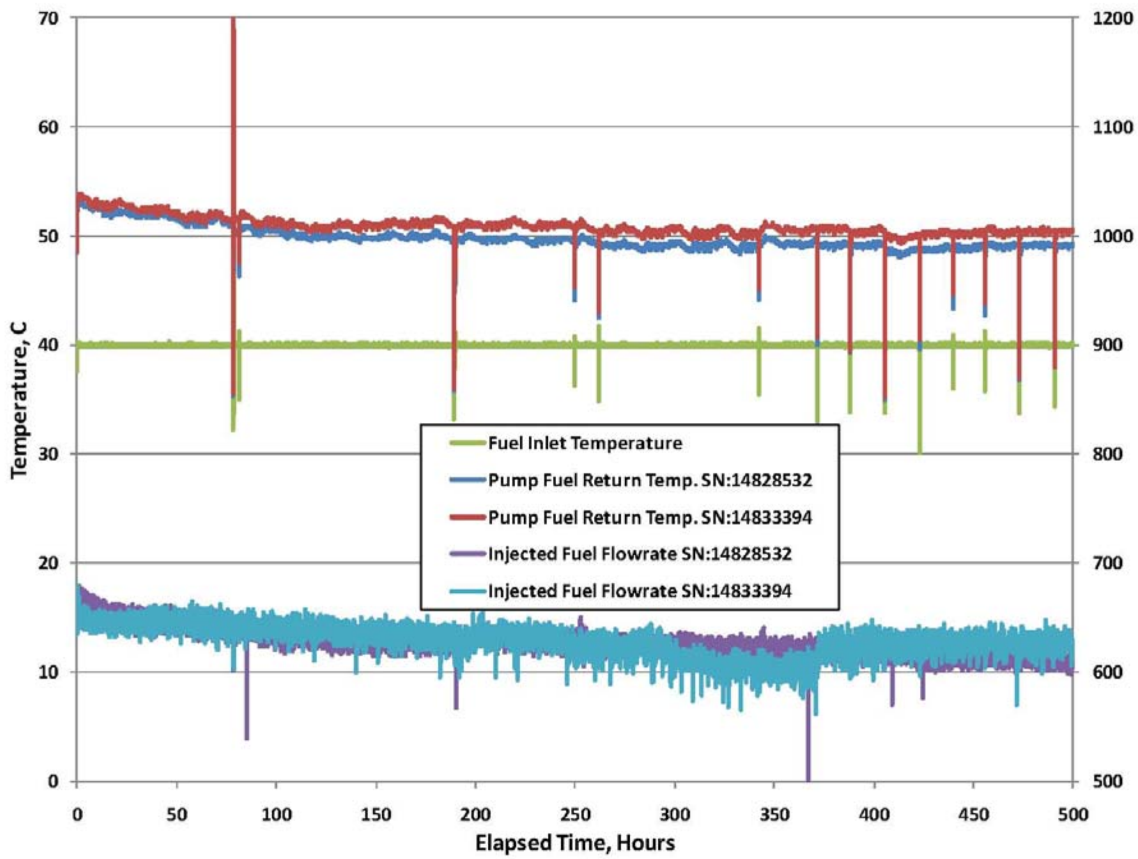

Figure 4 - Fuel Inlet, Fuel Return Temperatures, and Fuel Flowrate Histories for R8+22.5-ppm DCI-4A Fuel

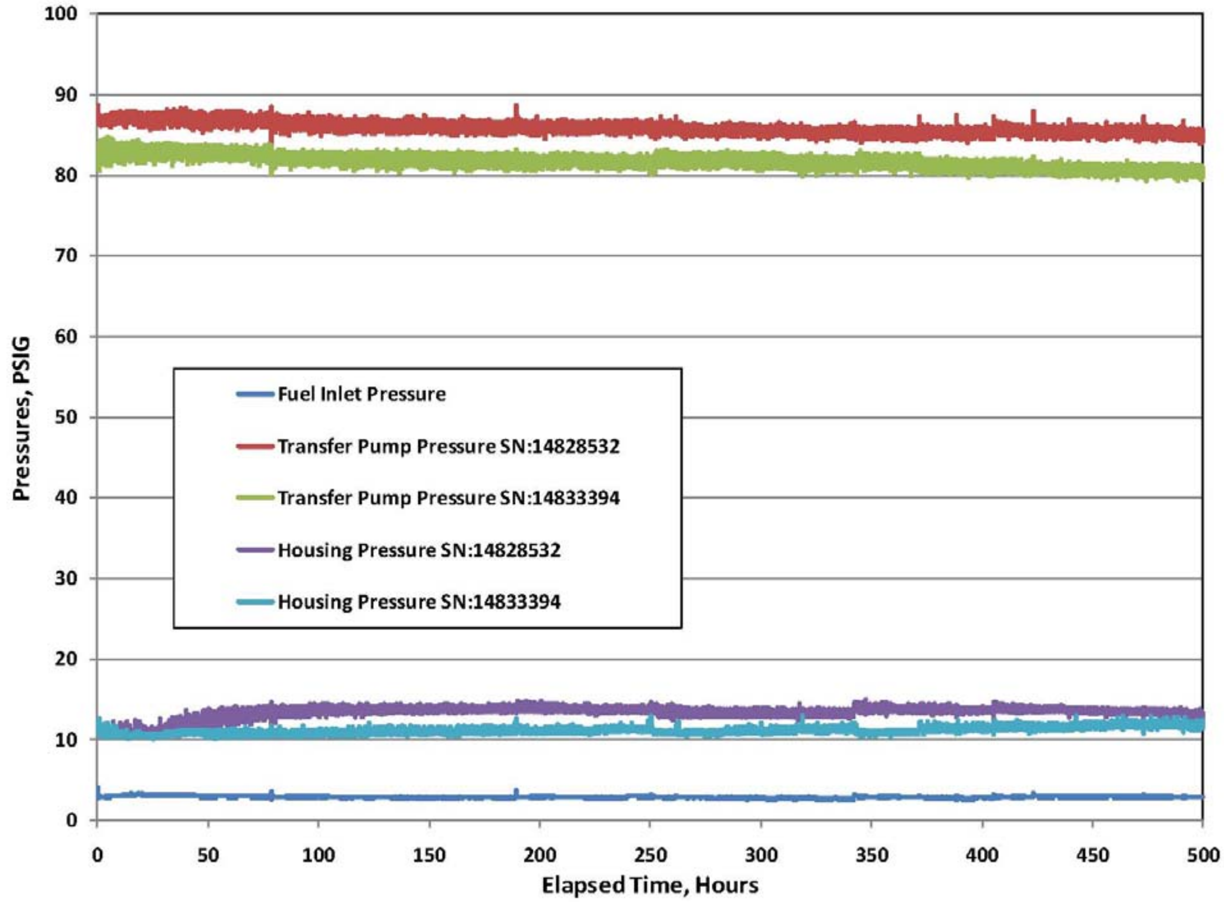

Figure 5 - Fuel Inlet, Transfer Pump, and Housing Pressure Histories for 25-hours on R8+22.5-ppm DCI-4A Fuel

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A Jet-A fuel was identified to be blended with R8 and exceed the minimum MIL-T-83133 density with 50-percent R8. The 50-percent R8/50-percent Jet-A blend density was measured to be 0.7800 g/ml at 15°C. Two 55-gallon drums of the blend were made. After blending, the R8/Jet-A blend was checked for lubricity using ASTM D 5001 BOCLE, the wear scar was 0.78 mm. The minimum amount of DCI-4A corrosion inhibitor, 9-ppm was added and the BOCLE reduced to 0.67-mm. The decision was made to treat the fuel at 22.5-ppm DCI-4A for the pump test. The treated R8 was introduced into the test stand and the stand was operated at an idle condition until 2L of fuel was flushed through each set of eight injectors.

The testing with the treated R8/Jet-A blend was initiated and the fuel injection pumps and stand control system function normally. The temperature and flow histories of the fuel injection pumps are shown in Figure 6. At the start of a day of testing around 175-hours, there was an excursion of the fuel inlet temperature. Investigations revealed the cooling water to the fuel return heat exchanger had been shut off in order to remove a component from an unrelated test. The test stand cooling system was re-plumbed to be independently supplied with cooling water. The fuel return temperatures were consistent after 200-hours of operation, which indicated there was not any unusual wear in the fuel injection pumps. Unusual wear in the pumps usually causes an increase in the fuel return temperatures. Both fuel injection pumps operating on the R8/Jet-A + 22.5-ppm DCI-4A fuel blend completed 500-hours of operation with only a small decrease in delivery. The delivery characteristics of fuel injection pumps SN: 14828535 and SN: 14828535 were consistently similar throughout the 500-hours of testing.

Figure 7 shows the fuel pressure histories for the test with the R8/Jet-A + 22.5-ppm DCI-4A fuel. The housing pressure for pumps SN: 14828535 and SN: 14828535 were very consistent throughout the 500-hours of testing. Usually wear in these pumps cause an increase in housing pressure due to internal leakage. The transfer pump pressure for pumps SN: 14828535 and SN: 14828535 were also very consistent throughout the 500-hours of testing. Both fuel injection pumps were free of the brown deposition that had previously been seen with the neat R8 fuel. Both fuel injection pumps appeared to be functioning normally at the completion of 500-hours on the test stand.

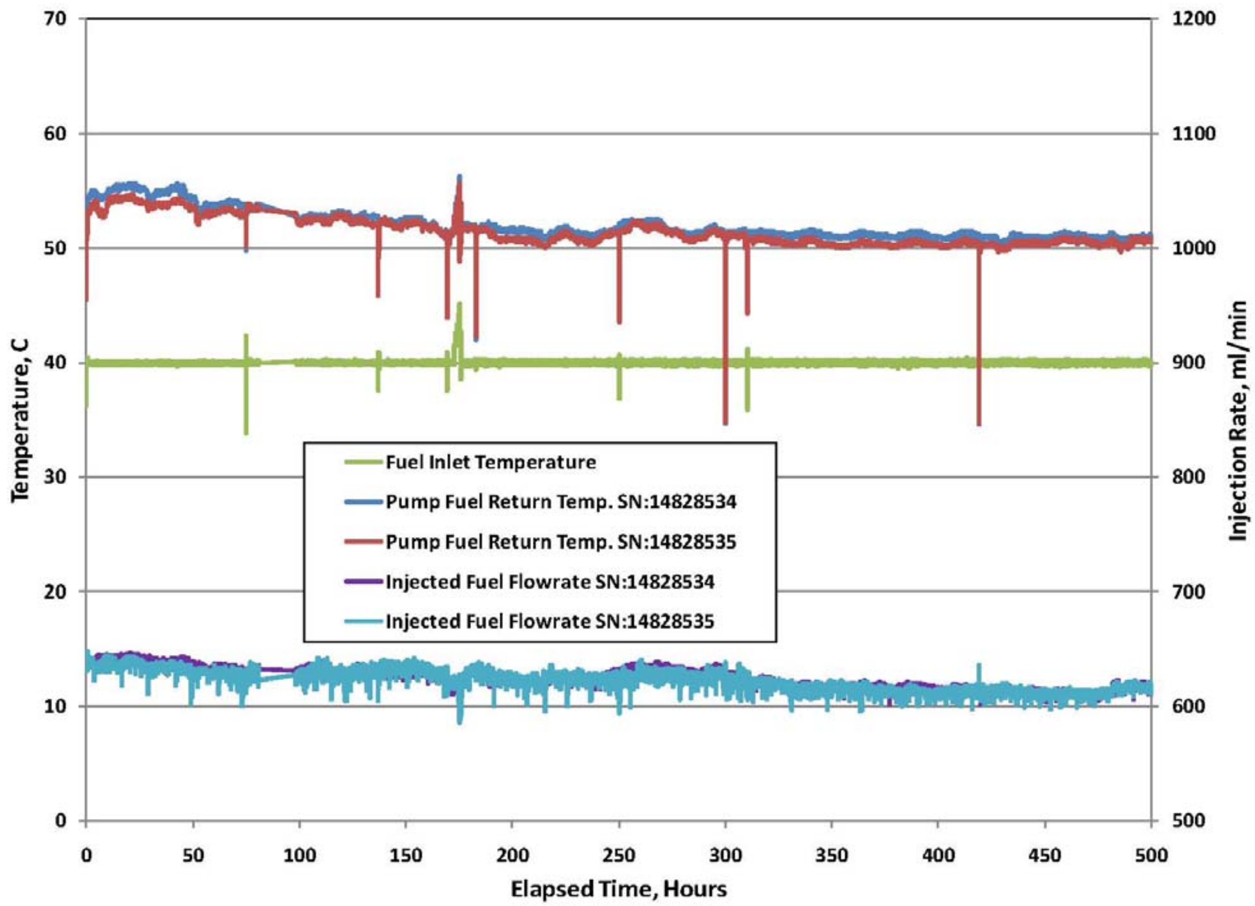

Figure 6 - Fuel Inlet, Fuel Return Temperatures, and Fuel Flowrate Histories for 25-hours on R8/Jet-A+22.5-ppm DCI-4A Fuel

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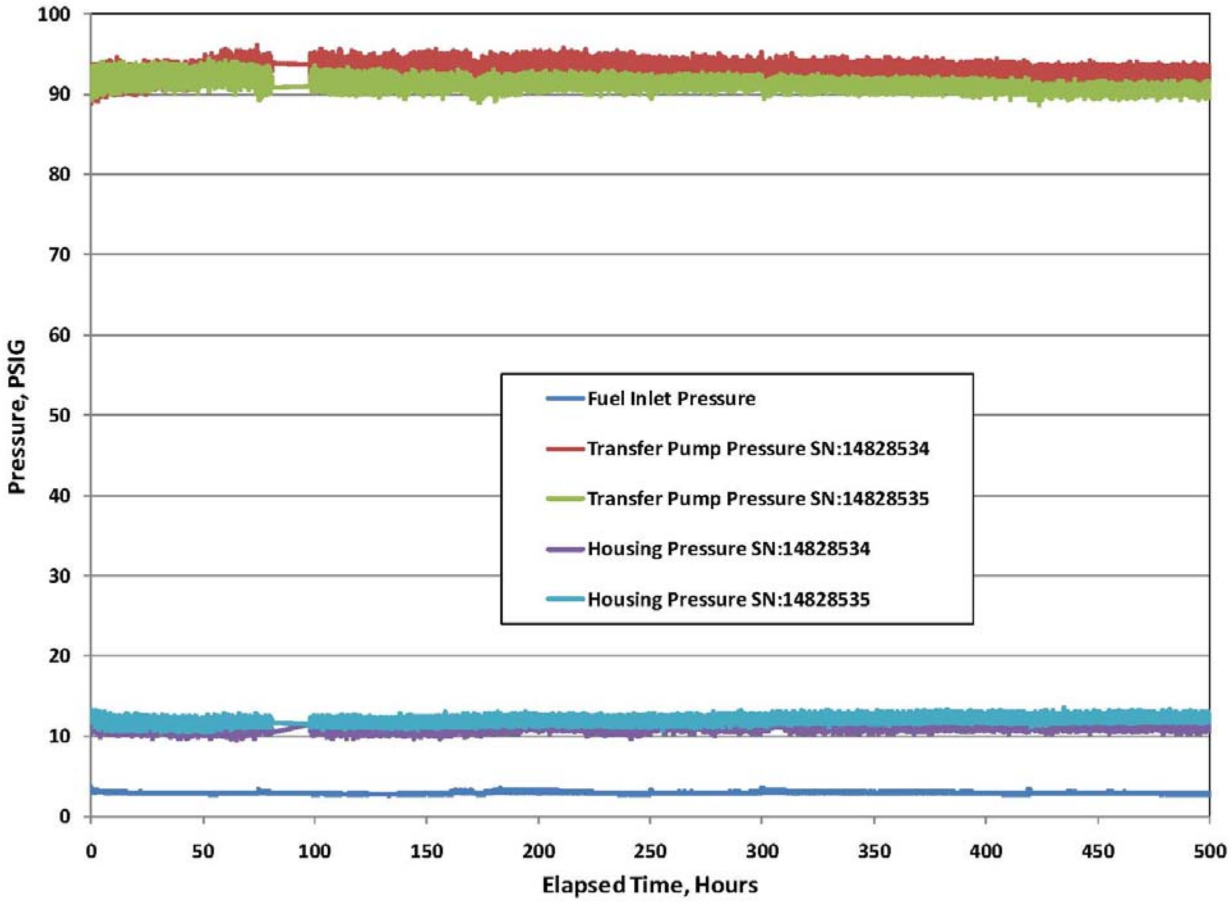

Figure 7 - Fuel Inlet, Transfer Pump, and Housing Pressure Histories for 25-hours on R8/Jet-A+22.5-ppm DCI-4A Fuel

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5.2 ROTARY PUMP PERFORMANCE MEASUREMENTS

Prior to the durability testing all the fuel injection pumps were run on an injection pump calibration stand to verify their performance with respect to their model number and application specification sheet. Although the pumps come from the factory set to meet their designated specification, because SwRI disassembles the pumps to take transfer pump blade measurements and roller-to-roller dimensions, the fuel injection pumps performance is validated. At the conclusion of testing the fuel injection pumps are installed on the calibration stand and checked for performance changes due to the test fuel. There are not any adjustments made to the fuel injection pumps by the calibration personnel.

5.2.1 R8 Fuel with 22.5-ppm DCI-4A CI/LI Additive

The Pre- and Post-Test performance curves for fuel injection pump SN: 14828532 are included as Table 2. Items in shaded boxes in Table 2 are values that fall outside of the specification for the fuel injection pump model. At low idle, 350-RPM, the SN: 14828532 pump was below the minimum delivery value that could result in a rough engine idle. At 1750-RPM and 1800-RPM the delivered quantity was slightly out of specification which could lead to a reduction in engine power. The results at 2025-RPM suggest the governor operation had not been compromised for the SN: 14828532 pump on R8+22.5-ppm DCI-4A fuel. The minimum delivery values at 200-RPM and 75-RPM are met; these conditions are significant for engine starting.

The Pre- and Post-Test performance curves for fuel injection pump SN: 14833394 are included as Table 3. There are not any values in Table 3 that fall outside of the specification for the fuel injection pump model. At 1900-RPM there did appear to be an increase in the quantity of fuel delivered that would indicate the governor action would cut in at a higher engine speed. However the 2025-RPM delivery result suggests the governor action is within specification for the SN: 14833394 pump on R8+22.5-ppm DCI-4A fuel. The minimum delivery values at 200-RPM and 75-RPM were also met.

APPENDIX I-2: R-8 HRJ Follow-on Pump Evaluations, SwRI Report #14406

Table 2 - Injection Pump SN: 14828532 Performance Specifications

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831- 5209 (arctic)	SN: 14828532
Test condition : 500 hrs @ 40C and 1800-RPM WOT	AL: R8 + 22.5-ppm DCI-4A

PUMP RPM	Description	Spec.	Before	After	Change
1000	Transfer pump psi.	60-62 psi	61	61	0
	Return Fuel	225-375 cc	335	330	-5
	Fuel Delivery	51.5 cc. Max.	52	48	-4
350	Low Idle	12-16 cc	14	**8**	-6
	Housing psi.	8-12 psi	3.5	10	6.5
	Cold Advance Solenoid	0-1 deg.	0.5	0.5	0
1750	Fuel Delivery	44.5 - 47.5 cc	46	**42**	-4
	Advance	3.75 - 4.75 deg.	4.05	4.23	0.18
1900	Fuel Delivery	31.5 cc min.	38	44	6
1600	Face Cam Fuel delivery	21.5 - 23.5 cc	22	22	0
	Advance	4 - 6 deg.	4.5	4.25	-0.25
1800	Fuel Delivery	44 cc min.	53	**42**	-11
	Transfer pump psi.	Record	91	85	-6
	Housing psi.	Record	8.5	9	0.5
2025	High Idle	15 cc max.	14	7	-7
	Transfer pump psi.	125 psi max.	107	102	-5
200	Fuel Delivery	40 cc min.	45	42	-3
	Shut-Off	4 cc max.	0.5	0.5	0
75	Fuel Delivery	26 cc min.	34	31	-3
	Transfer pump psi.	16 psi min.	20	25	5
	Air Timing	-1 deg. (+/-.5)	-2	-1	1
	Fluid Temp. Deg. C				
	Date		7/30/2009	9/8/2009	

Notes : Delivery Low at 350-RPM, Delivery low at 1750-RPM, Delivery low at 1800-RPM

Table 3 - Injection Pump SN: 14833394 Performance Specifications

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831- 5209 (arctic)	SN: 14833394
Test condition : 500 hrs @ 40C, 1800-RPM, WOT	AL: R8 + 22.5-ppm DCI-4A

PUMP RPM	Description	Spec.	Before	After	Change
1000	Transfer pump psi.	60-62 psi	65	61	-4.00
	Return Fuel	225-375 cc	250	320	70.00
	Fuel Delivery	51.5 cc. Max.	50	51	1.00
350	Low Idle	12-16 cc	14.5	13.5	-1.00
	Housing psi.	8-12 psi	9	9	0.00
	Cold Advance Solenoid	0-1 deg.	0.5	0.5	0.00
1750	Fuel Delivery	44.5 - 47.5 cc	47	47	0.00
	Advance	3.75 - 4.75 deg.	3.83	3.55	-0.28
1900	Fuel Delivery	31.5 cc min.	37	47	10.00
1600	Face Cam Fuel delivery	21.5 - 23.5 cc	22	22	0.00
	Advance	4 - 6 deg.	4.75	4.83	0.08
1800	Fuel Delivery	44 cc min.	46	47	1.00
	Transfer pump psi.	Record	98	88	-10.00
	Housing psi.	Record	9.5	8.5	-1.00
2025	High Idle	15 cc max.	9	1.5	-7.50
	Transfer pump psi.	125 psi max.	115	102	-13.00
200	Fuel Delivery	40 cc min.	43	48	5.00
	Shut-Off	4 cc max.	0	0	0.00
75	Fuel Delivery	26 cc min.	35	38	3.00
	Transfer pump psi.	16 psi min.	25	21	-4.00
	Air Timing	-1 deg. (+/-.5)	1.5	0	-1.50
	Fluid Temp. Deg. C				
	Date		7/30/2009	9/8/2009	

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5.2.2 R8/Jet-A Fuel Blend with 22.5-ppm DCI-4A CI/LI Additive

The Pre- and Post-Test performance curves for fuel injection pump SN: 14828534 are included as Table 4. Items in shaded boxes in Table 4 are values that fall outside of the specification for the fuel injection pump model. At low idle, 350-RPM, the SN: 14828534 pump was below the minimum delivery value that could result in a rough engine idle. At 1750-RPM the delivered quantity was slightly out of specification which could lead to a slight reduction in engine power. The results at 2025-RPM suggest the governor operation had not been compromised for the SN: 14828532 pump on the R8/Jet-A+22.5-ppm DCI-4A fuel blend. The minimum delivery values at 200-RPM and 75-RPM were met.

The Pre- and Post-Test performance curves for fuel injection pump SN: 14828535 are included as Table 5. Items in shaded boxes in Table 5 are values that fall outside of the specification for the fuel injection pump model. At low idle, 350-RPM, the SN: 14828535 pump was slightly below the minimum delivery value that may result in a rough engine idle. The 1750 and 1800-RPM results indicate that engine power would not be compromised with this pump. The 2025-RPM delivery result suggests the governor action is within specification for the SN: 14833395 pump on the R8/Jet-A+22.5-ppm DCI-4A fuel blend. The minimum delivery values that are critical for starting at 200-RPM and 75-RPM were also within specification.

5.3 ROTARY PUMP WEAR MEASUREMENTS

The transfer pump and plunger assemblies are integral to the fuel-metering system in the Stanadyne rotary pump, and by function are the most affected with low lubricity fuel. Accelerated wear in either the transfer pump blades or the roller-to-roller dimension results in a change of fueling condition that jeopardizes the quantity of fuel injected into the hydraulic head assembly. Wear in the transfer pump blades limits the amount of pressure necessary to maintain the proper amount of fuel in the chamber where opposing plungers, actuated by the rollers and cam, inject the metered fuel into the hydraulic head assembly. Roller-to-roller dimension variations alter the travel distance of the plungers, effectively changing metered fuel, injector pressure, and injection timing.

Table 4 - Injection Pump SN: 14828534 Performance Specifications

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831- 5209 (arctic)	SN: 14828534
Test condition : 500hrs @ 40C, 1800-RPM WOT	AL: R8 / Jet - A + 22.5ppm DCI-4A

PUMP RPM	Description	Spec.	Before	After	Change
1000	Transfer pump psi.	60-62 psi	65	65	0
	Return Fuel	225-375 cc	250	280	30
	Fuel Delivery	51.5 cc. Max.	50	48	-2
350	Low Idle	12-16 cc	14.5	8	-6.5
	Housing psi.	8-12 psi	9	9.5	0.5
	Cold Advance Solenoid	0-1 deg.	0.5	0.5	0
1750	Fuel Delivery	44.5 - 47.5 cc	47	44	-3
	Advance	3.75 - 4.75 deg.	3.83	4.39	0.56
1900	Fuel Delivery	31.5 cc min.	37	43	6
1600	Face Cam Fuel delivery	21.5 - 23.5 cc	22	22	0
	Advance	4 - 6 deg.	4.75	4.6	-0.15
1800	Fuel Delivery	44 cc min.	46	44	-2
	Transfer pump psi.	Record	98	98	0
	Housing psi.	Record	9.5	9.5	0
2025	High Idle	15 cc max.	9	12	3
	Transfer pump psi.	125 psi max.	115	111	-4
200	Fuel Delivery	40 cc min.	43	41	-2
	Shut-Off	4 cc max.	0	0	0
75	Fuel Delivery	26 cc min.	35	32	-3
	Transfer pump psi.	16 psi min.	25	25	0
	Air Timing	-1 deg. (+/-.5)	1.5	-1.5	-3
	Fluid Temp. Deg. C				
	Date		7/30/2009	12/4/2009	

Notes : Delivery low at 350-RPM, Delivery low at 1750-RPM

Table 5 - Injection Pump SN: 14828535 Performance Specifications

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831- 5209 (arctic)	SN: 14828535
Test condition : 500hrs @ 40C, 1800-RPM WOT	AL: R8 / Jet - A + 22.5ppm DCI-4A

PUMP RPM	Description	Spec.	Before	After	Change
1000	Transfer pump psi.	60-62 psi	63	63	0
	Return Fuel	225-375 cc	260	260	0
	Fuel Delivery	51.5 cc. Max.	51	50	-1
350	Low Idle	12-16 cc	16	11	-5
	Housing psi.	8-12 psi	10	10	0
	Cold Advance Solenoid	0-1 deg.	0.5	0.5	0
1750	Fuel Delivery	44.5 - 47.5 cc	48	45	-3
	Advance	3.75 - 4.75 deg.	4.02	4.13	0.11
1900	Fuel Delivery	31.5 cc min.	37	45	8
1600	Face Cam Fuel delivery	21.5 - 23.5 cc	22	22	0
	Advance	4 - 6 deg.	5	5.2	0.2
1800	Fuel Delivery	44 cc min.	49	45	-4
	Transfer pump psi.	Record	90	95	5
	Housing psi.	Record	10	10	0
2025	High Idle	15 cc max.	2	1.5	-0.5
	Transfer pump psi.	125 psi max.	110	110	0
200	Fuel Delivery	40 cc min.	43	43	0
	Shut-Off	4 cc max.	0.5	0.5	0
75	Fuel Delivery	26 cc min.	31	31	0
	Transfer pump psi.	16 psi min.	27	29	2
	Air Timing	-1 deg. (+/-.5)	-1.5	-1.5	0
	Fluid Temp. Deg. C				
	Date		7/30/2009	12/4/2009	

Notes : Delivery low at 350-RPM

5.3.1 R8 Fuel with 22.5-ppm DCI-4A CI/LI Additive

Tables 6 and 7 present the transfer pump blade and roller-to-roller dimension measurement results for the two fuel injection pumps that operated on R8 + 22.5-ppm DCI-4A fuel. There was one out-of-specification transfer blade measurement (blade #4) based on the dimension length C for pump SN: 14828532. Unlike the neat R8 fuel test, the width of the blades did not change dramatically, nor did the blades thicknesses decrease much. Both pump roller-to-roller dimensions changed more than the ± 0.0005-inch assembly specification tolerance. The roller-to-roller eccentricity specification is 0.008-inch maximum, of which pump SN: 14833394 exceeded the value after 500-hours testing with R8 + 22.5-ppm DCI-4A fuel. In general all transfer pump blades were in good condition, and the roller-to-roller dimensions changes reflect the slight performance changes seen on the calibration stand.

5.3.2 R8/Jet-A Fuel Blend with 22.5-ppm DCI-4A CI/LI Additive

Tables 8 and 9 present the transfer pump blade and roller-to-roller dimension measurement results for the two fuel injection pumps that operated on the R8/Jet-A + 22.5-ppm DCI-4A fuel blend. There was not any out-of-specification transfer blade measurements based on the dimension length C for either pump SN: 14828534 or SN: 14828535. Again, unlike the neat R8 fuel test, the width of the blades did not change dramatically, nor did the blades thicknesses decrease much. Pump SN: 14828532 roller-to-roller dimensions changed more than the ± 0.0005-inch assembly specification tolerance, whilst pump SN: 14828535 did not change. The roller-to-roller eccentricity specification is 0.008-inch maximum, of which neither pump exceeded the value after 500-hours testing with the R8/Jet-A + 22.5-ppm DCI-4A fuel blend. In general all transfer pump blades were in good condition, and the slight roller-to-roller dimensions changes may reflect the slight performance changes seen on the calibration stand.

Table 6 - Pump SN: 14828532 Blade Wear Measurements

Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5209	SN:14828532	Test Number : 2
Fuel description : R8 + 22.5-ppm DCI-4A		

Dimensional Measurements		Before ***0 hours***	After ***500***	***Change***
Transfer Pump Blade #1	Dimension A	13.780	13.779	-0.001
	Dimension B	9.948	9.946	-0.002
	Dimension C	12.673	12.673	0.000
	Dimension D	3.127	3.125	-0.002
	Dimension E	3.128	3.125	-0.003
	Dimension F	3.128	3.125	-0.003
Transfer Pump Blade #2	Dimension A	13.787	13.787	0.000
	Dimension B	10.078	10.076	-0.002
	Dimension C	12.673	12.668	-0.005
	Dimension D	3.127	3.126	-0.001
	Dimension E	3.129	3.127	-0.002
	Dimension F	3.129	3.127	-0.002
Transfer Pump Blade #3	Dimension A	13.779	13.775	-0.004
	Dimension B	10.048	10.046	-0.002
	Dimension C	12.672	12.670	-0.002
	Dimension D	3.128	3.127	-0.001
	Dimension E	3.129	3.126	-0.003
	Dimension F	3.130	3.128	-0.002
Transfer Pump Blade #4	Dimension A	13.794	13.792	-0.002
	Dimension B	9.986	9.982	-0.004
	Dimension C	12.667	12.662	-0.005
	Dimension D	3.123	3.120	-0.003
	Dimension E	3.123	3.120	-0.003
	Dimension F	3.123	3.120	-0.003
	Roller to Roller (in)	1.9620	1.9585	-0.004
	Eccentricity (in.)	0.0110	0.0125	0.002

Drive Backlash (In)	0.0040	0.0045	0.0005
Drive Backlash (Deg.)			

	MIN - HEIGHT (C)	MAX - HEIGHT (C)
Inches	0.4986	0.4993
Millimeters	12.66444	12.68222

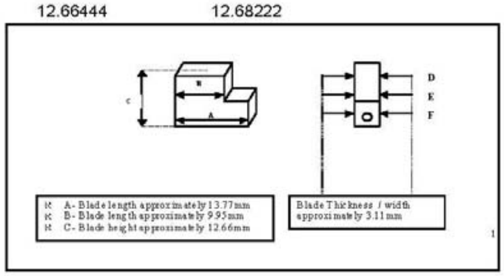

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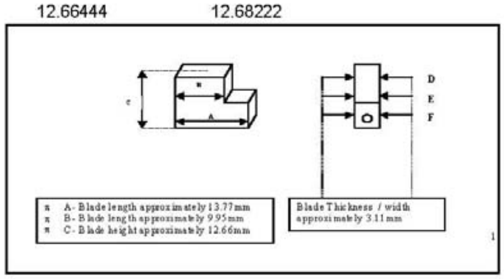
Table 7 - Pump SN: 14833394 Blade Wear Measurements

Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5209		14833394	Test Number : 2	
Fuel description : R8 + 22.5ppm DCI-4A				
		Before	After	
Dimensional Measurements		***0 hours***	***500Hrs***	***Change***
Transfer Pump Blade #1	Dimension A	13.797	13.795	-0.002
	Dimension B	10.102	10.101	-0.001
	Dimension C	12.676	12.676	0.000
	Dimension D	3.128	3.126	-0.002
	Dimension E	3.129	3.125	-0.004
	Dimension F	3.129	3.125	-0.004
Transfer Pump Blade #2	Dimension A	13.799	13.797	-0.002
	Dimension B	10.017	10.016	-0.001
	Dimension C	12.673	12.672	-0.001
	Dimension D	3.121	3.117	-0.004
	Dimension E	3.123	3.120	-0.003
	Dimension F	3.122	3.120	-0.002
Transfer Pump Blade #3	Dimension A	13.784	13.779	-0.005
	Dimension B	10.027	10.024	-0.003
	Dimension C	12.672	12.671	-0.001
	Dimension D	3.130	3.129	-0.001
	Dimension E	3.131	3.128	-0.003
	Dimension F	3.131	3.126	-0.005
Transfer Pump Blade #4	Dimension A	13.787	13.787	0.000
	Dimension B	10.070	10.070	0.000
	Dimension C	12.676	12.675	-0.001
	Dimension D	3.126	3.122	-0.004
	Dimension E	3.124	3.122	-0.002
	Dimension F	3.125	3.123	-0.002
	Roller to Roller (in)	1.9620	1.9629	0.0009
	Eccentricity (in.)	0.0035	0.0130	0.0095
	Drive Backlash (In)	0.0035	0.0045	0.0010
	Drive Backlash (Deg.)			

	MIN - HEIGHT (C)	MAX - HEIGHT (C)
Inches	0.4986	0.4993
Millimeters	12.66444	12.68222



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R-8 Pump Evaluations
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Table 8 - Pump SN: 14828534 Blade Wear Measurements

Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5209	SN:14828534	Test Number : R8-3
Fuel description : R8/Jet-A + 22.5-ppm DCI-4A		

		7/22/2009	12/7/2009	
Dimensional Measurements		***Before***	***After***	***Change***
Transfer Pump Blade #1	Dimension A	13.809	13.806	-0.003
	Dimension B	10.068	10.064	-0.004
	Dimension C	12.674	12.672	-0.002
	Dimension D	3.126	3.124	-0.002
	Dimension E	3.128	3.125	-0.003
	Dimension F	3.127	3.125	-0.002
Transfer Pump Blade #2	Dimension A	13.743	13.742	-0.001
	Dimension B	9.975	9.973	-0.002
	Dimension C	12.671	12.670	-0.001
	Dimension D	3.129	3.125	-0.004
	Dimension E	3.129	3.125	-0.004
	Dimension F	3.129	3.126	-0.003
Transfer Pump Blade #3	Dimension A	13.759	13.755	-0.004
	Dimension B	10.026	10.025	-0.001
	Dimension C	12.674	12.670	-0.004
	Dimension D	3.132	3.129	-0.003
	Dimension E	3.132	3.130	-0.002
	Dimension F	3.132	3.130	-0.002
Transfer Pump Blade #4	Dimension A	13.791	13.785	-0.006
	Dimension B	10.038	10.037	-0.001
	Dimension C	12.674	12.673	-0.001
	Dimension D	3.127	3.125	-0.002
	Dimension E	3.128	3.125	-0.003
	Dimension F	3.128	3.125	-0.003
	Roller to Roller (in)	1.9620	1.9610	-0.001
	Eccentricity (in.)	0.0110	0.0110	0.000
	Drive Backlash (In)	0.0040	0.0050	0.001
	Drive Backlash (Deg.)			

	MIN - HEIGHT (C)	MAX - HEIGHT (C)
Inches	0.4986	0.4993
Millimeters	12.66444	12.68222

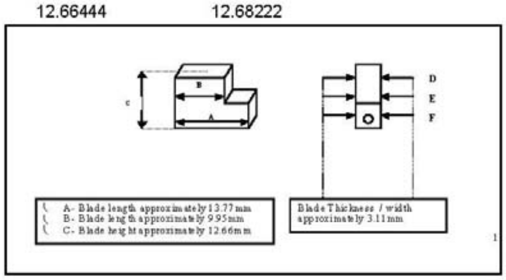

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Table 9 - Pump SN: 14828535 Blade Wear Measurements

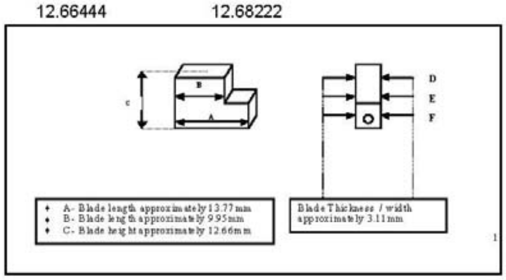
Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5209	SN:14828535	Test Number : R8-3
Fuel description : R8/Jet-A + 22.5-ppm DCI-4A		

		7/23/2009	12/7/2009	
Dimensional Measurements		***Before***	***After***	***Change***
Transfer Pump Blade #1	Dimension A	13.795	13.793	-0.002
	Dimension B	10.103	10.099	-0.004
	Dimension C	12.673	12.670	-0.003
	Dimension D	3.131	3.829	0.698
	Dimension E	3.131	3.128	-0.003
	Dimension F	3.131	3.130	-0.001
Transfer Pump Blade #2	Dimension A	13.806	13.800	-0.006
	Dimension B	10.060	10.056	-0.004
	Dimension C	12.672	12.670	-0.002
	Dimension D	3.124	3.121	-0.003
	Dimension E	3.125	3.122	-0.003
	Dimension F	3.126	3.123	-0.003
Transfer Pump Blade #3	Dimension A	13.778	13.776	-0.002
	Dimension B	9.964	9.961	-0.003
	Dimension C	12.672	12.669	-0.003
	Dimension D	3.123	3.120	-0.003
	Dimension E	3.124	3.122	-0.002
	Dimension F	3.125	3.123	-0.002
Transfer Pump Blade #4	Dimension A	13.789	13.776	-0.013
	Dimension B	9.923	9.961	0.038
	Dimension C	12.673	12.669	-0.004
	Dimension D	3.130	3.120	-0.010
	Dimension E	3.130	3.122	-0.008
	Dimension F	3.131	3.123	-0.008
	Roller to Roller (in)	1.9620	1.9620	0.000
	Eccentricity (in.)	0.0045	0.0010	-0.004

Drive Backlash (In)	0.0045	0.0050	0.001
Drive Backlash (Deg.)			

	MIN - HEIGHT (C)	MAX - HEIGHT (C)
Inches	0.4986	0.4993
Millimeters	12.66444	12.68222



5.4 FUEL INJECTOR RESULTS

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required.

New Bosch Model O432217104 injectors were used for both of the R8 fuel blend tests. The injector performance tests and rating results are shown in Table 10. The 0-hour injector test data for the R8/Jet-A + 22.5-ppm DCI-4A fuel blend was misplaced, however the injectors were functioning properly or they would not have been installed on the test stand. All the fuel injectors passed the post-test opening pressure evaluations after 500-hours of operation. An injector with decreased opening pressure will probably "fail' the chatter test and more than likely "fail" the spray pattern test. All injectors with the R8 fuel blended with DCI-4A and Jet-A passed the chatter, spray pattern, and assembly leakage tests after 500-hours of operation. With the R8 + 22.5-ppm DCI-4A fuel there was only one injector that revealed tip leakage after 500-hours of operation. With the R8/Jet-A + 22.5-ppm DCI-4A fuels blend half of the injectors revealed tip leakage after 500-hours of operation. Injector tip leakage could cause increased smoke emission upon engine start, and increased unburned hydrocarbon and carbon monoxide emissions.

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R-8 Pump Evaluations

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Table 10 - Fuel Injector Performance Evaluations after 500-Hours R8 Fuel Blend Usage

Stanadyne Rotary Pump Lubricity Evaluation

6.5L Fuel Injector Test Inspection [0-hr/500-hr]

Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure	Tip Leakage	Chatter	Spray pattern	Assy. Leakage	Pintle cond.	Lapped Surface	Date	Hrs.
R8-2	SN: 14833394	R8 + 22.5ppm DCI-4A	1-09	1875 / 1600	None / None	Good / Good	Good / Good	None / None	OK		7/6/09 & 9/21/09	500
			2-09	1975 / 1650	None / None	Good / Good	Good / Good	None / None	OK		"	500
			3-09	1950 / 1625	None / None	Good / Good	Good / Good	None / None	OK		"	500
			4-09	1925 / 1625	None / None	Good / Good	Good / Good	None / None	OK		"	500
			5-09	1950 / 1650	None / None	Good / Good	Good / Good	None / None	OK		"	500
			6-09	1950 / 1650	None / None	Good / Good	Good / Good	None / None	OK		"	500
			7-09	1875 / 1575	None / Wet	Good / Good	Good / Good	None / None	OK		"	500
			8-09	1925 / 1600	None / None	Good / Good	Good / Good	None / None	OK		"	500
R8-2	SN: 14828532	R8 + 22.5ppm DCI-4A	9-09	1875 / 1625	None / None	Good / Good	Good / Good	None / None	OK		7/6/09 & 9/21/09	500
			10-09	1950 / 1625	None / None	Good / Good	Good / Good	None / None	OK		"	500
			11-09	1875 / 1575	None / None	Good / Good	Good / Good	None / None	OK		"	500
			12-09	1925 / 1625	None / None	Good / Good	Good / Good	None / None	OK		"	500
			13-09	1900 / 1575	None / None	Good / Good	Good / Good	None / None	OK		"	500
			14-09	1925 / 1600	None / None	Good / Good	Good / Good	None / None	OK		"	500
			15-09	1850 / 1525	None / None	Good / Good	Good / Good	None / None	OK		"	500
			16-09	1925 / 1625	None / None	Good / Good	Good / Good	None / None	OK		"	500
R8-3	SN: 14828534	R8/Jet-A + 22.5ppm DCI-4A	17-09	/ 1575	/ None	/ Good	/ Good	/ None	OK		12/16/2009	500
			18-09	/ 1625	/ Wet	/ Good	/ Good	/ None	OK		"	500
			19-09	/ 1525	/ Wet	/ Good	/ Good	/ None	OK		"	500
			20-09	/ 1600	/ None	/ Good	/ Good	/ None	OK		"	500
			21-09	/ 1650	/ None	/ Good	/ Good	/ None	OK		"	500
			22-09	/ 1600	/ Wet	/ Good	/ Good	/ None	OK		"	500
			23-09	/ 1675	/ None	/ Good	/ Good	/ None	OK		"	500
			24-09	/ 1600	/ Wet	/ Good	/ Good	/ None	OK		"	500
R8-3	SN: 14828535	R8/Jet-A + 22.5ppm DCI-4A	25-09	/ 1575	/ Wet	/ Good	/ Good	/ None	OK		12/16/2009	500
			26-09	/ 1600	/ Wet	/ Good	/ Good	/ None	OK		"	500
			27-09	/ 1600	/ None	/ Good	/ Good	/ None	OK		"	500
			28-09	/ 1600	/ Wet	/ Good	/ Good	/ None	OK		"	500
			29-09	/ 1625	/ None	/ Good	/ Good	/ None	OK		"	500
			30-09	/ 1625	/ Wet	/ Good	/ Good	/ None	OK		"	500
			31-09	/ 1650	/ None	/ Good	/ Good	/ None	OK		"	500
			32-09	/ 1600	/ None	/ Good	/ Good	/ None	OK		"	500
			Spec. :	1500psig min	no drop off in 10 sec. @ 1400 psi	chatter	fine mist	dry, no seepage	shiny, no scratches	report		

5.5 ROTARY PUMP COMPONENT WEAR EVALUATIONS

After the fuel injection pump calibration and functional performance checks, the fuel injection pumps are disassembled and the components critical to pump operation are evaluated for parts conditions. A technician with over twenty years experience rebuilding, servicing, and testing Stanadyne fuel injection pumps performs the subjective wear rating.

5.5.1 R8 Fuel with 22.5-ppm DCI-4A CI/LI Additive – Pump SN: 14828532

The parts conditions and subjective wear ratings for fuel injection pump SN: 14828532 are summarized in Table 11. Images of the wear seen on the components of fuel injection pump SN: 14828532 are shown in Figures 8 through 25. Figure 8 shows a chip on the edge of the rotor near transfer pump blade slots. The chip was on the rotor as received and did not compromise the performance of pump SN: 14828532. Figures 9 and 10 show the condition of the injection pump rotor that carries the plungers and distributes the compressed fuel. Figure 9 and Figure 10 show the discharge ports are in good condition after 500-hours.

Figure 11 and Figure 12 is the Pre-Test and Post-Test conditions of fuel injection pump SN: 14828532 Roller Shoe and Roller conditions. Of note is the lack of a wear scar at the roller shoe leaf spring contact and the shiny, bright rollers shown in Figure 11. Figure 12 reveals only light polishing wear on the roller shoe from the leaf spring contact, and light polishing on the rollers. The rollers tend to discolor when combination rolling-sliding action occurs as the rollers follow the injection cam profile. Figure 13 and Figure 14 show the relatively small wear scar due to 500-hours operation on the roller shoe plunger contact. The wear seen in Figure 14 is typical for an adequate lubricity fuel. The injection pump cam ring shown in Figure 15 and Figure 16 does not reveal any distress from 500-hours of operation with the R8 + 22.5-ppm DCI-4A fuel.

The governor thrust washer condition before and after 500-hours is seen in Figure 17 and Figure 18. The polishing wear seen on the thrust washer in Figure 18 is typical for 500-hours of injection pump operation. Minor scuffing wear seen on the advance piston suggests the fuel pressure may have been fluctuating slightly in that area of the fuel injection pumps housing. The metering valve regulates the pressure to the rotor fill ports. The pressure is regulated by the action of the helix changing the outlet area of an orifice. Due to WOT operation a lightly polished area shows at one location on the helix. The wear on these components is normal considering the 500-hour duration of testing. The wear on the thrust washer, the advance piston wear, and the metering valve did not have an effect on pump operation.

Table 11 - Pump SN: 14828532 Component Wear Ratings

Stanadyne Pump Parts Evaluation

Pump Type : DB2831-5209	SN: 14828532
Test condition : 500 Hours @ 40C, 1800-RPM, WOT	AL: R8 + 22.5ppm DCI-4A

Part Name	Condition of part	Ratings: 0 = New 5 = Failed
BLADES	Very light wear at rotor slots & liner contact	1
BLD. SPRINGS	Normal	0
LINER	Polished - no scratches	1
TRANS.PUMP REG.	Lightly polished from roror contact	1
REG. PISTON	Two small wear spots	1.5
ROTOR	Some chipping at blade slots	1
ROTOR RET.	Wear from rotor contact	2
D-VALVE	Lightly polished in small areas	1
PLUNGERS	Wear at both ends of each plunger. One plunger looks discolored as if it got hot.	2.5
SHOES	Very small dimples at plunger contact. Light scarring at roller contact. Light wear at leaf spring contact.	2
ROLLERS	Light polishing wear.	2
LEAF SPRING	Light wear from shoe contact	1
CAM RING	Normal	1
THRST. WASH.	Polished at weight contact	1
THRST. SLEEVE.	Light wear at gov. arm slots	1
GOV. WEIGHTS	Wear at foot from thrust washer contact.	1.5
LINK HOOK	Very light wear on arm fingers	1
M-VALVE	Lightly polished	1
DR. SHAFT TANG	Lightly polished in small spots	1
DR. SHAFT SEALS	Normal	1
CAM PIN	Lightly polished	1
ADV. PISTON	Scuffing wear at top right side	3
HOUSING	Normal	1

Figure 8 - Pump SN: 14828532 Distributor Rotor Transfer Pump Blade Slots with Chip before Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 19 and 20 illustrates the minor level of wear seen in the transfer pump section of fuel injection pump SN: 14828532. Figure 19 shows the surface condition of the transfer pump liner prior to testing and Figure 20 shows the surface with light polishing after 500-hours of operation on the R8 + 22.5-ppm DCI-4A fuel. Also illustrative of the transfer pump section wear, are the transfer pump blade conditions shown in Figures 21 through Figure 24. The light edge wear shown in Figure 21 and Figure 22 corresponds to the surface on the transfer pump blades that contact and slide on the transfer pump liner, separated by a film of fuel. The side scuffing shown in Figure 23 and Figure 24 reflect wear from the transfer pump blade slots on the injection pump rotor. The wear seen on the transfer pump components is substantially reduced from the neat R8 fuel testing due to the presence of the CI/LI additive in pump SN: 14828532.

Figure 9 - Pump SN: 14828532 Distributor Rotor before Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 10 - Pump SN: 14828532 Distributor Rotor with 500-Hours Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 11 - Pump SN: 14828532 Rollers and Shoe before Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 12 - Pump SN: 14828532 Rollers and Shoe with 500-Hours Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 13 - Pump SN: 14828532 Roller Shoe before Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 14 - Pump SN: 14828532 Roller Shoe with 500-Hours Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 15 - Pump SN: 14828532 Cam Ring before Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 16 - Pump SN: 14828532 Cam Ring with 500-Hours Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 17 - Pump SN: 14828532 Thrust Washer before Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 18 - Pump SN: 14828532 Thrust Washer with 500-Hours Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 19 - Pump SN: 14828532 Transfer Pump Liner before Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 20 - Pump SN: 14828532 Transfer Pump Liner with 500-Hours Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 21 - Pump SN: 14828532 Transfer Pump Blade Edges before Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 22 - Pump SN: 14828532 Transfer Pump Blade Edges with 500-Hours Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 23 - Pump SN: 14828532 Transfer Pump Blade Sides before Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 24 - Pump SN: 14828532 Transfer Pump Blade Sides with 500-Hours Testing with R8 + 22.5-ppm DCI-4A Fuel

5.5.2 R8 Fuel with 22.5-ppm DCI-4A CI/LI Additive – Pump SN: 14833394

The parts conditions and subjective wear ratings for fuel injection pump SN: 14833394 are summarized in Table 12. Images of the wear seen on the components of fuel injection pump SN: 14833394 are shown in Figures 25 through 40. Figures 25 and Figure 26 show the condition of the injection pump rotor that carries the plungers and distributes the compressed fuel. Figure 26 shows the discharge ports and rotor are in good condition after 500-hours.

Figure 27 and Figure 28 is the Pre-Test and Post-Test conditions of fuel injection pump SN: 14833394 Roller Shoe and Roller conditions. Of note is the lack of a wear scar at the roller shoe leaf spring contact and the shiny, bright rollers shown in Figure 27. Figure 28 reveals only light polishing wear on the roller shoe from the leaf spring contact, and light polishing on the rollers. The rollers tend to discolor when combination rolling-sliding action occurs as the rollers follow the injection cam profile. Figure 29 and Figure 30 show the relatively small wear scar due to 500-hours operation on the roller shoe plunger contact. The wear seen in Figure 30 is typical for an adequate lubricity fuel. The injection pump cam ring shown in Figure 31 and Figure 32 does not reveal any distress from 500-hours operation with the R8 + 22.5-ppm DCI-4A fuel.

The governor thrust washer condition before and after 500-hours is seen in Figure 33 and Figure 34. The polishing wear seen on the thrust washer in Figure 34 is again typical for 500-hours of injection pump operation. Scuffing wear seen on the advance piston suggests the fuel pressure may have been fluctuating in that area of the fuel injection pumps housing. The metering valve regulates the pressure to the rotor fill ports. The pressure is regulated by the action of the helix changing the outlet area of an orifice. Due to WOT operation a lightly polished area shows at one location on the helix. The wear on these components is normal considering the 500-hour duration of testing. The wear on the thrust washer, the advance piston wear, and the metering valve did not have an effect on pump operation.

Figure 35 and 36 illustrates the minor level of wear seen in the transfer pump section of fuel injection pump SN: 14833394. Figure 35 shows the surface condition of the transfer pump liner prior to testing and Figure 36 shows the surface with light polishing after 500-hours of operation on the R8 + 22.5-ppm DCI-4A fuel. Also illustrative of the transfer pump section wear are the transfer pump blade conditions shown in Figures 37 through Figure 40. The light edge wear shown in Figure 37 and Figure 38 corresponds to the surface on the transfer pump blades that contact the transfer pump liner. The side scuffing shown in Figure 39 and Figure 40 reflect wear from the transfer pump blade slots on the injection pump rotor. The wear seen on the transfer pump components is substantially reduced from the neat R8 fuel testing due to the presence of the CI/LI additive in pump SN: 14833394.

Figure 25 - Pump SN: 14833394 Distributor Rotor before Testing with R8 + 22.5-ppm DCI-4A Fuel

APPENDIX I

R-8 Pump Evaluations

APPENDIX I-2: R-8 HRJ Follow-on Pump Evaluations, SwRI Report #14406

Table 12 - Pump SN: 14833394 Component Wear Ratings

Stanadyne Pump Parts Evaluation

Pump Type : DB2831-5209	SN: 14833394
Test condition : 500 Hours @ 40C, 1800-RPM, WOT	AL: R8 + 22.5ppm DCI-4A

Part Name	Condition of part	Ratings: 0 = New 5 = Failed
BLADES	Very light wear at rotor slots & liner contact	1
BLD. SPRINGS	Normal	0
LINER	Polished - no scratches	1
TRANS.PUMP REG.	Mostly polishing wear with one scratch from rotor contact	2
REG. PISTON	Looks almost new, small polished spot at the end	1
ROTOR	Very light wear at distributor ports. Some chipping at blade slots	1
ROTOR RET.	Light wear from rotor contact	1
D-VALVE	Lightly polished in small areas	1
PLUNGERS	Lightly polished in small areas	1
SHOES	Small dimples at plunger contact. Light scarring at roller contact. Light wear at leaf spring contact.	2.5
ROLLERS	Light wear. Strange texture like embedded metal flakes, possibly from cam ring.	2.5
LEAF SPRING	Light wear from shoe contact	1
CAM RING	Pitting at front of lobes	2.5
THRST. WASH.	Polished at weight contact	1
THRST. SLEEVE.	Light wear at gov. arm slots	1
GOV. WEIGHTS	Wear at foot from thrust washer contact.	1.5
LINK HOOK	Very light wear on arm fingers	1
M-VALVE	Normal	0
DR. SHAFT TANG	Lightly polished in small spots	1
DR. SHAFT SEALS	Normal	1
CAM PIN	Lightly polished	1
ADV. PISTON	Scuffing wear at top right side	3
HOUSING	Normal	1

Figure 26 - Pump SN: 14833394 Distributor Rotor with 500-Hours Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 27 - Pump SN: 14833394 Rollers and Shoe Condition before Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 28 - Pump SN: 14833394 Rollers and Shoe with
500-Hours Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 29 - Pump SN: 14833394 Roller Shoe Condition before
Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 30 - Pump SN: 14833394 Roller Shoe with 500-Hours Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 31 - Pump SN: 14833394 Cam Ring before Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 32 - Pump SN: 14833394 Cam Ring with
500-Hours Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 33 - Pump SN: 14833394 Thrust Washer before
Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 34 - Pump SN: 14833394 Thrust Washer with 500-Hours Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 35 - Pump SN: 14833394 Transfer Pump Liner before Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 36 - Pump SN: 14833394 Transfer Pump Liner with 500-Hours Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 37 - Pump SN: 14833394 Transfer Pump Blade Edges before Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 38 - Pump SN: 14833394 Transfer Pump Blade Edges with 500-Hours Testing with R8 + 22.5-ppm DCI-4A Fuel

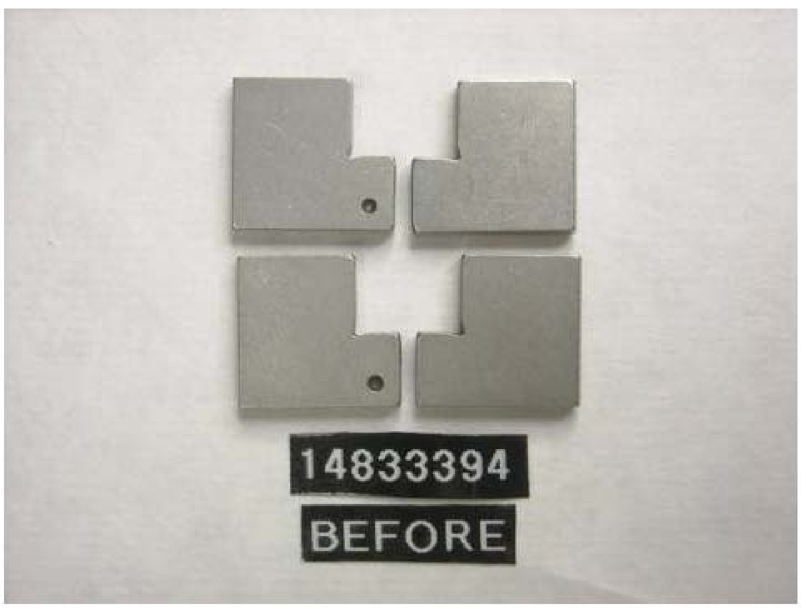

Figure 39 - Pump SN: 14833394 Transfer Pump Blade Sides before Testing with R8 + 22.5-ppm DCI-4A Fuel

Figure 40 - Pump SN: 14833394 Transfer Pump Blade Sides with 500-Hours Testing with R8 + 22.5-ppm DCI-4A Fuel

5.5.3 R8/Jet-A Fuel Blend with 22.5-ppm DCI-4A CI/LI Additive – Pump SN: 14828534

The parts conditions and subjective wear ratings for fuel injection pump SN: 14828534 are summarized in Table 13. Images of the wear seen on the components of fuel injection pump SN: 14828534 are shown in Figures 41 through 56. Figures 41 and Figure 42 show the condition of the injection pump rotor that carries the plungers and distributes the compressed fuel. Figure 42 shows the discharge ports and rotor are in good condition after 500-hours.

Figure 43 and Figure 44 is the Pre-Test and Post-Test conditions of fuel injection pump SN: 14828534 Roller Shoe and Roller conditions. Of note is the lack of a wear scar at the roller shoe leaf spring contact and the shiny, bright rollers shown in Figure 43. Figure 44 reveals only light polishing wear on the roller shoe from the leaf spring contact, and light polishing on the rollers. The rollers tend to discolor when combination rolling-sliding action occurs as the rollers follow the injection cam profile. Figure 45 and Figure 46 show the relatively small wear scar due to 500-hours operation on the roller shoe plunger contact. The wear seen in Figure 46 is typical for an adequate lubricity fuel. The injection pump cam ring shown in Figure 47 and Figure 48 does not reveal any distress from 500-hours operation with the R8 + 22.5-ppm DCI-4A fuel.

The governor thrust washer condition before and after 500-hours is seen in Figure 49 and Figure 50. The polishing wear seen on the thrust washer in Figure 50 is again typical for 500-hours of injection pump operation. Polishing and light scuffing wear seen on the advance piston suggests, slight fuel pressure fluctuations in that area of the fuel injection pump housing. The metering valve regulates the pressure to the rotor fill ports. The pressure is regulated by the action of the helix changing the outlet area of an orifice. Due to WOT operation a lightly polished area shows at one location on the helix. The wear on these components is normal considering the 500-hour duration of testing. The wear on the thrust washer, the advance piston wear, and the metering valve did not have an effect on pump operation.

Figure 51 and Figure 52 illustrates the minor level of wear seen in the transfer pump section of fuel injection pump SN: 14828534. Figure 51 shows the surface condition of the transfer pump liner prior to testing and Figure 52 shows the surface with light polishing after 500-hours of operation on the R8/Jet-A + 22.5-ppm DCI-4A fuel. Also illustrative of the transfer pump section wear are the transfer pump blade conditions shown in Figures 53 through Figure 56. The light edge wear shown in Figure 53 and Figure 54 corresponds to the surface on the transfer pump blades that contact the transfer pump liner. The side scuffing shown in Figure 55 and Figure 56 reflect wear from the transfer pump blade slots on the injection pump rotor. The wear seen on the transfer pump components is substantially reduced from the neat R8 fuel testing due to the presence of the CI/LI additive and Jet-A in pump SN: 14828534.

Table 13 - Pump SN: 14828534 Component Wear Ratings

Stanadyne Pump Parts Evaluation

Pump Type : DB2831-5209	SN: 14828534
Test condition : 500 @ 40C, 1800-RPM, WOT	AL: R8/Jet-A + 22.5ppm DCI-4A

Part Name	Condition of part	Ratings: 0 = New 5 = Failed
BLADES	Very light wear at rotor slots & liner contact.	1.5
BLD. SPRINGS	Good	0
LINER	Mostly polishing wear, light scuffing in one spot (1/8" long)	1.5
TRANS.PUMP REG.	Light contact polishing wear in a small area	1
REG. PISTON	Three small polished spots	1
ROTOR	Very light wear at distributor ports	1.5
ROTOR RET.	Polishing wear & very light scuffing wear from rotor contact	2.5
D-VALVE	Light polishing wear	1
PLUNGERS	Lightly polished in small spots	0.5
SHOES	Light wear at leaf spring contact. Light wear from plungers.	1.5
ROLLERS	Light polishing marks	1
LEAF SPRING	Light wear from shoe contact	1
CAM RING	Light polishing wear from roller contact	0.5
THRST. WASH.	Light polishing wear from weights.	1
THRST. SLEEVE.	Polishing wear from gov. arm slots	0.5
GOV. WEIGHTS	Wear at foot & heel, thrust washer contact & cage contact.	1.5
LINK HOOK	Light polishing wear on arm fingers & arm pivot shaft.	1
M-VALVE	Light polishing wear at helix.	1.5
DR. SHAFT TANG	Light polishing wear.	1
DR. SHAFT SEALS	Normal	1
CAM PIN	Very light polishing wear.	0.5
ADV. PISTON	Spring side top is mostly polished with light scuffing.	2
HOUSING	Normal	1

Figure 41 - Pump SN: 14828534 Distributor Rotor before Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 42 - Pump SN: 14828534 Distributor Rotor with 500-Hours Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 43 - Pump SN: 14828534 Rollers and Shoe before Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 44 - Pump SN: 14828534 Rollers and Shoe with 500-Hours Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 45 - Pump SN: 14828534 Roller Shoe before Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 46 - Pump SN: 14828534 Roller Shoe with 500-Hours Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 47 - Pump SN: 14828534 Cam Ring before Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 48 - Pump SN: 14828534 Cam Ring with 500-Hours Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 49 - Pump SN: 14828534 Thrust Washer before Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 50 - Pump SN: 14828534 Thrust Washer with 500-Hours Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 51 - Pump SN: 14828534 Transfer Pump Liner before Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 52 - Pump SN: 14828534 Transfer Pump Liner with 500-Hours Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 53 - Pump SN: 14828534 Transfer Pump Blade Edges before Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 54 - Pump SN: 14828534 Transfer Pump Blade Edges with 500-Hours Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

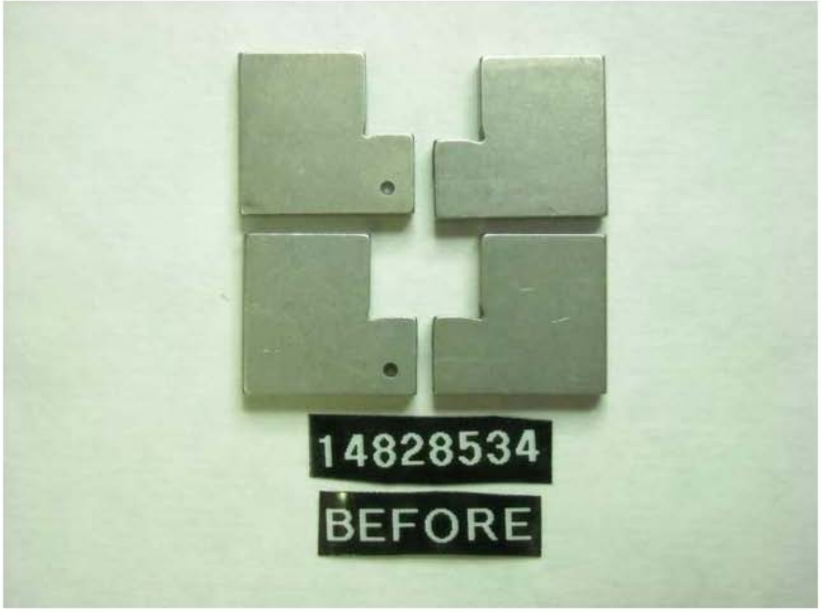

Figure 55 - Pump SN: 14828534 Transfer Pump Blade Sides before Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 56 - Pump SN: 14828534 Transfer Pump Blade Sides with 500-Hours Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

5.5.4 R8/Jet-A Fuel Blend with 22.5-ppm DCI-4A CI/LI Additive – Pump SN: 14828535

The parts conditions and subjective wear ratings for fuel injection pump SN: 14828535 are summarized in Table 14. Images of the wear seen on the components of fuel injection pump SN: 14828535 are shown in Figures 57 through 72. Figures 57 and Figure 58 show the condition of the injection pump rotor that carries the plungers and distributes the compressed fuel. Figure 58 shows the discharge ports and rotor are in good condition after 500-hours of operation with the R8/Jet-A + 22.5-ppm DCI-4A fuel blend.

Figure 59 and Figure 60 is the Pre-Test and Post-Test conditions of fuel injection pump SN: 14828535 Roller Shoe and Roller conditions. Of note is the lack of a wear scar at the roller shoe leaf spring contact and the shiny, bright rollers shown in Figure 59. Figure 60 reveals only light polishing wear on the roller shoe from the leaf spring contact, and light polishing on the rollers. The rollers tend to discolor when combination rolling-sliding action occurs as the rollers follow the injection cam profile. Figure 61 and Figure 62 show the relatively small wear scar due to 500-hours operation on the roller shoe plunger contact. The wear seen in Figure 62 is typical for an adequate lubricity fuel. The injection pump cam ring shown in Figure 63 and Figure 64 does not reveal any distress from 500-hours operation with the R8/Jet-A + 22.5-ppm DCI-4A fuel blend.

The governor thrust washer condition before and after 500-hours are shown in Figure 65 and Figure 66. The polishing wear seen on the thrust washer in Figure 66 is again typical for 500-hours of injection pump operation. Polishing and light scuffing wear seen on the advance piston suggests the fuel pressure fluctuations in that area of the fuel injection pump housing. The metering valve regulates the pressure to the rotor fill ports. The pressure is regulated by the action of the helix changing the outlet area of an orifice. Due to WOT operation a lightly polished area shows at one location on the helix. The wear on these components is normal considering the 500-hour duration of testing. The wear on the thrust washer, the advance piston wear, and the metering valve did not have an effect on pump operation.

Table 14 - Pump SN: 14828535 Component Wear Ratings

Stanadyne Pump Parts Evaluation

Pump Type : DB2831-5209	SN: 14828535
Test condition : 500 @ 40C, 1800-RPM, WOT	AL: R8/Jet-A + 22.5ppm DCI-4A

Part Name	Condition of part	Ratings: 0 = New 5 = Failed
BLADES	Very light wear at rotor slots & liner contact.	1.5
BLD. SPRINGS	Good	0
LINER	Light polishing wear, very light scuffing wear in small area.	1
TRANS.PUMP REG.	Light polishing wear in small areas from blade contact.	1
REG. PISTON	Three small polished spots	1
ROTOR	Light wear mark at discharge ports.	1.5
ROTOR RET.	Polishing wear & light scuffing wear from rotor contact	2.5
D-VALVE	Light polishing wear	0.5
PLUNGERS	Very lightly polished in small area.	0.5
SHOES	Light wear from leaf spring. Light wear from plungers.	1.5
ROLLERS	Light polishing wear.	1
LEAF SPRING	Light wear from shoe contact	1
CAM RING	Light polishing marks.	1
THRST. WASH.	Light polishing wear from weights.	1
THRST. SLEEVE.	Polishing wear from gov. arm slots	0.5
GOV. WEIGHTS	Light wear at foot & heel, thrust washer contact & cage contact.	1.5
LINK HOOK	Light polishing wear on arm fingers & arm pivot shaft.	1
M-VALVE	Light polishing wear at helix.	1.5
DR. SHAFT TANG	Light polishing wear.	1
DR. SHAFT SEALS	Normal	1
CAM PIN	Light polishing wear at cam ring contact.	1
ADV. PISTON	Spring side top is polished with some light scuffing.	2
HOUSING	Normal	1

Figure 67 and 68 illustrates the minor level of wear seen in the transfer pump section of fuel injection pump SN: 14828535 with the addition of Jet-A and CI/LI additive to the R8 fuel. Figure 67 shows the surface condition of the transfer pump liner prior to testing and Figure 68 shows the surface with light polishing after 500-hours of operation on the R8/Jet-A + 22.5-ppm DCI-4A fuel. Also illustrative of the transfer pump section wear are the transfer pump blade conditions shown in Figures 69 through Figure 72. The light edge wear shown in Figure 69 and Figure 70 corresponds to the surface on the transfer pump blades that contact the transfer pump liner. The side scuffing shown in Figure 71 and Figure 72 reflect wear from the transfer pump blade slots on the injection pump rotor. The wear seen on the transfer pump components is substantially reduced from the neat R8 fuel testing due to the presence of the CI/LI additive and Jet-A in pump SN: 14828535.

Figure 57 - Pump SN: 14828535 Distributor Rotor before Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 58 - Pump SN: 14828535 Distributor Rotor with 500-Hours Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 59 - Pump SN: 14828535 Rollers and Shoe before Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 60 - Pump SN: 14828535 Rollers and Shoe with
500-Hours Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 61 - Pump SN: 14828535 Roller Shoe before
Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 62 - Pump SN: 14828535 Roller Shoe with 500-Hours Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 63 - Pump SN: 14828535 Cam Ring before Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 64 - Pump SN: 14828535 Cam Ring with 500-Hours Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 65 - Pump SN: 14828535 Thrust Washer before Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 66 - Pump SN: 14828535 Thrust Washer with 500-Hours Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 67 - Pump SN: 14828535 Transfer Pump Liner before Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

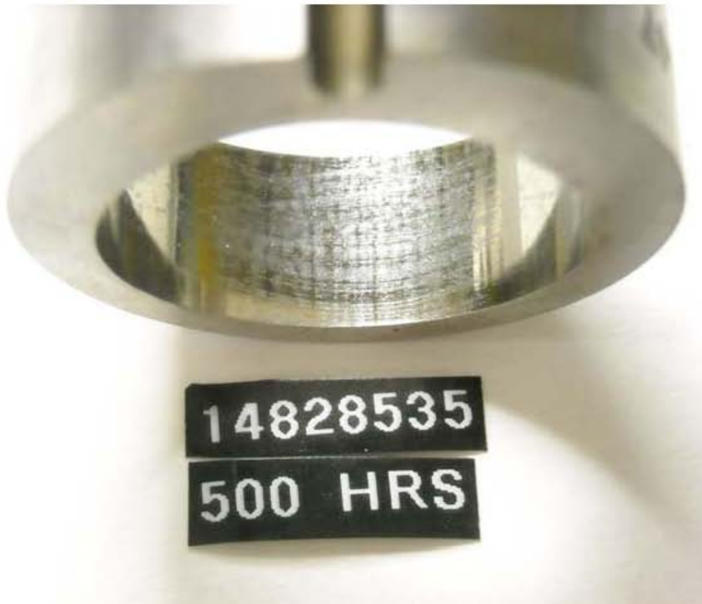

Figure 68 - Pump SN: 14828535 Transfer Pump Liner with 500-Hours Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 69 - Pump SN: 14828535 Transfer Pump Blade Edges before Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 70 - Pump SN: 14828535 Transfer Pump Blade Edges with 500-Hours Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

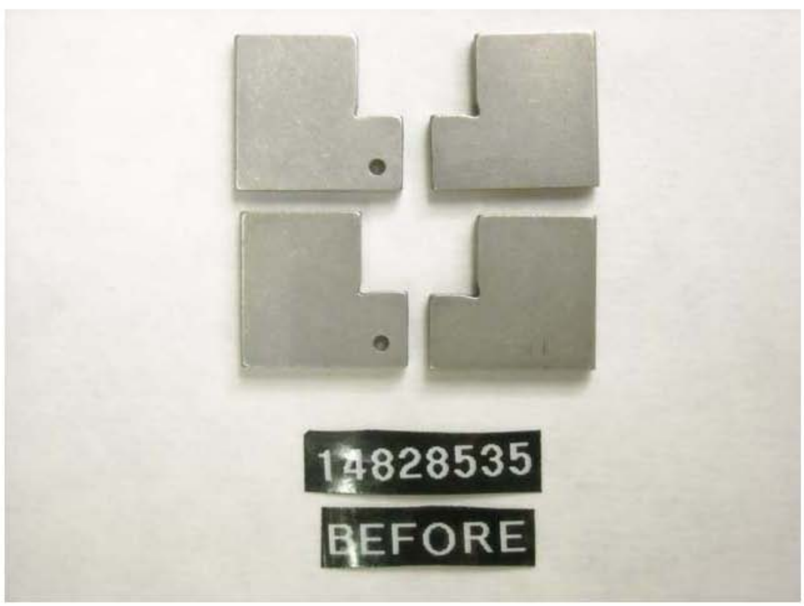

Figure 71 - Pump SN: 14828535 Transfer Pump Blade Sides before Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

Figure 72 - Pump SN: 14828535 Transfer Pump Blade Sides with 500-Hours Testing with R8/JET-A + 22.5-ppm DCI-4A Fuel

6.0 DISCUSSION OF RESULTS

In a previous study (1) the effect of synthetic R8 on the durability of the Stanadyne arctic rotary fuel injection pump that contains hardened parts was examined. This fuel injection pump is found on the HMMWV. In conducting the R8 pump stand test, it was found that the tests had to be stopped prematurely for the following reasons:

- Excessive fuel delivery
- Wear debris was observed
- Increased transfer pump pressure

The most frequent out of specification parameters during the post-test pump performance checks were:

- Change of injection timing
- Increased fuel flow at various speeds

For a results comparison to the R8 fuel, a prior test program performed on a synthetic kerosene grade S-5 was reviewed. (2) The comparison of the R8 and S-5 fuels performance in rotary fuel injection pumps discussed in the previous report (1) suggested that both fuels (R8 and S-5) when utilized neat resulted in premature component wear. On a positive note, reference 2 also performed tests with CI/LI additives in S-5 fuel that showed a substantial improvement if rotary fuel injection pump durability with synthetic fuel.

The purpose of this study was to determine the impacts of a QPL-25017 CI/LI additive on fuel injection pump durability with R8 fuel. The CI/LI additive DCI-4A was used at a 22.5-ppm concentration in R8 fuel and in a 50/50-percent blend of R8/Jet-A fuel. In conducting the pump stand tests with the two fuels, it was found that the both tests had completed 500-hours of operation with the following observations:

- Minor fuel delivery loss at rated speed
- Small fuel delivery loss at idle speed
- Wear debris minimal
- No unusual deposits
- Polishing to light scuffing wear seen on components; wear normal for 500-hours of operation
- Rotary fuel injection pumps functioning normally at 500-hours

The most frequent out of specification parameters during the post-test pump and fuel injector performance checks were:

- Tip dryness, seat sealing, of fuel injectors with R8/Jet-A fuel blend
- Decreased fuel flow at idle and rated speeds

7.0 CONCLUSIONS

The following conclusions are drawn from this project:

1. In conducting the R8 fuel blends pump stand tests, it was found that the tests could be operated to conclusion at 500-hours:

   - R8 fuel with 22.5-ppm DCI-4A CI/LI additive
   - R8/Jet-A fuel blend with 22.5-ppm DCI-4A CI/LI additive
   - Light component wear
   - Substantial durability increase over neat R8 fuel

2. The most frequent out of specification parameters during the post-test pump and fuel injector performance checks were:

   - Tip dryness, seat sealing, of fuel injectors with R8/Jet-A fuel blend
   - Decreased fuel flow at Idle and Rated speeds

3. Unusual heavy, brown deposition not present with either CI/LI treated R8 fuel.

4. R8 fuel with 22.5-ppm DCI-4A CI/LI additive was slightly more erratic in fuel delivery throughout the 500-hour test.

5. R8/Jet-A fuel blend with 22.5-ppm DCI-4A CI/LI additive had slightly less component wear, and slightly better 500-hour delivery performance.

8.0 RECOMMENDATIONS

The technical feasibility of using R8 fuel in rotary fuel injection equipment when blended with a CI/LI additive and petroleum based commercial aviation kerosene has been investigated:

1. It is recommended the blend of R8 and Jet-A fuels, with the addition of 22.5-ppm DCI-4A CI/LI, can be used in diesel rotary fuel injection equipment with minor durability impact and minor performance degradation.

2. It is suggested other CI/LI additives and additive treatment levels be investigated.

9.0 REFERENCES

1. Final Report for Southwest Research Institute® Project No. 08.13283.01.001, "Research of Renewable IPK Alternative Jet Fuel", G.R. Wilson III, December 19, 2008.

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Material Compatibility of R-8 Synthetic Fuel
(Materials Evaluation)

28 January 2010

Evaluation Report
(SA104002)

Report No. AFRL/RXS 10-002

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EXECUTIVE SUMMARY

Testing and evaluation were performed by the University of Dayton Research Institute for the Air Force Research Laboratory/Materials Integrity Branch (AFRL/RXSA) to determine the material compatibility of R-8 synthetic fuel with nonmetallic fuel system materials. The materials to be tested were exposed for 28 days to 100 pecent R-8 and a 50/50 blend of JP-8 and R-8 fuels. The same short list of materials had been previously evaluated in JP-8, 100 percent Fischer-Tropsch (F-T), and a 50/50 blend of JP-8 and F-T fuels. The AFRL/RXSA analyzed the data and determined, based on comparison with the JP-8 baseline results and JP-8/F-T blend results, the JP-8/R-8 blend generally affected materials similarly to the JP-8/F-T blend. However, if the JP-8/R-8 blend is to be used in the field, a few of the materials tested should be retested in the JP-8/R-8 blend along with the baseline JP-8 fuel to ensure compatibility.

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ACKNOWLEDGMENTS

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Material Compatibility of R-8 Synthetic Fuel

PURPOSE

Evaluate the compatibility of R-8 synthetic fuel with nonmetallic engine and airframe materials.

BACKGROUND

The Air Force Research Laboratory/Materials Integrity Branch (AFRL/RXSA) was asked to perform testing to determine the compatibility of fuel tank materials with a 50/50 blend of JP-8 and R-8 fuels. The R-8 is a synthetic fuel produced by Syntroleum Corporation that is derived from animal fat feedstock. Previous compatibility testing for the initial JP-8 +100 program and other alternative fuel and fuel additive programs allowed for the development and refinement of a short list of materials. These materials were chosen to represent the types of materials exposed to the fuel, with emphasis on those particular compounds that were most affected by previous fuels and additives tested. For this effort, the compatibility of the nonmetallic short list of materials was evaluated.

TEST PROCEDURE

All testing was in accordance with established ASTM International and SAE International test procedures outlined below. The materials tested were comprised of six adhesives, three fuel bladder materials, five coatings, six sealants, two noncuring groove sealants, four composites, one conductive foam material, four specific types of O-rings, two hose materials, four wire insulation materials, and one potting compound. Required testing included the following:

Adhesives	
• Lap Shear	ASTM D 1002
• Static Shear	MIL-R-46082, Method A
Fuel Bladders	
• Tensile Strength and Elongation	ASTM D 412
• Volume Swell	ASTM D 471
Coatings	
• Pencil Hardness	ASTM D 3363
• Tape Adhesion	ASTM D 3359, Method A
Sealants and Potting Compound	
• Peel Strength	SAE AS5127/1
• Hardness, Shore A	ASTM D 2240, SAE AS5127/1
• Tensile Strength and Elongation	ASTM D 412, SAE AS5127/1
• Volume Swell	ASTM D 471, SAE AS5127/1
Noncuring Groove Sealants	
• Volume Swell	ASTM D 471

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Composites
- Interlaminar Shear — ASTM D 6272

Foam
- Tensile Strength and Elongation — ASTM D 412
- Resistivity — ASTM D 257

O-rings
- Hardness, Shore M — ASTM D 2240
- Tensile Strength and Elongation — ASTM D 1414
- Compression Set — ASTM D 395
- Volume Swell — ASTM D 471

Hose Material
- Hardness, Shore A — ASTM D 2240
- Tensile Strength and Elongation — ASTM D 412
- Volume Swell — ASTM D 471

Wire Insulation
- Tensile Strength and Elongation — ASTM D 412

The test parameters were the same as have been used on other material compatibility programs, and the baseline (no soak) was taken from other programs. The standard 28 days of fuel soak at elevated temperatures in JP-8, 100 percent R-8, and the 50/50 blend of JP-8 and R-8 fuels was coupled with standard physical properties testing to measure the effects of the fuels on the materials. A duration of 28 days was selected for the fuel soak to provide some longer-term indication of the materials' degradation and performance when exposed to the various fuels.

In analyzing the data, a logical evaluation criterion was to compare the results after aging in JP-8 fuel with results after aging in the JP-8/R-8 blend fuel to identify any significant differences. For each test, "allowable" variations were determined based on standard deviations in the test methods. Differences greater than these allowable variations indicate increased possibility variations in the data are significant and cannot be attributed to normal data scatter for this type of test. When this occurred, the data required closer examination to determine if additional testing was needed or if the data clearly indicated a failure. For some materials there are specification limits, expressed as maximum or minimum values, that can help determine if the material still meets certain requirements after aging. Test requirements noted in the data tables were based on specification limits, when available. Otherwise, test requirements provided were based on experience and previous test programs. In the tables, a value outside the allowable variation from JP-8 is marked in red, as is a failure to meet the test requirements. However, a red marking in the tables does not necessarily mean the material tested is incompatible with the fuel. Final determination of compatibility must consider the overall test results for a given material and the implications of these results for in-service aircraft.

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TEST RESULTS

The completed test results are contained in Tables 1 through 22. Results after fuel aging in 100 percent R-8 and the 50/50 blend of R-8 and JP-8 fuels are compared against the JP-8 baseline specimens, and the differences have been calculated and noted in the tables. Values for the unaged materials are also listed for reference. "Failures" are listed in red. For instances where the results do not meet the test requirements and are outside of the allowable variation from the JP-8 baseline results, further testing may be needed, or monitoring of the material may be recommended if the fuel is employed in the field.

Tables 1 through 22 also contain previous test results obtained after aging the materials in 100 percent Fischer-Tropsch (F-T) fuel or a 50/50 blend of F-T and JP-8 fuels. These data have been included to provide additional points of comparison because, after processing, the R-8 fuel is very similar in composition to fuel derived from coal or natural gas utilizing the F-T process. Neither F-T nor R-8 fuel contain any aromatic compounds, which are known to facilitate the swelling of some elastomeric materials. It is important to note, in most instances, the JP-8 baseline and F-T results have been taken from previous test programs. Therefore, some of the test specimens were obtained from different batches of the source material and might not allow for a direct comparison of test values.

All of the results for the six adhesives tested met the test requirements. The only results that fell outside of the allowable variation from the JP-8 baseline results were for lap shear strength of the nitrile epoxy film after aging in R-8 and the 50/50 blend of JP-8 and R-8 fuels (Table 1).

Table 1

Adhesives

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
Vinyl Phenolic	Lap Shear	Unaged	>1500 psi	3755 psi[1]	~.	~
		28d/200°F/JP-8 (POSF 4751)	>1500 psi	3509 psi[1]	~	~
		28d/200°F/F-T	>1500 psi	3632 psi[1]	250 psi decr.	+ 123 psi
		28d/200°F/[JP-8/F-T Blend]	>1500 psi	3392 psi[1]	250 psi decr.	- 117 psi
		28d/200°F/R-8	>1500 psi	3663 psi	250 psi decr.	+ 154 psi
		28d/200°F/[JP-8/R-8 Blend]	>1500 psi	3376 psi	250 psi decr.	- 133 psi

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel,* AFRL/MLS 06-103 (September 2006).

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Table 1

Adhesives Cont'd

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
Epoxy Paste	Lap Shear	Unaged	>1500 psi	3153 psi[2]	~	~
		28d/200°F/JP-8 (POSF 4751)	>1500 psi	3178 psi[2]	~	~
		28d/200°F/F-T	>1500 psi	3051 psi[2]	250 psi decr.	- 127 psi
		28d/200°F/[JP-8/F-T Blend]	>1500 psi	3036 psi[2]	250 psi decr.	- 142 psi
		28d/200°F/R-8	>1500 psi	3399 psi	250 psi decr.	+ 221 psi
		28d/200°F/[JP-8/R-8 Blend]	>1500 psi	3337 psi	250 psi decr.	+ 159 psi
Nitrile Phenolic	Lap Shear	Unaged	>1500 psi	3132 psi[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	>1500 psi	1803 psi[1]	~	~
		28d/200°F/F-T	>1500 psi	1645 psi[1]	250 psi decr.	- 158 psi
		28d/200°F/[JP-8/F-T Blend]	>1500 psi	2315 psi[1]	250 psi decr.	+ 512 psi
		28d/200°F/R-8	>1500 psi	2916 psi	250 psi decr.	+1113 psi
		28d/200°F/[JP-8/R-8 Blend]	>1500 psi	2712 psi	250 psi decr.	+ 909 psi
Epoxy Paste	Lap Shear	Unaged	>1500 psi	3165 psi[2]	~	~
		28d/200°F/JP-8 (POSF 4751)	>1500 psi	3534 psi[2]	~	~
		28d/200°F/F-T	>1500 psi	4098 psi[2]	250 psi decr.	+ 564 psi
		28d/200°F/[JP-8/F-T Blend]	>1500 psi	3771 psi[2]	250 psi decr.	+ 237 psi
		28d/200°F/R-8	>1500 psi	3387 psi	250 psi decr.	- 147 psi
		28d/200°F/[JP-8/R-8 Blend]	>1500 psi	4120 psi	250 psi decr.	+ 586 psi
Nitrile Epoxy Film	Lap Shear	Unaged	>1500 psi	5914 psi[2]	~	~
		28d/200°F/JP-8 (POSF 4751)	>1500 psi	5391 psi[2]	~	~
		28d/200°F/F-T	>1500 psi	5605 psi[2]	250 psi decr.	+ 214 psi
		28d/200°F/[JP-8/F-T Blend]	>1500 psi	5456 psi[2]	250 psi decr.	+ 65 psi
		28d/200°F/R-8	>1500 psi	4933 psi	250 psi decr.	- 458 psi
		28d/200°F/[JP-8/R-8 Blend]	>1500 psi	4730 psi	250 psi decr.	- 661 psi
Methacrylate	Static Shear	Unaged	>1200 psi	2474 psi[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	>1200 psi	2281 psi[1]	~	~
		28d/200°F/F-T	>1200 psi	3212 psi[1]	250 psi decr.	+ 931 psi
		28d/200°F/[JP-8/F-T Blend]	>1200 psi	2198 psi[1]	250 psi decr.	- 93 psi
		28d/200°F/R-8	>1200 psi	3711 psi	250 psi decr.	+ 1420 psi
		28d/200°F/[JP-8/R-8 Blend]	>1200 psi	3978 psi	250 psi decr.	+ 1697 psi

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel,* AFRL/MLS 06-103 (September 2006).
2 = Data taken from *Fischer-Tropsch Fuel Compatibility with Selected Epoxy Adhesives,* AFRL/RXS 08-025 (April 2008).

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The only results for the nitrile and polyurethane bladder inner liners that did not meet the test requirements were elongation of the nitrile inner liner after aging in F-T, R-8, and the JP-8/R-8 blend and volume swell of the polyurethane inner liner after aging in the JP-8/R-8 blend. However, the volume swell of the polyurethane inner liner after aging in the JP-8/R-8 blend was within the allowable variation from the JP-8 baseline. There were several instances in which test results were outside of the allowable variation from the JP-8 baseline. For the nitrile inner liner, the tensile strength results after aging in R-8 and the JP-8/R-8 blend, the elongation after aging in F-T, R-8, and the R-8 blend, and the volume swell after aging in F-T and the JP-8/R-8 blend were outside of the allowable variation from the JP-8 baseline. For the polyurethane inner liner, all of the results after aging in the R-8 and JP-8/R-8 blend were within the allowable variation from the JP-8 baseline, but in previous testing, the elongation after aging in F-T and the volume swell after aging in F-T were not within the allowable variation from the JP-8 baseline. As was stated previously, it is possible that some variation in the results is due to testing of inner liner materials originating from different batches. Based on a comparison of the overall results, the polyurethane bladder inner liner does not appear to pose any concern. However, the nitrile bladder inner liner material might need to be retested side-by-side with the JP-8 baseline to determine if the variation in the results is attributable to the fuel or to differences between batches of the material itself (Tables 2 and 3).

Table 2

Nitrile Bladder Inner Liner

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
Nitrile	Tensile Strength	Unaged	> 1500 psi	2441 psi[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	> 1500 psi	2222 psi[1]	~	~
		28d/160°F/F-T	> 1500 psi	2155 psi[1]	200 psi decr.	- 67 psi
		28d/160°F/[JP-8/F-T Blend]	> 1500 psi	2373 psi[1]	200 psi decr.	+ 151 psi
		28d/160°F/R-8	> 1500 psi	1898 psi	200 psi decr.	- 324 psi
		28d/160°F/[JP-8/R-8 Blend]	> 1500 psi	1750 psi	200 psi decr.	-472 psi
	Elongation	Unaged	> 300%	568%[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	> 300%	345%[1]	~	~
		28d/160°F/F-T	> 300%	226%[1]	40% decr.	- 119%
		28d/160°F/[JP-8/F-T Blend]	> 300%	338%[1]	40% decr.	- 7%
		28d/160°F/R-8	> 300%	250%	40% decr.	- 95%
		28d/160°F/[JP-8/R-8 Blend]	> 300%	247%	40% decr.	- 98%
	Volume Swell	Unaged	< 25%	~	~	~
		28d/160°F/JP-8 (POSF 4751)	< 25%	-4.7%[1]	~	~
		28d/160°F/F-T	< 25%	-12.1%[1]	+/- 5%	- 7.4%
		28d/160°F/[JP-8/F-T Blend]	< 25%	-4.7%[1]	+/- 5%	0%
		28d/160°F/R-8	< 25%	-8.7%	+/- 5%	- 4%
		28d/160°F/[JP-8/R-8 Blend]	< 25%	6.0%	+/- 5%	+ 10.7%

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel*, AFRL/MLS 06-103 (September 2006).

Table 3

Polyurethane Bladder Inner Liner

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
Polyurethane	Tensile Strength	Unaged	> 1500 psi	3292 psi[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 1500 psi	2607 psi[1]	~	~
		28d/200°F/F-T	> 1500 psi	3217 psi[1]	200 psi decr.	+ 610 psi
		28d/200°F/[JP-8/F-T Blend]	> 1500 psi	2897 psi[1]	200 psi decr.	+ 290 psi
		28d/200°F/R-8	> 1500 psi	3597 psi	200 psi decr.	+ 990 psi
		28d/200°F/[JP-8/R-8 Blend]	> 1500 psi	3299 psi	200 psi decr.	+ 692 psi
	Elongation	Unaged	> 300%	449%[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 300%	490%[1]	~	~
		28d/200°F/F-T	> 300%	410%[1]	40% decr.	- 80%
		28d/200°F/[JP-8/F-T Blend]	> 300%	464%[1]	40% decr.	- 26%
		28d/200°F/R-8	> 300%	454%	40% decr.	- 36%
		28d/200°F/[JP-8/R-8 Blend]	> 300%	514%	40% decr.	+ 24%
	Volume Swell	Unaged	< 25%	~	~	~
		28d/200°F/JP-8 (POSF 4751)	< 25%	23.2%[1]	~	~
		28d/200°F/F-T	< 25%	3.5%[1]	+/- 5%	- 19.7%
		28d/200°F/[JP-8/F-T Blend]	< 25%	23.2%[1]	+/- 5%	0%
		28d/200°F/R-8	< 25%	19.7%	+/- 5%	- 3.5%
		28d/200°F/[JP-8/R-8 Blend]	< 25%	27.5%	+/- 5%	+ 4.3%

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel*, AFRL/MLS 06-103 (September 2006).

The volume swell results for the self-sealing layer of a MIL-T-5578 bladder after aging in R-8 and the JP-8/R-8 blend were outside the allowable variation from the JP-8 baseline results, however, the swell of the materials in all cases was significant (42.7% to 58.0%) (Table 4).

Table 4

Self-Sealing Bladder Material

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
MIL-T-5578 (Self-sealing layer)	Volume Swell	Unaged	~	~	~	~
		30min/75°/JP-8 (POSF 4751)	~	58.0%	~	~
		30min/75°F/R-8	~	42.7%	± 5%	- 15.3%
		30min/75°F/[JP-8/R-8 Blend]	~	48.8%	± 5%	- 9.2%

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For the five coatings, the only results that did not meet the test requirements were tape adhesion of the AMS-S-4384 nitrile material after aging in R-8 and the JP-8/R-8 blend. Additionally, the only result for pencil hardness outside the allowable variation from the baseline JP-8 was for BMS 10-39 after aging in R-8. In this instance a slight softening of the coating occurred relative to the results obtained after aging in each of the other fuels (Table 5).

Table 5

Coatings

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS-S-4383 (nitrile)	Pencil Hardness	Unaged	~	2H[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	≥ unaged	>6H[1]	~	~
		28d/200°F/F-T	≥ unaged	>6H[1]	± 1 pt	0
		28d/200°F/[JP-8/F-T Blend]	≥ unaged	>6H[1]	± 1 pt	0
		28d/200°F/R-8	≥ unaged	>6H	± 1 pt	0
		28d/200°F/[JP-8/R-8 Blend]	≥ unaged	6H	± 1 pt	-1
	Tape Adhesion	Unaged	Pass	Passed[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	Pass	Passed[1]	~	~
		28d/200°F/F-T	Pass	Passed[1]	~	~
		28d/200°F/[JP-8/F-T Blend]	Pass	Passed[1]	~	~
		28d/200°F/R-8	Pass	Failed	~	~
		28d/200°F/[JP-8/R-8 Blend]	Pass	Failed	~	~
AMS-C-27725 (nitrile)	Pencil Hardness	Unaged	~	> 6H[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	≥ unaged	> 6H[1]	~	~
		28d/200°F/F-T	≥ unaged	>6H[1]	± 1 pt	0
		28d/200°F/[JP-8/F-T Blend]	≥ unaged	>6H[1]	± 1 pt	0
		28d/200°F/R-8	≥ unaged	>6H	± 1 pt	0
		28d/200°F/[JP-8/R-8 Blend]	≥ unaged	>6H	± 1 pt	0
	Tape Adhesion	Unaged	Pass	Passed[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	Pass	Passed[1]	~	~
		28d/200°F/F-T	Pass	Passed[1]	~	~
		28d/200°F/[JP-8/F-T Blend]	Pass	Passed[1]	~	~
		28d/200°F/R-8	Pass	Passed	~	~
		28d/200°F/[JP-8/R-8 Blend]	Pass	Passed	~	~

6B – 5B – 4B – 3B – 2B – B – HB – F- H – 2H – 3H – 4H – 5H – 6H
Softer ... Harder

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel,* AFRL/MLS 06-103 (September 2006).

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Table 5

Coatings Cont'd

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
BMS 10-20 (epoxy)	Pencil Hardness	Unaged	~	> 6H[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	≥ unaged	> 6H[1]	~	~
		28d/200°F/F-T	≥ unaged	>6H[1]	± 1 pt	0
		28d/200°F/[JP-8/F-T Blend]	≥ unaged	>6H[1]	± 1 pt	0
		28d/200°F/R-8	≥ unaged	>6H	± 1 pt	0
		28d/200°F/[JP-8/R-8 Blend]	≥ unaged	>6H	± 1 pt	0
	Tape Adhesion	Unaged	Pass	Passed[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	Pass	Passed[1]	~	~
		28d/200°F/F-T	Pass	Passed[1]	~	~
		28d/200°F/[JP-8/F-T Blend]	Pass	Passed[1]	~	~
		28d/200°F/R-8	Pass	Passed	~	~
		28d/200°F/[JP-8/R-8 Blend]	Pass	Passed	~	~
BMS 10-39 (epoxy)	Pencil Hardness	Unaged	~	> 6H[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	≥ unaged	> 6H[1]	~	~
		28d/200°F/F-T	≥ unaged	>6H[1]	± 1 pt	0
		28d/200°F/[JP-8/F-T Blend]	≥ unaged	>6H[1]	± 1 pt	0
		28d/200°F/R-8	≥ unaged	5H	± 1 pt	- 2
		28d/200°F/[JP-8/R-8 Blend]	≥ unaged	>6H	± 1 pt	0
	Tape Adhesion	Unaged	Pass	Passed[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	Pass	Passed[1]	~	~
		28d/200°F/F-T	Pass	Passed[1]	~	~
		28d/200°F/[JP-8/F-T Blend]	Pass	Passed[1]	~	~
		28d/200°F/R-8	Pass	Passed	~	~
		28d/200°F/[JP-8/R-8 Blend]	Pass	Passed	~	~
MIL-DTL-24441 (epoxy-polyamide)	Pencil Hardness	Unaged	~	> 6H[1]	~	~
		28d/120°F/JP-8 (POSF 4751)	≥ unaged	> 6H[1]	~	~
		28d/120°F/F-T	≥ unaged	>6H[1]	1 pt decrease	0
		28d/120°F/[JP-8/F-T Blend]	≥ unaged	>6H[1]	1 pt decrease	0
		28d/120°F/R-8	≥ unaged	>6H	1 pt decrease	0
		28d/120°F/[JP-8/R-8 Blend]	≥ unaged	>6H	1 pt decrease	0
	Tape Adhesion	Unaged	Pass	Passed[1]	~	~
		28d/120°F/JP-8 (POSF 4751)	Pass	Passed[1]	~	~
		28d/120°F/F-T	Pass	Passed[1]	~	~
		28d/120°F/[JP-8/F-T Blend]	Pass	Passed[1]	~	~
		28d/120°F/R-8	Pass	Passed	~	~
		28d/120°F/[JP-8/R-8 Blend]	Pass	Passed	~	~

6B – 5B – 4B – 3B – 2B – B – HB – F- H – 2H – 3H – 4H – 5H – 6H

Softer Harder

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel*, AFRL/MLS 06-103 (September 2006).

The majority of results for the dichromate cured polysulfide (AMS-S-8802) met the test requirements, with the exception of volume swell after aging in F-T fuel, R-8 fuel, and the JP-8/R-8 blend. The elongation results after aging in all of the alternative fuels and blends, as well as the tensile strength results after aging in R-8 and the JP-8/R-8 blend, were outside the allowable variations from the baseline (Table 6).

Table 6

Dichromate Cured AMS-S-8802 Polysulfide Sealant

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS-S-8802 (Polysulfide) (Dichromate cured)	Tensile Strength	Unaged	> 200 psi	518 psi[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 200 psi	406 psi1	~	~
		28d/200°F/F-T	> 200 psi	395 psi[1]	35 psi decrease	-11 psi
		28d/200°F/[JP-8/F-T Blend]	> 200 psi	390 psi[1]	35 psi decrease	- 16 psi
		28d/200°F/R-8	> 200 psi	365 psi	35 psi decrease	- 41 psi
		28d/200°F/[JP-8/R-8 Blend]	> 200 psi	309 psi	35 psi decrease	- 97 psi
	Elongation	Unaged	> 150%	507%[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 150%	347%[1]	~	~
		28d/200°F/F-T	> 150%	261%[1]	25% decrease	- 86%
		28d/200°F/[JP-8/F-T Blend]	> 150%	258%[1]	25% decrease	- 89%
		28d/200°F/R-8	> 150%	214%	25% decrease	- 133%
		28d/200°F/[JP-8/R-8 Blend]	> 150%	171%	25% decrease	- 176%
	Volume Swell	Unaged	~	~	~	~
		28d/200°F/JP-8 (POSF 4751)	0% to 20%	4.0%[1]	~	~
		28d/200°F/F-T	0% to 20%	-0.4%[1]	5% increase	- 4.4%
		28d/200°F/[JP-8/F-T Blend]	0% to 20%	0.1%[1]	5% increase	- 3.9%
		28d/200°F/R-8	0% to 20%	-4%	5% increase	- 8.0%
		28d/200°F/[JP-8/R-8 Blend]	0% to 20%	-2%	5% increase	- 6.0%
	Hardness, Shore A	Unaged	> 35 pts	62[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 35 pts	62[1]	~	~
		28d/200°F/F-T	> 35 pts	64[1]	± 5 pts	+ 2
		28d/200°F/[JP-8/F-T Blend]	> 35 pts	58[1]	± 5 pts	- 4
		28d/200°F/R-8	> 35 pts	62	± 5 pts	0
		28d/200°F/[JP-8/R-8 Blend]	> 35 pts	62	± 5 pts	0
	Peel Strength	Unaged	>20 lbs / 100%	36 lbs/100%[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	>20 lbs / 100%	40 lbs/100%[1]	~	~
		28d/200°F/F-T	>20 lbs / 100%	42 lbs/100%[1]	8 lbs decrease	+ 2 lbs
		28d/200°F/[JP-8/F-T Blend]	>20 lbs / 100%	39 lbs/100%[1]	8 lbs decrease	- 1 lb
		28d/200°F/R-8	>20 lbs / 100%	36 lbs/100%	8 lbs decrease	-4 lbs
		28d/200°F/[JP-8/R-8 Blend]	>20 lbs / 100%	33 lbs/100%	8 lbs decrease	- 7 lbs

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel*, AFRL/MLS 06-103 (September 2006).

APPENDIX J
Materials Compatibility
APPENDIX J-1: Material Compatibility of R-8 Synthetic Fuel

AFRL/RXS 10-002

The majority of results for the manganese dioxide cured polysulfide (AMS-S-8802) met the test requirements, with the exception of volume swell after aging in all fuels, and elongation after aging in R-8 and the JP-8/R-8 blend. The results that fell outside of the allowable variation from the JP-8 baseline were as follows: tensile strength after aging in R-8 and the JP-8/R-8 blend; elongation after aging in R-8 and the JP-8/R-8 blend; Shore A hardness after aging in F-T and R-8; and peel strength after aging in R-8 and the JP-8/R-8 blend. The consistent loss of elongation and peel strength after aging in R-8 and the JP-8/R-8 blend may be cause for some concern (Table 7).

Table 7

Manganese Dioxide Cured AMS-S-8802 Polysulfide Sealant

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS-S-8802 (Polysulfide) (Manganese-dioxide cured)	Tensile Strength	Unaged	> 200 psi	395 psi[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 200 psi	415 psi[1]	~	~
		28d/200°F/F-T	> 200 psi	491 psi[1]	35 psi decrease	+ 76 psi
		28d/200°F/[JP-8/F-T Blend]	> 200 psi	410 psi[1]	35 psi decrease	- 5 psi
		28d/200°F/R-8	> 200 psi	368 psi	35 psi decrease	- 47 psi
		28d/200°F/[JP-8/R-8 Blend]	> 200 psi	326 psi	35 psi decrease	- 89 psi
	Elongation	Unaged	> 150%	271%[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 150%	195%[1]	~	~
		28d/200°F/F-T	> 150%	192%[1]	25% decrease	- 3%
		28d/200°F/[JP-8/F-T Blend]	> 150%	221%[1]	25% decrease	+ 26%
		28d/200°F/R-8	> 150%	110%	25% decrease	- 85%
		28d/200°F/[JP-8/R-8 Blend]	> 150%	110%	25% decrease	- 85%
	Volume Swell	Unaged	~	~	~	~
		28d/200°F/JP-8 (POSF 4751)	0% to 20%	- 2.1%[1]	~	~
		28d/200°F/F-T	0% to 20%	-5.3%[1]	5% increase	- 3.2%
		28d/200°F/[JP-8/F-T Blend]	0% to 20%	-5.0%[1]	5% increase	- 2.9%
		28d/200°F/R-8	0% to 20%	-7%	5% increase	- 4.9%
		28d/200°F/[JP-8/R-8 Blend]	0% to 20%	-6%	5% increase	- 3.9%
	Hardness, Shore A	Unaged	> 35 pts	62[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 35 pts	56[1]	~	~
		28d/200°F/F-T	> 35 pts	62[1]	± 5 pts	+ 6
		28d/200°F/[JP-8/F-T Blend]	> 35 pts	58[1]	± 5 pts	+ 2
		28d/200°F/R-8	> 35 pts	64	± 5 pts	+ 8
		28d/200°F/[JP-8/R-8 Blend]	> 35 pts	58	± 5 pts	+ 2
	Peel Strength	Unaged	>20 lbs / 100%	52 lbs/100%[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	>20 lbs / 100%	44 lbs/100%[1]	~	~
		28d/200°F/F-T	>20 lbs / 100%	41 lbs/100%[1]	8 lbs decrease	- 3 lbs
		28d/200°F/[JP-8/F-T Blend]	>20 lbs / 100%	44 lbs/100%[1]	8 lbs decrease	0 lbs
		28d/200°F/R-8	>20 lbs / 100%	29 lbs/100%	8 lbs decrease	- 15 lbs
		28d/200°F/[JP-8/R-8 Blend]	>20 lbs / 100%	27 lbs/100%	8 lbs decrease	- 17 lbs

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel,* AFRL/MLS 06-103 (September 2006).

APPENDIX J
Materials Compatibility
APPENDIX J-1: Material Compatibility of R-8 Synthetic Fuel

AFRL/RXS 10-002

The majority of results for fluorosilicone sealant (AMS 3375) met the test requirements, with the exception of volume swell after aging in both alternative fuels and their blends, and in the previous testing, elongation after aging in the JP-8/F-T blend. The results that fell outside of the allowable variation from the JP-8 baseline were as follows: tensile strength after aging in F-T, R-8, and the JP-8/R-8 blend; elongation after aging in the JP-8/F-T blend; and Shore A hardness after aging in the JP-8/F-T and JP-8/R-8 blends (Table 8).

Table 8

AMS 3375 Fluorosilicone Sealant

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS 3375 (Fluorosilicone)	Tensile Strength	Unaged	> 200 psi	643 psi[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 200 psi	394 psi[1]	~	~
		28d/200°F/F-T	> 200 psi	345 psi[1]	35 psi decrease	- 49 psi
		28d/200°F/[JP-8/F-T Blend]	> 200 psi	405 psi[1]	35 psi decrease	+ 11 psi
		28d/200°F/R-8	> 200 psi	294 psi	35 psi decrease	- 100 psi
		28d/200°F/[JP-8/R-8 Blend]	> 200 psi	312 psi	35 psi decrease	- 82 psi
	Elongation	Unaged	> 150%	355%[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 150%	173%[1]	~	~
		28d/200°F/F-T	> 150%	164%[1]	25% decrease	- 9%
		28d/200°F/[JP-8/F-T Blend]	> 150%	113%[1]	25% decrease	- 60%
		28d/200°F/R-8	> 150%	176%	25% decrease	+ 3%
		28d/200°F/[JP-8/R-8 Blend]	> 150%	184%	25% decrease	+ 11%
	Volume Swell	Unaged	~	~	~	~
		28d/200°F/JP-8 (POSF 4751)	0% to 20%	1.1%[1]	~	~
		28d/200°F/F-T	0% to 20%	-0.6%[1]	5% increase	- 1.7%
		28d/200°F/[JP-8/F-T Blend]	0% to 20%	-0.2%[1]	5% increase	- 1.3%
		28d/200°F/R-8	0% to 20%	-2%	5% increase	-3.1%
		28d/200°F/[JP-8/R-8 Blend]	0% to 20%	-1%	5% increase	-2.1%
	Hardness, Shore A	Unaged	> 35 pts	45[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 35 pts	40[1]	~	~
		28d/200°F/F-T	> 35 pts	42[1]	± 5 pts	+ 2
		28d/200°F/[JP-8/F-T Blend]	> 35 pts	61[1]	± 5 pts	+ 21
		28d/200°F/R-8	> 35 pts	45	± 5 pts	+ 5
		28d/200°F/[JP-8/R-8 Blend]	> 35 pts	47	± 5 pts	+ 7
	Peel Strength	Unaged	>10 lbs / 100%	14 lbs/100%[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	>10 lbs / 100%	11 lbs/100%[1]	~	~
		28d/200°F/F-T	>10 lbs / 100%	24 lbs/100%[1]	8 lbs decrease	+ 13 lbs
		28d/200°F/[JP-8/F-T Blend]	>10 lbs / 100%	14 lbs/100%[1]	8 lbs decrease	+ 3 lbs
		28d/200°F/R-8	>10 lbs / 100%	19 lbs/100%	8 lbs decrease	+ 8 lbs
		28d/200°F/[JP-8/R-8 Blend]	>10 lbs / 100%	18 lbs/100%	8 lbs decrease	+ 7 lbs

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel,* AFRL/MLS 06-103 (September 2006).

AFRL/RXS 10-002

The majority of results for the polyurethane sealant (AMS 3379) met the test requirements, with the exception of volume swell after aging in R-8 fuel, and percentage cohesive failure in the peel strength testing after aging in all of the fuels and blends. Results that fell outside of the allowable variation from the JP-8 baseline were as follows: tensile strength and elongation after aging in F-T fuel in previous testing; and Shore A hardness after aging in the all of the alternative fuels and blends. It is important to note the tensile strength and elongation results after aging in R-8 were acceptable (Table 9).

Table 9

AMS 3379 Polyurethane Sealant

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS 3379 (Polyurethane)	Tensile Strength	Unaged	> 200 psi	451 psi[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 200 psi	654 psi[1]	~	~
		28d/200°F/F-T	> 200 psi	440 psi[1]	35 psi decrease	- 214 psi
		28d/200°F/[JP-8/F-T Blend]	> 200 psi	669 psi[1]	35 psi decrease	+ 15 psi
		28d/200°F/R-8	> 200 psi	932 psi	35 psi decrease	+ 278 psi
		28d/200°F/[JP-8/R-8 Blend]	> 200 psi	1004 psi	35 psi decrease	+ 350 psi
	Elongation	Unaged	> 150%	863%[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 150%	615%[1]	~	~
		28d/200°F/F-T	> 150%	382%[1]	25% decrease	- 233%
		28d/200°F/[JP-8/F-T Blend]	> 150%	671%[1]	25% decrease	+ 56%
		28d/200°F/R-8	> 150%	710%	25% decrease	+ 95%
		28d/200°F/[JP-8/R-8 Blend]	> 150%	812%	25% decrease	+ 197%
	Volume Swell	Unaged	~	~	~	~
		28d/200°F/JP-8 (POSF 4751)	0% to 30%	13.9%[1]	~	~
		28d/200°F/F-T	0% to 30%	7.0%[1]	5% increase	- 6.9%
		28d/200°F/[JP-8/F-T Blend]	0% to 30%	11.5%[1]	5% increase	- 2.4%
		28d/200°F/R-8	0% to 30%	-1%	5% increase	- 14.9%
		28d/200°F/[JP-8/R-8 Blend]	0% to 30%	5%	5% increase	- 8.9%
	Hardness, Shore A	Unaged	> 35 pts	67[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 35 pts	46[1]	~	~
		28d/200°F/F-T	> 35 pts	64[1]	± 5 pts	+ 18
		28d/200°F/[JP-8/F-T Blend]	> 35 pts	54[1]	± 5 pts	+ 8
		28d/200°F/R-8	> 35 pts	64	± 5 pts	+ 18
		28d/200°F/[JP-8/R-8 Blend]	> 35 pts	64	± 5 pts	+ 18
	Peel Strength	Unaged	>20 lbs / 100%	27 lbs/100%[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	>20 lbs / 100%	25 lbs/28%[1]	~	~
		28d/200°F/F-T	>20 lbs / 100%	25 lbs/71%[1]	8 lbs decrease	0
		28d/200°F/[JP-8/F-T Blend]	>20 lbs / 100%	26 lbs/85%[1]	8 lbs decrease	+ 1 lb
		28d/200°F/R-8	>20 lbs / 100%	24 lbs/35%	8 lbs decrease	- 1 lb
		28d/200°F/[JP-8/R-8 Blend]	>20 lbs / 100%	33 lbs/35%	8 lbs decrease	+ 8 lbs

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel*, AFRL/MLS 06-103 (September 2006).

APPENDIX J
Materials Compatibility
APPENDIX J-1: Material Compatibility of R-8 Synthetic Fuel

AFRL/RXS 10-002

The majority of results for the polythioether sealant (AMS 3277) met the test requirements, with the exception of volume swell after aging in F-T fuel, and elongation after aging in R-8 fuel and the JP-8/R-8 blend. The results that fell outside of the allowable variation from the JP-8 baseline were as follows: elongation after aging in R-8 fuel and the JP-8/R-8 blend; and Shore A hardness after aging in the F-T and the JP-8/F-T blend in the previous testing. The consistent loss of elongation after aging in R-8 and the JP-8/R-8 blend may be cause for some concern (Table 10).

Table 10

AMS 3277 Polythioether Sealant

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS 3277 (Polythioether)	Tensile Strength	Unaged	> 200 psi	338 psi[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 200 psi	335 psi[1]	~	~
		28d/200°F/F-T	> 200 psi	402 psi[1]	35 psi decrease	+ 67 psi
		28d/200°F/[JP-8/F-T Blend]	> 200 psi	339 psi[1]	35 psi decrease	+ 4 psi
		28d/200°F/R-8	> 200 psi	305 psi	35 psi decrease	- 30 psi
		28d/200°F/[JP-8/R-8 Blend]	> 200 psi	302 psi	35 psi decrease	- 33 psi
	Elongation	Unaged	> 150%	323%[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 150%	178%[1]	~	~
		28d/200°F/F-T	> 150%	218%[1]	25% decrease	+ 40%
		28d/200°F/[JP-8/F-T Blend]	> 150%	256%[1]	25% decrease	+ 78%
		28d/200°F/R-8	> 150%	120%	25% decrease	- 58%
		28d/200°F/[JP-8/R-8 Blend]	> 150%	117%	25% decrease	- 61%
	Volume Swell	Unaged	~	~	~	~
		28d/200°F/JP-8 (POSF 4751)	0% to 25%	7.3%[1]	~	~
		28d/200°F/F-T	0% to 25%	-1.4%[1]	5% increase	- 8.7%
		28d/200°F/[JP-8/F-T Blend]	0% to 25%	1.4%[1]	5% increase	- 5.9%
		28d/200°F/R-8	0% to 25%	0%	5% increase	- 7.3%
		28d/200°F/[JP-8/R-8 Blend]	0% to 25%	3%	5% increase	- 4.3%
	Hardness, Shore A	Unaged	> 35 pts	48[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 35 pts	42[1]	~	~
		28d/200°F/F-T	> 35 pts	50[1]	± 5 pts	+ 8
		28d/200°F/[JP-8/F-T Blend]	> 35 pts	36[1]	± 5 pts	- 6
		28d/200°F/R-8	> 35 pts	46	± 5 pts	+ 4
		28d/200°F/[JP-8/R-8 Blend]	> 35 pts	44	± 5 pts	+ 2
	Peel Strength	Unaged	>20 lbs / 100%	58 lbs/100%[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	>20 lbs / 100%	38 lbs/100%[1]	~	~
		28d/200°F/F-T	>20 lbs / 100%	49 lbs/100%[1]	8 lbs decrease	+ 11 lbs
		28d/200°F/[JP-8/F-T Blend]	>20 lbs / 100%	47 lbs/100%[1]	8 lbs decrease	+ 9 lbs
		28d/200°F/R-8	>20 lbs / 100%	37 lbs/100%	8 lbs decrease	- 1 lb
		28d/200°F/[JP-8/R-8 Blend]	>20 lbs / 100%	36 lbs/100%	8 lbs decrease	- 2 lbs

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel,* AFRL/MLS 06-103 (September 2006).

APPENDIX J
Materials Compatibility
APPENDIX J-1: Material Compatibility of R-8 Synthetic Fuel

The majority of results for the low density polysulfide sealant (AMS 3281) met the test requirements, with the exception of volume swell after aging in all fuels. The results that fell outside of the allowable variation from the JP-8 baseline were as follows: elongation after aging in the JP-8/R-8 blend; in the previous testing, the elongation and Shore A hardness after aging in F-T fuel were outside of the allowable variation (Table 11).

Table 11

AMS 3281 Low-Density Polysulfide Sealant

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS 3281 (Low-Density Polysulfide)	Tensile Strength	Unaged	> 200 psi	266 psi[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 200 psi	257 psi[1]	~	~
		28d/200°F/F-T	> 200 psi	288 psi[1]	35 psi decrease	+ 31 psi
		28d/200°F/[JP-8/F-T Blend]	> 200 psi	259 psi[1]	35 psi decrease	+ 2 psi
		28d/200°F/R-8	> 200 psi	256 psi	35 psi decrease	- 1 psi
		28d/200°F/[JP-8/R-8 Blend]	> 200 psi	234 psi	35 psi decrease	- 23 psi
	Elongation	Unaged	> 150%	596%[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 150%	258%[1]	~	~
		28d/200°F/F-T	> 150%	221%[1]	25% decrease	- 37%
		28d/200°F/[JP-8/F-T Blend]	> 150%	235%[1]	25% decrease	- 23%
		28d/200°F/R-8	> 150%	234%	25% decrease	- 24%
		28d/200°F/[JP-8/R-8 Blend]	> 150%	166%	25% decrease	- 92%
	Volume Swell	Unaged	~	~	~	~
		28d/200°F/JP-8 (POSF 4751)	0% to 20%	- 4.4%[1]	~	~
		28d/200°F/F-T	0% to 20%	-5.7%[1]	5% increase	- 1.3%
		28d/200°F/[JP-8/F-T Blend]	0% to 20%	-3.9%[1]	5% increase	+ 0.5%
		28d/200°F/R-8	0% to 20%	-3%	5% increase	+ 1.4%
		28d/200°F/[JP-8/R-8 Blend]	0% to 20%	-1%	5% increase	+ 3.4%
	Hardness, Shore A	Unaged	> 35 pts	38[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 35 pts	43[1]	~	~
		28d/200°F/F-T	> 35 pts	50[1]	± 5 pts	+ 7
		28d/200°F/[JP-8/F-T Blend]	> 35 pts	47[1]	± 5 pts	+ 4
		28d/200°F/R-8	> 35 pts	48	± 5 pts	+ 5
		28d/200°F/[JP-8/R-8 Blend]	> 35 pts	47	± 5 pts	+ 4
	Peel Strength	Unaged	>20 lbs / 100%	36 lbs/100%[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	>20 lbs / 100%	30 lbs/100%[1]	~	~
		28d/200°F/F-T	>20 lbs / 100%	27 lbs/100%[1]	8 lbs decrease	- 3 lbs
		28d/200°F/[JP-8/F-T Blend]	>20 lbs / 100%	29 lbs/100%[1]	8 lbs decrease	- 1 lb
		28d/200°F/R-8	>20 lbs / 100%	22 lbs/100%	8 lbs decrease	- 8 lbs
		28d/200°F/[JP-8/R-8 Blend]	>20 lbs / 100%	33 lbs/100%	8 lbs decrease	+ 3 lbs

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel*, AFRL/MLS 06-103 (September 2006).

All results for the two noncuring groove sealants met the volume swell test requirements. The only result that was not within the allowable variation from the JP-8 baseline was the volume swell of the fluorosilicone (MIL-S-85334) sealant after aging in R-8 fuel (Table 12).

Table 12

Noncuring Groove Sealants

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS 3283 (Polysulfide)	Volume Swell	Unaged	~	~	~	~
		28d/160°F/JP-8 (POSF 4751)	1% to 12%	4.1%[1]	~	~
		28d/160°F/[JP-8/F-T Blend]	1% to 12%	3.5%[1]	± 5%	- 0.6%
		28d/160°F/R-8	1% to 12%	2%	± 5%	- 2.1%
		28d/160°F/[JP-8/R-8 Blend]	1% to 12%	4%	± 5%	- 0.1%
MIL-S-85334 (Fluorosilicone)	Volume Swell	Unaged	~	~	~	~
		28d/160°F/JP-8 (POSF 4751)	1% to 12%	10.7%[1]	~	~
		28d/160°F/[JP-8/F-T Blend]	1% to 12%	8.3%[1]	± 5%	- 2.4%
		28d/160°F/R-8	1% to 12%	4%	± 5%	- 6.7%
		28d/160°F/[JP-8/R-8 Blend]	1% to 12%	7%	± 5%	- 3.7%

1 = Data taken from *Fischer-Tropsch Compatibility with Selected B-1B Materials*, AFRL/RXS 08-017 (April 2008).

All results for the foam material after aging in R-8 and the JP-8/R-8 blend met the test requirements and were within the allowable variation from the JP-8 baseline. In previous testing, the tensile strength and elongation results after aging in the JP-8/F-T blend did not meet the testing requirements. Also, the elongation values after aging in F-T and the JP-8/F-T blend were outside the allowable variation from the JP-8 baseline. The test results after aging in F-T and the JP-8/F-T blend were reviewed, and retesting was performed in which the foam was deemed to be compatible for use in the JP-8/F-T blend, so the R-8 fuel also does not be cause for any concern (Table 13).

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Table 13

Foam

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
MIL-F-87260 (Conductive) (Polyurethane)	Tensile Strength	Unaged	> 10 psi	15 psi[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 10 psi	10 psi[1]	~	~
		28d/200°F/F-T	> 10 psi	10 psi[1]	5 psi decr.	0 psi
		28d/200°F/[JP-8/F-T Blend]	> 10 psi	9 psi[1]	5 psi decr.	- 1 psi
		28d/200°F/R-8	> 10 psi	12 psi	5 psi decr.	+ 2 psi
		28d/200°F/[JP-8/R-8 Blend]	> 10 psi	12 psi	5 psi decr.	+ 2 psi
	Elongation	Unaged	> 100%	118%[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 100%	134%[1]	~	~
		28d/200°F/F-T	> 100%	109%[1]	15% decr.	- 25%
		28d/200°F/[JP-8/F-T Blend]	> 100%	99%[1]	15% decr.	- 35%
		28d/200°F/R-8	> 100%	132%	15% decr.	- 2%
		28d/200°F/[JP-8/R-8 Blend]	> 100%	124%	15% decr.	- 10%
	Resistivity	Unaged	< 1.0E+12	1.3E+11[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	< 1.0E+12	2.5E+10[1]	~	~
		28d/200°F/F-T	< 1.0E+12	4.6E+10[1]	~	+ 2.1E+10
		28d/200°F/[JP-8/F-T Blend]	< 1.0E+12	5.3E+10[1]	~	+ 2.8E+10
		28d/200°F/R-8	< 1.0E+12	3.1E+10	~	+ 6.0E+9
		28d/200°F/[JP-8/R-8 Blend]	< 1.0E+12	3.5E+10	~	+ 1.0E+10

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel*, AFRL/MLS 06-103 (September 2006).

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All results for the four composite materials tested met the test requirements listed, and all results were within the allowable variation from the baseline (Table 14).

Table 14

Composites

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
Graphite / Epoxy	Interlaminar Shear	Unaged	>5000 psi	11,141 psi[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	>5000 psi	6867 psi[1]	~	~
		28d/200°F/F-T	>5000 psi	7573 psi[1]	500 psi decr.	+ 706 psi
		28d/200°F/[JP-8/F-T Blend]	>5000 psi	8546 psi[1]	500 psi decr.	+ 1679 psi
		28d/200°F/R-8	>5000 psi	7670 psi	500 psi decr.	+ 803 psi
		28d/200°F/[JP-8/R-8 Blend]	>5000 psi	7227 psi	500 psi decr.	+ 360 psi
Graphite / BMI	Interlaminar Shear	Unaged	>5000 psi	12,330 psi[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	>5000 psi	8798 psi[1]	~	~
		28d/200°F/F-T	>5000 psi	10,090 psi[1]	500 psi decr.	+ 1292 psi
		28d/200°F/[JP-8/F-T Blend]	>5000 psi	10,360 psi[1]	500 psi decr.	+ 1563 psi
		28d/200°F/R-8	>5000 psi	10,970 psi	500 psi decr.	+ 2172 psi
		28d/200°F/[JP-8/R-8 Blend]	>5000 psi	9139 psi	500 psi decr.	+ 341 psi
Graphite / Epoxy	Interlaminar Shear	Unaged	>5000 psi	8110 psi	~	~
		28d/200°F/JP-8 (POSF 4751)	>5000 psi	8120 psi	~	~
		28d/200°F/R-8	>5000 psi	9645 psi	500 psi decr.	+ 1525 psi
		28d/200°F/[JP-8/R-8 Blend]	>5000 psi	9824 psi	500 psi decr.	+ 1704 psi
Graphite / BMI	Interlaminar Shear	Unaged	>5000 psi	9993 psi	~	~
		28d/200°F/JP-8 (POSF 4751)	>5000 psi	8702 psi	~	~
		28d/200°F/R-8	>5000 psi	9244 psi	500 psi decr.	+ 542 psi
		28d/200°F/[JP-8/R-8 Blend]	>5000 psi	9392 psi	500 psi decr.	+ 690 psi

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel,* AFRL/MLS 06-103 (September 2006).

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All results for the AMS-P-5315 nitrile O-ring material met the test requirements. However, there were several instances in which the results were outside the allowable variation from the JP-8 baseline. The volume swell results after aging in F-T fuel and R-8 fuel, and the compression set results after aging in both alternative fuels and blends were outside the allowable variations from the JP-8 baseline. Similar to previous conclusions concerning 100 percent F-T fuel, the volume swell results would be a cause for concern if the 100 percent R-8 fuel was used. However, the results for 50/50 blends of R-8 and F-T with JP-8 were similar and indicate less likelihood of leaks occurring (Table 15).

Table 15

Nitrile O-ring (AMS-P-5315)

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS-P-5315 (Nitrile)	Tensile Strength	Unaged	> 1000 psi	1783 psi[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	> 1000 psi	1233 psi[1]	~	~
		28d/160°F/F-T	> 1000 psi	1390 psi[1]	125 psi decr.	+ 157 psi
		28d/160°F/[JP-8/F-T Blend]	> 1000 psi	1290 psi[1]	125 psi decr.	+ 57 psi
		28d/160°F/R-8	> 1000 psi	1504 psi	125 psi decr.	+ 271 psi
		28d/160°F/[JP-8/R-8 Blend]	> 1000 psi	1242 psi	125 psi decr.	+ 9 psi
	Elongation	Unaged	> 200%	309%[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	> 200%	251%[1]	~	~
		28d/160°F/F-T	> 200%	238%[1]	35% decr.	- 13%
		28d/160°F/[JP-8/F-T Blend]	> 200%	237%[1]	35% decr.	- 14%
		28d/160°F/R-8	> 200%	230%	35% decr.	- 21%
		28d/160°F/[JP-8/R-8 Blend]	> 200%	217%	35% decr.	- 34%
	Volume Swell	Unaged	~	~	~	~
		28d/160°F/JP-8 (POSF 4751)	0% to 25%	15.5%[1]	~	~
		28d/160°F/F-T	0% to 25%	1.0%[1]	± 10%	- 14.5%
		28d/160°F/[JP-8/F-T Blend]	0% to 25%	7.0%[1]	± 10%	- 8.5%
		28d/160°F/R-8	0% to 25%	1%	± 10%	- 14.5%
		28d/160°F/[JP-8/R-8 Blend]	0% to 25%	7%	± 10%	- 8.5%
	Hardness, Shore M	Unaged	~	68	~	~
		28d/160°F/JP-8 (POSF 4751)	± 5 pts from unaged	70	~	~
		28d/160°F/F-T	± 5 pts from unaged	73	± 5 pts	+ 3
		28d/160°F/[JP-8/F-T Blend]	± 5 pts from unaged	72	± 5 pts	+ 2
		28d/160°F/R-8	± 5 pts from unaged	73	± 5 pts	+ 3
		28d/160°F/[JP-8/R-8 Blend]	± 5 pts from unaged	68	± 5 pts	- 2
	Compression Set	Unaged	~	~	~	~
		28d/160°F/JP-8 (POSF 4751)	< 50%	25.7%[1]	~	~
		28d/160°F/F-T	< 50%	34.3%[1]	5% increase	+ 8.6%
		28d/160°F/[JP-8/F-T Blend]	< 50%	35.6%[1]	5% increase	+ 9.9%
		28d/160°F/R-8	< 50%	35%	5% increase	+ 9.3%
		28d/160°F/[JP-8/R-8 Blend]	< 50%	31%	5% increase	+ 5.3%

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel,* AFRL/MLS 06-103 (September 2006).

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All results for the fluorosilicone O-ring material conforming to AMS-R-25988 met the test requirements and were within the allowable variations from the JP-8 baseline (Table 16).

Table 16

Fluorosilicone O-ring (AMS-R-25988)

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS-R-25988 (Fluorosilicone)	Tensile Strength	Unaged	> 500 psi	984 psi[1]	~	~
		28d/225°F/JP-8 (POSF 4751)	> 500 psi	540 psi[1]	~	~
		28d/225°F/F-T	> 500 psi	718 psi[1]	125 psi decr.	+ 178 psi
		28d/225°F/[JP-8/F-T Blend]	> 500 psi	717 psi[1]	125 psi decr.	+ 177 psi
		28d/225°F/R-8	> 500 psi	702 psi	125 psi decr.	+ 162 psi
		28d/225°F/[JP-8/R-8 Blend]	> 500 psi	694 psi	125 psi decr.	+ 154 psi
	Elongation	Unaged	> 125%	195%[1]	~	~
		28d/225°F/JP-8 (POSF 4751)	> 125%	129%[1]	~	~
		28d/225°F/F-T	> 125%	164%[1]	35% decr.	+ 35%
		28d/225°F/[JP-8/F-T Blend]	> 125%	163%[1]	35% decr.	+ 34%
		28d/225°F/R-8	> 125%	161%	35% decr.	+ 32%
		28d/225°F/[JP-8/R-8 Blend]	> 125%	167%	35% decr.	+ 38%
	Volume Swell	Unaged	~	~	~	~
		28d/225°F/JP-8 (POSF 4751)	0% to 25%	10.5%[1]	~	~
		28d/225°F/F-T	0% to 25%	9.3%[1]	± 10%	- 1.2%
		28d/225°F/[JP-8/F-T Blend]	0% to 25%	9.9%[1]	± 10%	- 0.6%
		28d/225°F/R-8	0% to 25%	9%	± 10%	- 1.5%
		28d/225°F/[JP-8/R-8 Blend]	0% to 25%	10%	± 10%	- 0.5%
	Hardness, Shore M	Unaged	~	69[1]	~	~
		28d/225°F/JP-8 (POSF 4751)	- 20 pts from unaged	69[1]	~	~
		28d/225°F/F-T	- 20 pts from unaged	70[1]	± 5 pts	+ 1
		28d/225°F/[JP-8/F-T Blend]	- 20 pts from unaged	70[1]	± 5 pts	+ 1
		28d/225°F/R-8	- 20 pts from unaged	72	± 5 pts	+ 3
		28d/225°F/[JP-8/R-8 Blend]	- 20 pts from unaged	71	± 5 pts	+ 2
	Compression Set	Unaged	~	~	~	~
		28d/225°F/JP-8 (POSF 4751)	< 65%	41.4%[1]	~	~
		28d/225°F/F-T	< 65%	38.6%[1]	5% increase	- 2.8%
		28d/225°F/[JP-8/F-T Blend]	< 65%	34.2%[1]	5% increase	- 7.2%
		28d/225°F/R-8	< 65%	24%	5% increase	- 17.4%
		28d/225°F/[JP-8/R-8 Blend]	< 65%	39%	5% increase	- 2.4%

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel*, AFRL/MLS 06-103 (September 2006).

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All results for the fluorocarbon Good-Low-Temperature (GLT) O-ring material conforming to AMS-R-83485 met the test requirements. Additionally, all results for the R-8 and JP-8/R-8 blend were within the allowable variation from the JP-8 baseline. In previous testing, the Shore M hardness after aging in the JP-8/F-T blend were outside the allowable variation from the JP-8 baseline; these results indicated some increased softening of the material when aged in the JP-8/F-T blend relative to the results obtained after aging in the other fuels (Table 17).

Table 17

Fluorocarbon GLT O-ring (AMS-R-83485)

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS-R-83485 (Fluorocarbon GLT)	Tensile Strength	Unaged	> 1000 psi	1644 psi[1]	~	~
		28d/325°F/JP-8 (POSF 4751)	> 1000 psi	1110 psi[1]	~	~
		28d/325°F/F-T	> 1000 psi	1198 psi[1]	125 psi decr.	+ 88 psi
		28d/325°F/[JP-8/F-T Blend]	> 1000 psi	1232 psi[1]	125 psi decr.	+ 122 psi
		28d/325°F/R-8	> 1000 psi	1293 psi	125 psi decr.	+ 183 psi
		28d/325°F/[JP-8/R-8 Blend]	> 1000 psi	1235 psi	125 psi decr.	+ 125 psi
	Elongation	Unaged	> 150%	166%[1]	~	~
		28d/325°F/JP-8 (POSF 4751)	> 150%	202%[1]	~	~
		28d/325°F/F-T	> 150%	203%[1]	35% decr.	+ 1%
		28d/325°F/[JP-8/F-T Blend]	> 150%	199%[1]	35% decr.	- 3%
		28d/325°F/R-8	> 150%	196%	35% decr.	- 6%
		28d/325°F/[JP-8/R-8 Blend]	> 150%	187%	35% decr.	- 15%
	Volume Swell	Unaged	~	~	~	~
		28d/325°F/JP-8 (POSF 4751)	0% to 10%	6.6%[1]	~	~
		28d/325°F/F-T	0% to 10%	4.4%[1]	± 10%	- 2.2%
		28d/325°F/[JP-8/F-T Blend]	0% to 10%	6.4%[1]	± 10%	- 0.2%
		28d/325°F/R-8	0% to 10%	5%	± 10%	- 1.6%
		28d/325°F/[JP-8/R-8 Blend]	0% to 10%	5%	± 10%	- 1.6%
	Hardness, Shore M	Unaged	~	76[1]	~	~
		28d/325°F/JP-8 (POSF 4751)	± 5 pts from unaged	74[1]	~	~
		28d/325°F/F-T	± 5 pts from unaged	75[1]	± 5 pts	+ 1
		28d/325°F/[JP-8/F-T Blend]	± 5 pts from unaged	67[1]	± 5 pts	- 7
		28d/325°F/R-8	± 5 pts from unaged	76	± 5 pts	+ 2
		28d/325°F/[JP-8/R-8 Blend]	± 5 pts from unaged	76	± 5 pts	+ 2
	Compression Set	Unaged	~	~	~	~
		28d/325°F/JP-8 (POSF 4751)	< 60%	32.9%[1]	~	~
		28d/325°F/F-T	< 60%	34.3%[1]	5% increase	+ 1.4%
		28d/325°F/[JP-8/F-T Blend]	< 60%	28.4%[1]	5% increase	- 4.5%
		28d/325°F/R-8	< 60%	35%	5% increase	+ 2.1%
		28d/325°F/[JP-8/R-8 Blend]	< 60%	29%	5% increase	- 3.9%

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel*, AFRL/MLS 06-103 (September 2006).

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All results for the fluorocarbon O-ring material conforming to AMS 7276 met the test requirements. Additionally, all results were within the allowable variation from the JP-8 baseline except for elongation after aging in both alternative fuels and blends; and in the previous testing, Shore M hardness and compression set after aging in the JP-8/F-T blend. The Shore M hardness and compression set results did not show an indication of a problem with R-8 or the JP-8/R-8 blend (Table 18).

Table 18

Fluorocarbon O-ring (AMS 7276)

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS 7276 (Fluorocarbon)	Tensile Strength	Unaged	> 1000 psi	1799 psi[1]	~	~
		28d/325°F/JP-8 (POSF 4751)	> 1000 psi	1369 psi[1]	~	~
		28d/325°F/F-T	> 1000 psi	1586 psi[1]	125 psi decr.	+ 217 psi
		28d/325°F/[JP-8/F-T Blend]	> 1000 psi	1386 psi[1]	125 psi decr.	+ 17 psi
		28d/325°F/R-8	> 1000 psi	1434 psi	125 psi decr.	+ 65 psi
		28d/325°F/[JP-8/R-8 Blend]	> 1000 psi	1388 psi	125 psi decr.	+ 19 psi
	Elongation	Unaged	> 150%	229%[1]	~	~
		28d/325°F/JP-8 (POSF 4751)	> 150%	342%[1]	~	~
		28d/325°F/F-T	> 150%	233%[1]	35% decr.	- 109%
		28d/325°F/[JP-8/F-T Blend]	> 150%	216%[1]	35% decr.	- 126%
		28d/325°F/R-8	> 150%	254%	35% decr.	- 88%
		28d/325°F/[JP-8/R-8 Blend]	> 150%	241%	35% decr.	- 101%
	Volume Swell	Unaged	~	~	~	~
		28d/325°F/JP-8 (POSF 4751)	0% to 10%	6.7%[1]	~	~
		28d/325°F/F-T	0% to 10%	4.8%[1]	± 10%	- 1.9%
		28d/325°F/[JP-8/F-T Blend]	0% to 10%	5.5%[1]	± 10%	- 1.2%
		28d/325°F/R-8	0% to 10%	4%	± 10%	- 2.7%
		28d/325°F/[JP-8/R-8 Blend]	0% to 10%	5%	± 10%	- 1.7%
	Hardness, Shore M	Unaged	~	76[1]	~	~
		28d/325°F/JP-8 (POSF 4751)	± 5 pts from unaged	74[1]	~	~
		28d/325°F/F-T	± 5 pts from unaged	76[1]	± 5 pts	+ 2
		28d/325°F/[JP-8/F-T Blend]	± 5 pts from unaged	68	± 5 pts	- 6
		28d/325°F/R-8	± 5 pts from unaged	77	± 5 pts	+ 3
		28d/325°F/[JP-8/R-8 Blend]	± 5 pts from unaged	76	± 5 pts	+ 2
	Compression Set	Unaged	~	~	~	~
		28d/325°F/JP-8 (POSF 4751)	< 60%	22.9%[1]	~	~
		28d/325°F/F-T	< 60%	24.3%[1]	5% increase	+ 1.4%
		28d/325°F/[JP-8/F-T Blend]	< 60%	40.2%[1]	5% increase	+ 17.3%
		28d/325°F/R-8	< 60%	24%	5% increase	+ 1.1%
		28d/325°F/[JP-8/R-8 Blend]	< 60%	27%	5% increase	+ 4.1%

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel*, AFRL/MLS 06-103 (September 2006).

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All of the results for the acrylic/nitrile hose material conforming to MIL-H-4495 met the test requirements. However, in many cases the results after aging in the alternative fuels and blends were outside the allowable variation from the JP-8 baseline (Table 19). Although there were instances of results outside of the allowable variation, another standard practice for determining the compatibility of hose materials with various fluids is to use the following criteria: tensile strength and elongation results must be greater than -45 percent from the unaged results. Additionally, the hardness value cannot decrease by more than 15 points from the unaged results, and the volume swell is required to be between 0 and 25 percent. The only results that failed to meet these criteria were for volume swell after aging in the four alternative fuels and blends.

Table 19

Acrylic/Nitrile Hose

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
MIL-H-4495 (Acrylic/Nitrile)	Tensile Strength	Unaged	> 1200 psi	1684 psi[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	> 1200 psi	1627 psi[1]	~	~
		28d/160°F/F-T	> 1200 psi	1649 psi[1]	125 psi decr.	+ 22 psi
		28d/160°F/[JP-8/F-T Blend]	> 1200 psi	1534 psi[1]	125 psi decr.	- 93 psi
		28d/160°F/R-8	> 1200 psi	1538 psi	125 psi decr.	- 89 psi
		28d/160°F/[JP-8/R-8 Blend]	> 1200 psi	1400 psi	125 psi decr.	- 227 psi
	Elongation	Unaged	> 150%	250%[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	> 150%	207%[1]	~	~
		28d/160°F/F-T	> 150%	187%[1]	25% decr.	- 20%
		28d/160°F/[JP-8/F-T Blend]	> 150%	199%[1]	25% decr.	- 8%
		28d/160°F/R-8	> 150%	175%	25% decr.	- 32%
		28d/160°F/[JP-8/R-8 Blend]	> 150%	167%	25% decr.	- 40%
	Volume Swell	Unaged	~	~	~	~
		28d/160°F/JP-8 (POSF 4751)	< 8%	2.3%[1]	~	~
		28d/160°F/F-T	< 8%	-9.6%[1]	± 5%	- 11.9%
		28d/160°F/[JP-8/F-T Blend]	< 8%	-4.9%[1]	± 5%	- 7.2%
		28d/160°F/R-8	< 8%	-10.5%	± 5%	- 12.8%
		28d/160°F/[JP-8/R-8 Blend]	< 8%	-6.0%	± 5%	- 8.3%
	Hardness, Shore A	Unaged	~	66[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	± 5 pts from unaged	62[1]	~	~
		28d/160°F/F-T	± 5 pts from unaged	77[1]	± 5 pts	+ 15
		28d/160°F/[JP-8/F-T Blend]	± 5 pts from unaged	68[1]	± 5 pts	+ 6
		28d/160°F/R-8	± 5 pts from unaged	70	± 5 pts	+ 8
		28d/160°F/[JP-8/R-8 Blend]	± 5 pts from unaged	64	± 5 pts	+ 2

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel*, AFRL/MLS 06-103 (September 2006).

APPENDIX J
Materials Compatibility
APPENDIX J-1: Material Compatibility of R-8 Synthetic Fuel

After aging in R-8 and the JP-8/R-8 blend, all results for the epichlorohydrin hose material conforming to MIL-DTL-26521 met the test requirements. The only result that did not meet the test requirements was the tensile strength after aging in the JP-8/F-T blend for a previous evaluation. This result was also outside the allowable variation from the JP-8 baseline. The only other two results which were outside the allowable variation from the JP-8 baseline were the Shore A hardness results after aging in F-T fuel and the JP-8/R-8 blend (Table 20).

Table 20

Epichlorohydrin Hose

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
MIL-DTL-26521 (Epichlorohydrin)	Tensile Strength	Unaged	> 1500 psi	1806 psi[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	> 1500 psi	1684 psi[1]	~	~
		28d/160°F/F-T	> 1500 psi	1575 psi[1]	125 psi decr.	- 109 psi
		28d/160°F/[JP-8/F-T Blend]	> 1500 psi	1383 psi[1]	125 psi decr.	- 301 psi
		28d/160°F/R-8	> 1500 psi	1718 psi	125 psi decr.	+ 34 psi
		28d/160°F/[JP-8/R-8 Blend]	> 1500 psi	1674 psi	125 psi decr.	- 10 psi
	Elongation	Unaged	> 300%	538%[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	> 300%	320%[1]	~	~
		28d/160°F/F-T	> 300%	317%[1]	25% decr.	- 3%
		28d/160°F/[JP-8/F-T Blend]	> 300%	525%[1]	25% decr.	+ 205%
		28d/160°F/R-8	> 300%	511%	25% decr.	+ 191%
		28d/160°F/[JP-8/R-8 Blend]	> 300%	491%	25% decr.	+ 171%
	Volume Swell	Unaged	~	~	~	~
		28d/160°F/JP-8 (POSF 4751)	< 8%	2.7%[1]	~	~
		28d/160°F/F-T	< 8%	-2.1%[1]	± 5%	- 4.8%
		28d/160°F/[JP-8/F-T Blend]	< 8%	2.4%[1]	± 5%	- 0.3%
		28d/160°F/R-8	< 8%	-2.2%	± 5%	- 4.9%
		28d/160°F/[JP-8/R-8 Blend]	< 8%	1.7%	± 5%	- 1.0%
	Hardness, Shore A	Unaged	~	62[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	± 5 pts from unaged	65[1]	~	~
		28d/160°F/F-T	± 5 pts from unaged	72[1]	± 5 pts	+ 7
		28d/160°F/[JP-8/F-T Blend]	± 5 pts from unaged	61[1]	± 5 pts	- 4
		28d/160°F/R-8	± 5 pts from unaged	63	± 5 pts	- 2
		28d/160°F/[JP-8/R-8 Blend]	± 5 pts from unaged	58	± 5 pts	- 7

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel*, AFRL/MLS 06-103 (September 2006).

APPENDIX J
Materials Compatibility
APPENDIX J-1: Material Compatibility of R-8 Synthetic Fuel

All results for the four wire insulation materials met the test requirements. However, there were several instances in which the results were outside the allowable variation from the JP-8 baseline: tensile strength of the Teflon film after aging in 100 percent F-T; elongation of the polyethylene film after aging in 100 percent F-T, 100 percent R-8, and the JP-8/R-8 blend; tensile strength of the Kapton film after aging in the JP-8/F-T blend, 100 percent R-8, and the JP-8/R-8 blend; and elongation of the Kapton film after aging in the JP-8/F-T blend. Due to potential issues with the F-T fuel, actual wire insulations were tested. This testing indicated no issues with the F-T or JP-8/F-T blend, so the likelihood R-8 fuel would cause any serious issues is minimal (Table 21).

Table 21

Wire Insulations

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
TFE Teflon Film	Tensile Strength	Unaged	> 500 psi	1937 psi[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	> 500 psi	1973 psi[1]	~	~
		28d/160°F/F-T	> 500 psi	1767 psi[1]	150 psi decr.	- 206 psi
		28d/160°F/[JP-8/F-T Blend]	> 500 psi	2001 psi[1]	150 psi decr.	+ 28 psi
		28d/160°F/R-8	> 500 psi	4006 psi	150 psi decr.	+ 2033 psi
		28d/160°F/[JP-8/R-8 Blend]	> 500 psi	4401 psi	150 psi decr.	+ 2428 psi
	Elongation	Unaged	> 25%	208%[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	> 25%	122%[1]	~	~
		28d/160°F/F-T	> 25%	142%[1]	15% decr.	+ 20%
		28d/160°F/[JP-8/F-T Blend]	> 25%	181%[1]	15% decr.	+ 59%
		28d/160°F/R-8	> 25%	261%	15% decr.	+ 139%
		28d/160°F/[JP-8/R-8 Blend]	> 25%	324%	15% decr.	+ 202%
Polyethylene Film	Tensile Strength	Unaged	> 500 psi	3818 psi[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	> 500 psi	3076 psi[1]	~	~
		28d/160°F/F-T	> 500 psi	3209 psi[1]	250 psi decr.	+ 133 psi
		28d/160°F/[JP-8/F-T Blend]	> 500 psi	3279 psi[1]	250 psi decr.	+ 203 psi
		28d/160°F/R-8	> 500 psi	3847 psi	250 psi decr.	+ 771 psi
		28d/160°F/[JP-8/R-8 Blend]	> 500 psi	3814 psi	250 psi decr.	+ 738 psi
	Elongation	Unaged	> 25%	343%[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	> 25%	672%[1]	~	~
		28d/160°F/F-T	> 25%	179%[1]	50% decr.	- 493%
		28d/160°F/[JP-8/F-T Blend]	> 25%	640%[1]	50% decr.	- 32%
		28d/160°F/R-8	> 25%	102%	50% decr.	- 570%
		28d/160°F/[JP-8/R-8 Blend]	> 25%	93%	50% decr.	- 579%

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel*, AFRL/MLS 06-103 (September 2006).

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Table 21

Wire Insulations Cont'd

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
Nylon 101 Film	Tensile Strength	Unaged	> 500 psi	10,431 psi[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	> 500 psi	11,824 psi[1]	~	~
		28d/160°F/F-T	> 500 psi	12,438 psi[1]	850 psi decr.	+ 614 psi
		28d/160°F/[JP-8/F-T Blend]	> 500 psi	12,265 psi[1]	850 psi decr.	+ 441 psi
		28d/160°F/R-8	> 500 psi	12,981 psi	850 psi decr.	+ 1157 psi
		28d/160°F/[JP-8/R-8 Blend]	> 500 psi	12,766 psi	850 psi decr.	+ 942 psi
	Elongation	Unaged	> 25%	360%[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	> 25%	35%[1]	~	~
		28d/160°F/F-T	> 25%	42%[1]	5% decr.	+ 7%
		28d/160°F/[JP-8/F-T Blend]	> 25%	71%[1]	5% decr.	+ 36%
		28d/160°F/R-8	> 25%	35%	5% decr.	0%
		28d/160°F/[JP-8/R-8 Blend]	> 25%	114%	5% decr.	+ 79%
Kapton Film	Tensile Strength	Unaged	> 500 psi	24,719 psi[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 500 psi	25,203 psi[1]	~	~
		28d/200°F/F-T	> 500 psi	28,268 psi[1]	1800 psi decr.	+ 3065 psi
		28d/200°F/[JP-8/F-T Blend]	> 500 psi	22,047 psi[1]	1800 psi decr.	-3156 psi
		28d/200°F/R-8	> 500 psi	22,419 psi	1800 psi decr.	- 2784 psi
		28d/200°F/[JP-8/R-8 Blend]	> 500 psi	20,719 psi	1800 psi decr.	- 4484 psi
	Elongation	Unaged	> 25%	48%[1]	~	~
		28d/200°F/JP-8 (POSF 4751)	> 25%	42%[1]	~	~
		28d/200°F/F-T	> 25%	63%[1]	5% decr.	+ 21%
		28d/200°F/[JP-8/F-T Blend]	> 25%	28%[1]	5% decr.	- 14%
		28d/200°F/R-8	> 25%	65%	5% decr.	+ 23%
		28d/200°F/[JP-8/R-8 Blend]	> 25%	56%	5% decr.	+ 14%

1 = Data taken from *Evaluation of Material Compatibility of Fischer-Tropsch Fuel*, AFRL/MLS 06-103 (September 2006).

APPENDIX J

Materials Compatibility

APPENDIX J-1: Material Compatibility of R-8 Synthetic Fuel

All results for the potting compound material met the test requirements after aging in R-8 and the JP-8/R-8 blend with the exception of elongation. In previous testing, both the tensile strength and elongation results after aging in JP-8 and the JP-8/F-T blend did not meet the test requirements. The only results that were outside the allowable variation from the JP-8 baseline were the Shore A hardness results after aging in 100 percent R-8 and the JP-8/R-8 blend. Based on overall results and comparison with the previous testing, it does not appear the R-8 fuel or JP-8/R-8 blend should be a cause for concern for the potting compound material (Table 22).

Table 22

Potting Compound

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
MIL-PRF-8516 (Type II, Class 1) (Polysulfide)	Tensile Strength	Unaged	> 100 psi	215 psi[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	> 100 psi	36 psi[1]	~	~
		28d/160°F/[JP-8/F-T Blend]	> 100 psi	46 psi[1]	35 psi decrease	+ 10 psi
		28d/160°F/R-8	> 100 psi	134 psi	35 psi decrease	+ 98 psi
		28d/160°F/[JP-8/R-8 Blend]	> 100 psi	160 psi	35 psi decrease	+ 124 psi
	Elongation	Unaged	> 150%	192%[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	> 150%	72%[1]	~	~
		28d/160°F/[JP-8/F-T Blend]	> 150%	82%[1]	25% decrease	+ 10%
		28d/160°F/R-8	> 150%	119%	25% decrease	+ 47%
		28d/160°F/[JP-8/R-8 Blend]	> 150%	140%	25% decrease	+ 68%
	Volume Swell	Unaged	~	~	~	~
		28d/160°F/JP-8 (POSF 4751)	> -20%	-17.0%	~	~
		28d/160°F/[JP-8/F-T Blend]	> -20%	~	± 10%	~
		28d/160°F/R-8	> -20%	-13.4%	± 10%	+ 3.6%
		28d/160°F/[JP-8/R-8 Blend]	> -20%	-11.4%	± 10%	+ 5.6%
	Hardness, Shore A	Unaged	> 20 pts	45[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	> 20 pts	55[1]	~	~
		28d/160°F/[JP-8/F-T Blend]	> 20 pts	54[1]	± 5 pts	- 1
		28d/160°F/R-8	> 20 pts	33	± 5 pts	- 22
		28d/160°F/[JP-8/R-8 Blend]	> 20 pts	36	± 5 pts	- 19
	Peel Strength	Unaged	>10 lbs / 100%	14 lbs/100%[1]	~	~
		28d/160°F/JP-8 (POSF 4751)	>10 lbs / 100%	22 lbs/100%[1]	~	~
		28d/160°F/[JP-8/F-T Blend]	>10 lbs / 100%	21 lbs/100%[1]	8 lbs decrease	- 1 lb
		28d/160°F/R-8	>10 lbs / 100%	16 lbs/100%	8 lbs decrease	- 6 lbs
		28d/160°F/[JP-8/R-8 Blend]	>10 lbs / 100%	18 lbs/100%	8 lbs decrease	- 4 lbs

1 = Data taken from *Fischer-Tropsch Compatibility with Selected C-17 Materials,* AFRL/RXS 07-083 (December 2007).

APPENDIX J

Materials Compatibility

APPENDIX J-1: Material Compatibility of R-8 Synthetic Fuel

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CONCLUSIONS

In general, 100 percent R-8 and 100 percent F-T appeared to have a similar effect on virtually all of the materials. Therefore, previous conclusions about F-T not appearing to be suitable for use would also apply to the 100 percent R-8 fuel. The 50/50 blend of JP-8 and R-8 fuels and 50/50 blend of JP-8 and F-T fuels also appeared to have a similar effect on materials, but there were a couple of instances in which the results appeared to indicate potential concerns. Similar results between the alternative fuels and blends were expected, because the hydrocarbon mixture produced by each process was said (by AFRL/RZPF fuels branch individuals) to be very similar.

Review of the data indicates the following potential concerns:

In testing the bladder inner liner materials, there were some instances in which the results after aging in 100 percent R-8 and JP-8/R-8 blend did not meet the test requirements and were not similar to F-T results. Additionally, there were some instances in which the results were outside of the allowable variation from the JP-8 baseline. Based on a comparison of the overall results, the polyurethane bladder inner liner does not seem to pose any concern. However, the nitrile bladder might need to be retested side-by-side with the JP-8 baseline to determine if the variation in the results is attributable to the fuel or to variation in batches of the material itself.

In testing of the coatings, all results were satisfactory with the exception of pencil hardness of the BMS 10-39 epoxy coating after aging in 100 percent R-8 and tape adhesion of the AMS-S-4383 nitrile coating after aging in 100 percent R-8 and the JP-8/R-8 blend. These results also differed from previous F-T results The BMS 10-39 epoxy coating, which after aging in R-8 only exhibited a slight softening, does not require retesting because the results after aging in the JP-8/R-8 blend were satisfactory. However, the AMS-S-4383 coating should be retested and new baseline results obtained to determine if there are any compatibility issues with the material before the JP-8/R-8 blend is certified for use.

In testing the sealant materials, the majority of results met the test requirements, but there were some instances, mainly for volume swell and elongation, in which they did not. Additionally, the majority of results for the sealant materials after aging in the JP-8/R-8 blend showed good consistency with the results obtained after aging in the JP-8/F-T blend. Therefore, the overall results after aging in the JP-8/R-8 blend do not appear to pose any immediate concerns. However, it might be advisable to retest the AMS-S-8802 manganese dioxide cured polysulfide and the AMS 3277 polythioether in the JP-8/R-8 blend and obtain new baseline results to address any potential concerns. Some results for these materials were not similar to previous JP-8/F-T results, which were generated some time ago using different sealant batches.

The results for the AMS-P-5315 nitrile O-ring material after aging in the JP-8/R-8 blend and 100 percent R-8 were very similar to the analogous results obtained after aging in the JP-8/F-T blend and 100 percent F-T. This was particularly the case for volume swell, where the results were essentially identical. Therefore, the nitrile O-ring material would pose the same concerns in the JP-8/R-8 blend as those which have been expressed previously for the JP-8/F-T blend. Exposure to the blend after long-term service and compression setting in a higher aromatic fuel may pose a risk for minor leaks in couplings containing these types of O-rings.

APPENDIX J
Materials Compatibility
APPENDIX J-1: Material Compatibility of R-8 Synthetic Fuel

Although there were some instances in which the MIL-PRF-8516 potting compound material did not meet the test requirements after aging in 100 percent R-8 and the JP-8/R-8 blend, virtually all of the results exceeded those that were obtained previously after aging in the JP-8 baseline and JP-8/F-T blend. Therefore, it is not believe that this material will experience any increased degradation over that which occurs upon its exposure to JP-8 alone.

RECOMMENDATIONS

- Since there were some differences in the results obtained after aging in the JP-8/R-8 blend versus those obtained after aging in the JP-8/F-T blend, the following materials should be tested and new baseline data obtained with the same batch of material:

  - Nitrile Bladder Inner liner
  - AMS-S-4383 nitrile coating
  - AMS-S-8802 manganese dioxide cured polysulfide sealant
  - AMS 3277 polythioether sealant

- Retesting the above-mentioned materials will help identify whether the discrepancy can be attributed to differences in the fuels or to variation in the materials themselves, because, in some cases, material properties can vary from batch to batch. This is one of the difficulties in all compatibility testing; identifying the parameters for evaluating the magnitude of property changes that are acceptable when the materials are exposed to alternative fuels/additives, without assigning parameters more stringent than the variability within the materials themselves.

- Additionally, it is recommended the same level of awareness be maintained concerning the performance of nitrile O-rings upon exposure to the JP-8/R-8 blend as was recommened for their exposure to the JP-8/F-T blend. Additionally, same as with the 100 percent F-T blend, it does not appear the 100 percent R-8 fuel would be suitable for use.

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Materials Compatibility
APPENDIX J-1: Material Compatibility of R-8 Synthetic Fuel

AFRL/RXS 10-002

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PUBLICATION REVIEW: This report has been reviewed and approved.

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APPENDIX J
Materials Compatibility
APPENDIX J-1: Material Compatibility of R-8 Synthetic Fuel

- **Failure Analysis/Accident Investigation**
  - Structural
  - Electronic
  - Chemical

- **Consultations on**
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  - Materials and Component Failure Analysis
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  - Welding, Joining and Adhesive Bonding
  - Electrostatic Discharge Control and Process Specs/Standards

- **Nondestructive Inspection**

- **Electrostatic Discharge (ESD) Testing**

- **ESD Material Qualifications/Acceptance Testing**

- **Composites Supportability**

APPENDIX J
Materials Compatibility
APPENDIX J-2: R-8 Synthetic Fuel Material Compatibility Phase II Testing

R-8 Synthetic Fuel Material Compatibility Phase II Testing
(Materials Evaluation)

28 January 2010

Evaluation Report
(SA104002)

Report No. AFRL/RXS 10-003

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APPENDIX J-2: R-8 Synthetic Fuel Material Compatibility Phase II Testing

AFRL/RXS 10-003

EXECUTIVE SUMMARY

As recommended in report number AFRL/RXS 10-002, testing and evaluation were performed to further examine the material compatibility of R-8 synthetic fuel with four materials: a nitrile bladder innerliner, an AMS-S-4383 nitrile coating, an AMS-S-8802 polysulfide sealant, and an AMS 3277 polythioether sealant. The materials were exposed for 28 days at elevated temperatures to twelve different fuels: two JP-8 fuels, two Fischer-Tropsch (F-T) fuels and 50/50 blends of each with JP-8, and three hydrotreated renewable jet (HRJ) fuels and 50/50 blends of each with JP-8. The AFRL/RXSA analyzed the data and determined, based on comparison with the JP-8 baseline and JP-8/F-T blend results, the JP-8/R-8 blend, and other 50/50 JP-8/HRJ blends tested, generally appeared to have a very similar effect on materials as did the JP-8/F-T blends and JP-8 fuels tested.

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AFRL/RXS 10-003

R-8 Synthetic Fuel Material Compatibility Phase II Testing

PURPOSE

Evaluate the compatibility of R-8 and several other synthetic fuels with select nonmetallic materials as recommended in report number AFRL/RXS 10-002.

BACKGROUND

The Air Force Research Laboratory/Materials Integrity Branch (AFRL/RXSA) was asked to perform testing to determine the compatibility of fuel tank materials with a 50/50 blend of JP-8 and R-8 fuels. The R-8 is a synthetic fuel produced by Syntroleum Corporation and derived from animal fat feedstock. Previous compatibility testing for the initial JP-8 +100 program and other alternative fuel and fuel additive programs allowed for the development and refinement of a short list of materials. These materials were chosen to represent the types of materials exposed to the fuel, with emphasis on those particular compounds that were most affected by previous fuels and additives tested. For the initial effort, the compatibility of the nonmetallic short list of materials was evaluated. The results of the intial testing are documented in report number AFRL/RXS 10-002, "Material Compatibility of R-8 Synthetic Fuel."

Results contained in the initial report indicate there may be some concerns for the JP-8/R-8 blend with four of the materials, since they exhibited results different from both JP-8 and the JP-8/Fischer-Tropsch (JP-8/F-T) blend. However, the JP-8 and JP-8/F-T blend data were generated at least two to three years earlier. Therefore, the actual materials tested in the R-8 compatibility program were either cured at a separate time, originated from a different batch of material, or originated from the same batch but had been sitting in storage for at least two to three years. To determine whether the discrepancies were due to differences in the fuels or variations in the materials themselves, it was recommended the materials in question be retested and new baseline data be obtained with the same batch of material. This report contains data for a nitrile bladder innerliner, an AMS-S-4383 nitrile coating, an AMS-S-8802 manganese dioxide cured polysulfide sealant, and an AMS 3277 polythioether sealant. These materials were tested unaged, as well as after aging for 28 days at elevated temperatures in the fuels listed in Table 1. Fuels were provided by the Air Force Research Laboratory/Fuels & Energy Branch (AFRL/RZPF) and consisted of two JP-8s, two Fischer-Tropsch derived synthetic fuels and a 50/50 blend of each with JP-8, and three hydrotreated renewable jet (HRJ) fuels and a 50/50 blend of each with JP-8. The fuels denoted as R-8, EERC (Energy & Environmental Research Center), and UOP are the HRJ fuels.

Table 1

Fuels Used for Fluid Immersions

Fuel Name	ID
JP-8	POSF 4751
JP-8	POSF 5699
R-8	POSF 5480
JP-8/R-8 Blend	POSF 5645
EERC	POSF 5910
JP-8/EERC Blend	POSF 5911
UOP	POSF 5912
JP-8/UOP Blend	POSF 5913
Shell F-T	POSF 5832
JP-8/Shell F-T Blend	POSF 5834
Sasol F-T	POSF 5654
JP-8/Sasol F-T Blend	POSF 5666

TEST PROCEDURE

All testing was in accordance with established ASTM International and SAE International test procedures outlined below. The materials tested were comprised of a nitrile bladder innerliner, an AMS-S-4383 nitrile coating, an AMS-S-8802 manganese dioxide cured polysulfide sealant, and an AMS 3277 polythioether sealant. Required testing included the following:

Fuel Bladders
- Tensile Strength and Elongation — ASTM D 412
- Volume Swell — ASTM D 471

Coatings
- Pencil Hardness — ASTM D 3363
- Tape Adhesion — ASTM D 3359, Method A

Sealants
- Peel Strength — SAE AS5127/1
- Hardness, Shore A — ASTM D 2240, SAE AS5127/1
- Tensile Strength and Elongation — ASTM D 412, SAE AS5127/1
- Volume Swell — ASTM D 471, SAE AS5127/1

The test parameters were the same as have been used on other material compatibility programs, and the baseline (no soak) data were taken from other programs. The standard 28 days of fuel soak at elevated temperatures in the various fuels was coupled with standard physical properties testing to measure the effects of the fuels on the materials. A duration of 28 days was selected for the fuel soak to provide some longer-term indication of the materials' degradation and performance when exposed to the various fuels.

In analyzing the data, a logical evaluation criterion was to compare the results after aging in JP-8 fuel with results after aging in the alternative fuels and blends to identify any significant differences. For each test, "allowable" variations were determined based on standard deviations in the test methods. Differences greater than these allowable variations indicate increased possibility variations in the data are significant and cannot be attributed to normal data scatter for this type of test. When this occurred, the data required closer examination to determine if additional testing was needed or if the data clearly indicated a failure. For some materials there are specification limits, expressed as maximum or minimum values, that can help determine if the material still meets certain requirements after aging. Test requirements noted in the data tables were based on specification limits, when available. Otherwise, test requirements provided were based on experience and previous test programs. In the tables, a value outside the allowable variation from JP-8 is marked in red, as is a failure to meet the test requirements. However, a red marking in the tables does not necessarily mean the material tested is incompatible with the fuel. Final determination of compatibility must consider the overall test results for a given material and the implications of these results for in-service aircraft.

TEST RESULTS

The completed test results are contained in Tables 1 through 4 and their accompanying figures. Results after fuel aging in various alternative fuels and blends are compared against the JP-8 baseline specimens, and the differences have been calculated and noted in the tables. Since there were two different JP-8 fuels used, the alternative fuels' "allowable variations" will be compared against the closer JP-8 value. Additionally, a relatively large number of materials have already been tested in F-T fuel and the JP-8/F-T blend, with the risk level determined to be minimum and/or acceptable. Therefore, the test results after aging in the various HRJ fuels and blends will also be compared against the F-T and JP-8/F-T blend results. Values for the unaged materials are also listed for reference. "Failures" are listed in red. When results do not meet the test requirements and are outside of the allowable variations from the JP-8 baseline data, the overall test results should be closely considered and/or monitoring of the material may be recommended if the fuel is employed in the field.

Table 2 contains the test results for the nitrile bladder innerliner material. All of the tensile strength and volume swell results for this material met the listed test requirements and were within the allowable variations from the JP-8 baseline. However, the elongation results failed to meet the test requirements after aging in all of the fuels. The only instance in which the material met the elongation requirement was for the unaged material. There were also two instances in which the elongation test results were outside of the allowable variation from the JP-8 baseline: after aging in 100 percent EERC and 100 percent Sasol F-T. All of the elongation results after aging in the JP-8/synthetic blend fuels were very consistent, from 252 to 263 percent. Figures 1, 2, and 3 have been included to provide graphical perspectives of the data. The red line on each graph represents the test requirement, and the yellow shaded region represents the allowable variation from one of the JP-8 aged test results.

Since all of the elongation results after fuel immersion failed to meet the test requirement, the material was examined more carefully. After further analysis and discussion with the company that manufactures the bladders, it was discovered the material needs to be oiled to maintain its conditioning and full flexibility, otherwise it tends to become hard and brittle. Additionally, the material is slightly anisotropic, so the orientation of the test coupons must be notated. From separate additional test results of in-house material, tensile strength tested 10 percent higher and elongation 13 percent lower between longitudinal and transverse directions.

APPENDIX J
Materials Compatibility
APPENDIX J-2: R-8 Synthetic Fuel Material Compatibility Phase II Testing

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Table 2

Nitrile Bladder Innerliner

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
Nitrile Bladder Innerliner	Tensile Strength	Unaged	> 1500 psi	1463 psi	~	~
		28d/160°F/JP-8 (POSF 4751)	> 1500 psi	1561 psi	~	~
		28d/160°F/JP-8 (POSF 5699)	> 1500 psi	1683 psi	200 psi decr.	~
		28d/160°F/R-8	> 1500 psi	1859 psi	200 psi decr.	+ 298 psi
		28d/160°F/[JP-8/R-8 Blend]	> 1500 psi	1643 psi	200 psi decr.	+ 82 psi
		28d/160°F/EERC	> 1500 psi	1775 psi	200 psi decr.	+ 214 psi
		28d/160°F/[JP-8/EERC Blend]	> 1500 psi	1755 psi	200 psi decr.	+ 194 psi
		28d/160°F/UOP	> 1500 psi	1816 psi	200 psi decr.	+ 255 psi
		28d/160°F/[JP-8/UOP Blend]	> 1500 psi	1610 psi	200 psi decr.	+ 49 psi
		28d/160°F/Shell F-T	> 1500 psi	1776 psi	200 psi decr.	+ 215 psi
		28d/160°F/[JP-8/Shell F-T Blend]	> 1500 psi	1720 psi	200 psi decr.	+ 159 psi
		28d/160°F/Sasol F-T	> 1500 psi	1692 psi	200 psi decr.	+ 131 psi
		28d/160°F/[JP-8/Sasol F-T Blend]	> 1500 psi	1563 psi	200 psi decr.	+ 2 psi
	Elongation	Unaged	> 300%	387%	~	~
		28d/160°F/JP-8 (POSF 4751)	> 300%	278%	~	~
		28d/160°F/JP-8 (POSF 5699)	> 300%	283%	40% decr.	~
		28d/160°F/R-8	> 300%	254%	40% decr.	- 24%
		28d/160°F/[JP-8/R-8 Blend]	> 300%	254%	40% decr.	- 24%
		28d/160°F/EERC	> 300%	222%	40% decr.	- 56%
		28d/160°F/[JP-8/EERC Blend]	> 300%	255%	40% decr.	- 23%
		28d/160°F/UOP	> 300%	256%	40% decr.	- 22%
		28d/160°F/[JP-8/UOP Blend]	> 300%	254%	40% decr.	- 24%
		28d/160°F/Shell F-T	> 300%	240%	40% decr.	- 38%
		28d/160°F/[JP-8/Shell F-T Blend]	> 300%	263%	40% decr.	- 15%
		28d/160°F/Sasol F-T	> 300%	232%	40% decr.	- 46%
		28d/160°F/[JP-8/Sasol F-T Blend]	> 300%	252%	40% decr.	- 26%

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Table 2 (Concluded)

Nitrile Bladder Innerliner

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
Nitrile Bladder Innerliner	Volume Swell	Unaged	< 25%	~	~.	~
		28d/160°F/JP-8 (POSF 4751)	< 25%	- 2%	~	~
		28d/160°F/JP-8 (POSF 5699)	< 25%	- 5%	± 5%	~
		28d/160°F/R-8	< 25%	- 10%	± 5%	- 5%
		28d/160°F/[JP-8/R-8 Blend]	< 25%	- 7%	± 5%	- 2%
		28d/160°F/EERC	< 25%	- 10%	± 5%	- 5%
		28d/160°F/[JP-8/EERC Blend]	< 25%	- 6%	± 5%	- 1%
		28d/160°F/UOP	< 25%	- 9%	± 5%	- 4%
		28d/160°F/[JP-8/UOP Blend]	< 25%	- 5%	± 5%	0%
		28d/160°F/Shell F-T	< 25%	- 9%	± 5%	- 4%
		28d/160°F/[JP-8/Shell F-T Blend]	< 25%	- 7%	± 5%	- 2%
		28d/160°F/Sasol F-T	< 25%	- 9%	± 5%	- 4%
		28d/160°F/[JP-8/Sasol F-T Blend]	< 25%	- 5%	± 5%	0%

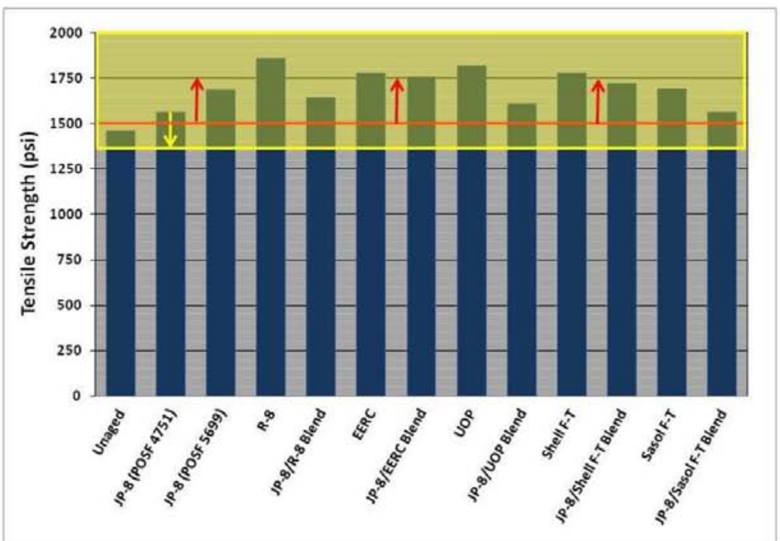

Figure 1. Tensile Strength Results for the Nitrile Bladder Innerliner

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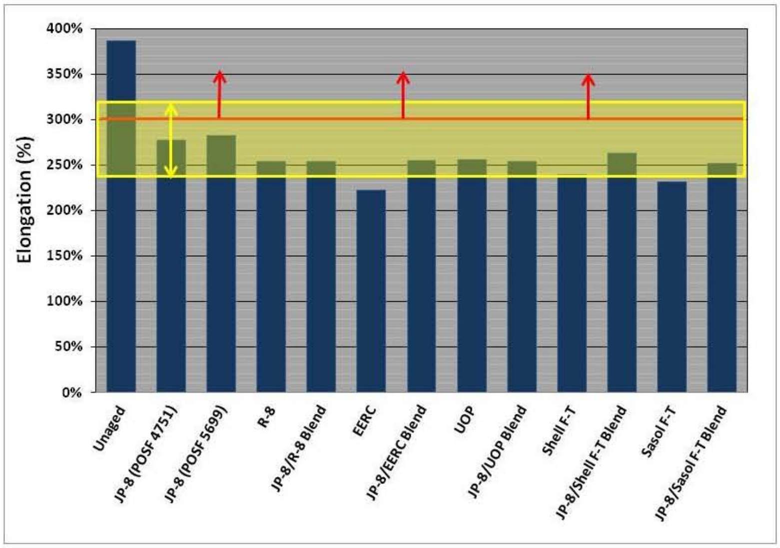

Figure 2. Elongation Results for the Nitrile Bladder Innerliner

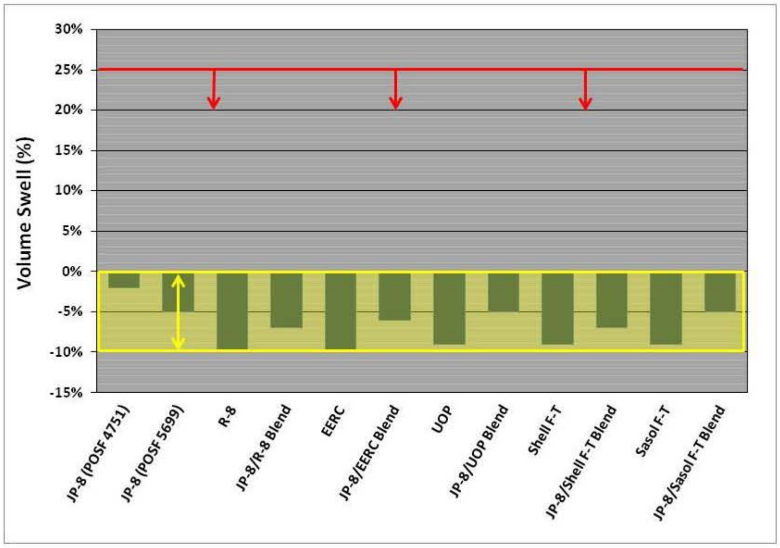

Figure 3. Volume Swell Results for the Nitrile Bladder Innerliner

Table 3 contains the test results for the AMS-S-4383 nitrile coating. All of the pencil hardness results met the listed test requirement and were within the allowable variation from the JP-8 baseline, however, many of the tape adhesion tests resulted in failures. All of the results shown are based on two panels aged in each fuel. The only instances in which both panels passed the tape adhesion test were the unaged case and after aging in 100 percent Sasol F-T. One of the two panels passed after aging in the two JP-8 fuels and the 100 percent EERC synthetic fuel. The application procedures and tape adhesion test method used are being reviewed to determine the rootcause of these failures in all of the fuels. It is also notable the pencil hardness results after aging in the two JP-8s varied from eachother by greater than the allowable amount.

Table 3

AMS-S-4383 Nitrile Coating

Material Description	Test	Conditioning	Test Requirements	Test Results (Panel 1 / Panel 2)	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS-S-4383 (nitrile)	Pencil Hardness	Unaged	≥ unaged	HB / HB	~	~
		28d/160°F/JP-8 (POSF 4751)	≥ unaged	H / H	~	~
		28d/160°F/JP-8 (POSF 5699)	≥ unaged	3H / 3H	1 pt. decrease	~
		28d/160°F/R-8	≥ unaged	>6H / >6H	1 pt. decrease	> +5
		28d/160°F/[JP-8/R-8 Blend]	≥ unaged	5H / 5H	1 pt. decrease	+ 4
		28d/160°F/EERC	≥ unaged	5H / 5H	1 pt. decrease	+ 4
		28d/160°F/[JP-8/EERC Blend]	≥ unaged	6H / 6H	1 pt. decrease	+ 5
		28d/160°F/UOP	≥ unaged	4H / 4H	1 pt. decrease	+ 3
		28d/160°F/[JP-8/UOP Blend]	≥ unaged	3H / 3H	1 pt. decrease	+ 2
		28d/160°F/Shell F-T	≥ unaged	4H / 4H	1 pt. decrease	+ 3
		28d/160°F/[JP-8/Shell F-T Blend]	≥ unaged	3H / 3H	1 pt. decrease	+ 2
		28d/160°F/Sasol F-T	≥ unaged	3H / 3H	1 pt. decrease	+ 2
		28d/160°F/[JP-8/Sasol F-T Blend]	≥ unaged	3H / 3H	1 pt. decrease	+ 2
	Tape Adhesion	Unaged	Pass	Passed / Passed	~	~
		28d/160°F/JP-8 (POSF 4751)	Pass	Failed / Passed	~	~
		28d/160°F/JP-8 (POSF 5699)	Pass	Failed / Passed	~	~
		28d/160°F/R-8	Pass	Failed / Failed	~	~
		28d/160°F/[JP-8/R-8 Blend]	Pass	Failed / Failed	~	~
		28d/160°F/EERC	Pass	Passed / Failed	~	~
		28d/160°F/[JP-8/EERC Blend]	Pass	Failed / Failed	~	~
		28d/160°F/UOP	Pass	Failed / Failed	~	~
		28d/160°F/[JP-8/UOP Blend]	Pass	Failed / Failed	~	~
		28d/160°F/Shell F-T	Pass	Failed / Failed	~	~
		28d/160°F/[JP-8/Shell F-T Blend]	Pass	Failed / Failed	~	~
		28d/160°F/Sasol F-T	Pass	Passed / Passed	~	~
		28d/160°F/[JP-8/Sasol F-T Blend]	Pass	Failed / Failed	~	~

6B – 5B – 4B – 3B – 2B – B – HB – F- H – 2H – 3H – 4H – 5H – 6H
Softer Harder

Table 4 contains the test results for the AMS-S-8802 manganese dioxide cured polysulfide sealant. All of the results met the test requirements, except for volume swell after aging in all of the fuels and percent cohesive failure in peel strength testing after aging in the JP-8/Shell F-T blend, Sasol F-T, and the JP-8/Sasol F-T blend. Although the volume swell results failed to meet the test requirement of 0 to 20 percent after aging, they were all relatively consistent and within the allowable variation from the JP-8 baseline. Additionally, although failure modes were not 100 percent cohesive (within the sealant) after aging in the JP-8/Shell F-T blend, Sasol F-T, or JP-8/Sasol F-T blend, the strength values still met the test requirement and were within the allowable variation from the JP-8 baseline. It is possible and more likely for adhesive failures to occur when there is insufficient cleaning and surface preparation of the substrate than from an attack of the fuel through the sealant on the sealant/substate interface, and retests were not performed since the strength values were acceptable. The only other instances in which the results were outside of the allowable variation from the baseline were for elongation after aging in Shell F-T and Sasol F-T, as well as Shore A hardness after aging in R-8, EERC, the JP-8/EERC blend, and Sasol F-T.

To better clarify and analyze these results, graphs of the data are contained in Figures 4, 5, 6, 7, and 8. The red line (or red shaded area if the requirement is a range) on each graph represents the test requirement, and the yellow shaded region represents the allowable variation from one (or both) of the JP-8 aged test results. As the graphs depict, most of the test results were relatively consistent, and those that were not within the allowable variations from the baseline were only slightly outside of the allowable region.

Table 4

Manganese Dioxide Cured AMS-S-8802 Polysulfide Sealant

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS-S-8802 (Polysulfide) (Manganese-dioxide cured)	Tensile Strength	Unaged	> 200 psi	497 psi	~.	~
		28d/200°F/JP-8 (POSF 4751)	> 200 psi	419 psi	~	~
		28d/200°F/JP-8 (POSF 5699)	> 200 psi	419 psi	35 psi decrease	~
		28d/200°F/R-8	> 200 psi	437 psi	35 psi decrease	+ 18 psi
		28d/200°F/[JP-8/R-8 Blend]	> 200 psi	430 psi	35 psi decrease	+ 11 psi
		28d/200°F/EERC	> 200 psi	474 psi	35 psi decrease	+ 55 psi
		28d/200°F/[JP-8/EERC Blend]	> 200 psi	438 psi	35 psi decrease	+ 19 psi
		28d/200°F/UOP	> 200 psi	442 psi	35 psi decrease	+ 23 psi
		28d/200°F/[JP-8/UOP Blend]	> 200 psi	411 psi	35 psi decrease	- 8 psi
		28d/200°F/Shell F-T	> 200 psi	426 psi	35 psi decrease	+ 7 psi
		28d/200°F/[JP-8/Shell F-T Blend]	> 200 psi	433 psi	35 psi decrease	+ 14 psi
		28d/200°F/Sasol F-T	> 200 psi	423 psi	35 psi decrease	+ 4 psi
		28d/200°F/[JP-8/Sasol F-T Blend]	> 200 psi	413 psi	35 psi decrease	- 6 psi

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Table 4 (Continued)

Manganese Dioxide Cured AMS-S-8802 Polysulfide Sealant

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS-S-8802 (Polysulfide) (Manganese-dioxide cured)	Elongation	Unaged	> 150%	269%	~	~
		28d/200°F/JP-8 (POSF 4751)	> 150%	206%	~	~
		28d/200°F/JP-8 (POSF 5699)	> 150%	196%	25% decrease	~
		28d/200°F/R-8	> 150%	173%	25% decrease	- 23%
		28d/200°F/[JP-8/R-8 Blend]	> 150%	188%	25% decrease	- 8%
		28d/200°F/EERC	> 150%	188%	25% decrease	- 8%
		28d/200°F/[JP-8/EERC Blend]	> 150%	196%	25% decrease	0%
		28d/200°F/UOP	> 150%	180%	25% decrease	- 16%
		28d/200°F/[JP-8/UOP Blend]	> 150%	194%	25% decrease	- 2%
		28d/200°F/Shell F-T	> 150%	168%	25% decrease	- 28%
		28d/200°F/[JP-8/Shell F-T Blend]	> 150%	198%	25% decrease	+ 2%
		28d/200°F/Sasol F-T	> 150%	168%	25% decrease	- 28%
		28d/200°F/[JP-8/Sasol F-T Blend]	> 150%	203%	25% decrease	+ 7%
	Volume Swell	Unaged	~	~	~	~
		28d/200°F/JP-8 (POSF 4751)	0% to 20%	- 3%	~	~
		28d/200°F/JP-8 (POSF 5699)	0% to 20%	- 3%	5% increase	~
		28d/200°F/R-8	0% to 20%	- 6%	5% increase	- 3%
		28d/200°F/[JP-8/R-8 Blend]	0% to 20%	- 5%	5% increase	- 2%
		28d/200°F/EERC	0% to 20%	- 7%	5% increase	- 4%
		28d/200°F/[JP-8/EERC Blend]	0% to 20%	- 5%	5% increase	- 2%
		28d/200°F/UOP	0% to 20%	- 6%	5% increase	- 3%
		28d/200°F/[JP-8/UOP Blend]	0% to 20%	- 5%	5% increase	- 2%
		28d/200°F/Shell F-T	0% to 20%	- 5%	5% increase	- 2%
		28d/200°F/[JP-8/Shell F-T Blend]	0% to 20%	- 4%	5% increase	- 1%
		28d/200°F/Sasol F-T	0% to 20%	- 6%	5% increase	- 3%
		28d/200°F/[JP-8/Sasol F-T Blend]	0% to 20%	- 4%	5% increase	- 1%

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Table 4 (Concluded)

Manganese Dioxide Cured AMS-S-8802 Polysulfide Sealant

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS-S-8802 (Polysulfide) (Manganese-dioxide cured)	Hardness, Shore A	Unaged	> 35 pts	64	~	~
		28d/200°F/JP-8 (POSF 4751)	> 35 pts	59	~	~
		28d/200°F/JP-8 (POSF 5699)	> 35 pts	59	± 5 pts	~
		28d/200°F/R-8	> 35 pts	65	± 5 pts	+ 6
		28d/200°F/[JP-8/R-8 Blend]	> 35 pts	64	± 5 pts	+ 5
		28d/200°F/EERC	> 35 pts	65	± 5 pts	+ 6
		28d/200°F/[JP-8/EERC Blend]	> 35 pts	52	± 5 pts	- 7
		28d/200°F/UOP	> 35 pts	63	± 5 pts	+ 4
		28d/200°F/[JP-8/UOP Blend]	> 35 pts	60	± 5 pts	+ 1
		28d/200°F/Shell F-T	> 35 pts	51	± 5 pts	- 8
		28d/200°F/[JP-8/Shell F-T Blend]	> 35 pts	56	± 5 pts	- 3
		28d/200°F/Sasol F-T	> 35 pts	64	± 5 pts	+ 5
		28d/200°F/[JP-8/Sasol F-T Blend]	> 35 pts	63	± 5 pts	+ 4
	Peel Strength	Unaged	>20 lbs / 100%	58 lbs / 100%	~	~
		28d/200°F/JP-8 (POSF 4751)	>20 lbs / 100%	39 lbs / 100%	~	~
		28d/200°F/JP-8 (POSF 5699)	>20 lbs / 100%	38 lbs / 100%	~	~
		28d/200°F/R-8	>20 lbs / 100%	42 lbs / 100%	8 lbs decrease	+ 4 lbs
		28d/200°F/[JP-8/R-8 Blend]	>20 lbs / 100%	40 lbs / 100%	8 lbs decrease	+ 2 lbs
		28d/200°F/EERC	>20 lbs / 100%	41 lbs / 100%	8 lbs decrease	+ 3 lbs
		28d/200°F/[JP-8/EERC Blend]	>20 lbs / 100%	42 lbs / 100%	8 lbs decrease	+ 4 lbs
		28d/200°F/UOP	>20 lbs / 100%	41 lbs / 100%	8 lbs decrease	+ 3 lbs
		28d/200°F/[JP-8/UOP Blend]	>20 lbs / 100%	47 lbs / 100%	8 lbs decrease	+ 9 lbs
		28d/200°F/Shell F-T	>20 lbs / 100%	40 lbs / 100%	8 lbs decrease	+ 2 lbs
		28d/200°F/[JP-8/Shell F-T Blend]	>20 lbs / 100%	35 lbs / 80%	8 lbs decrease	- 3 lbs
		28d/200°F/Sasol F-T	>20 lbs / 100%	38 lbs / 95%	8 lbs decrease	0 lbs
		28d/200°F/[JP-8/Sasol F-T Blend]	>20 lbs / 100%	38 lbs / 70%	8 lbs decrease	0 lbs

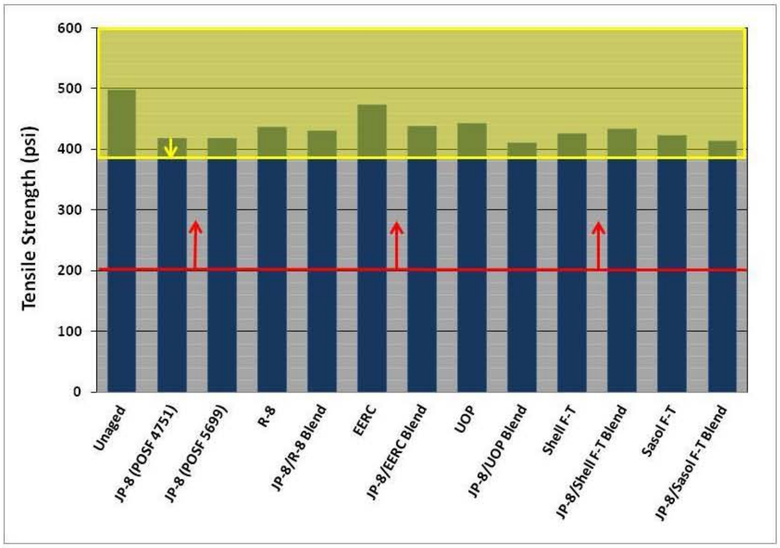

Figure 4. Tensile Strength Results for the AMS-S-8802 Polysulfide Sealant

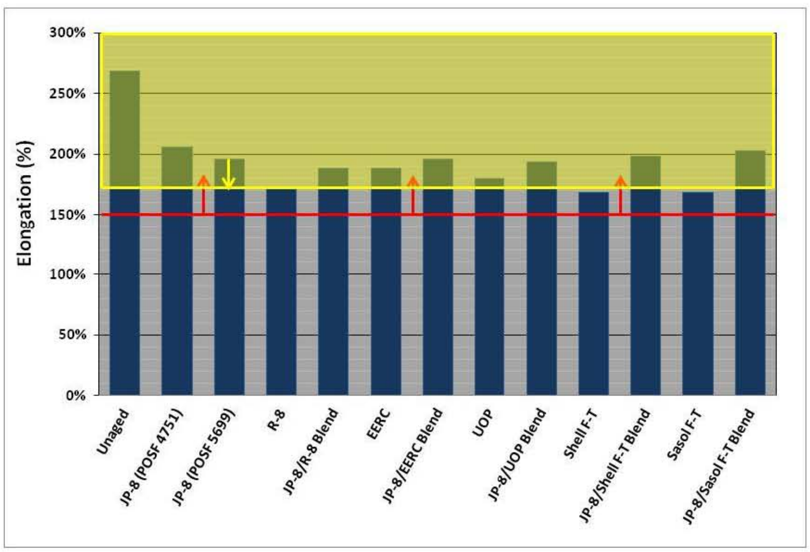

Figure 5. Elongation Results for the AMS-S-8802 Polysulfide Sealant

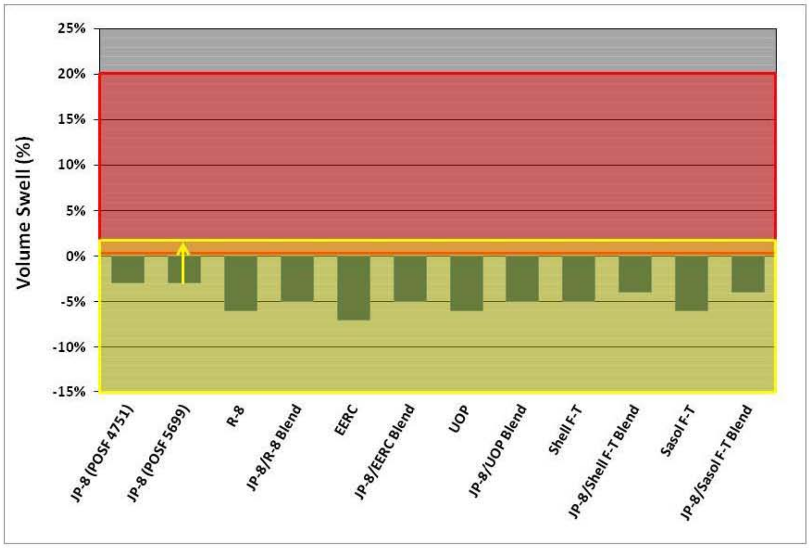

Figure 6. Volume Swell Results for the AMS-S-8802 Polysulfide Sealant

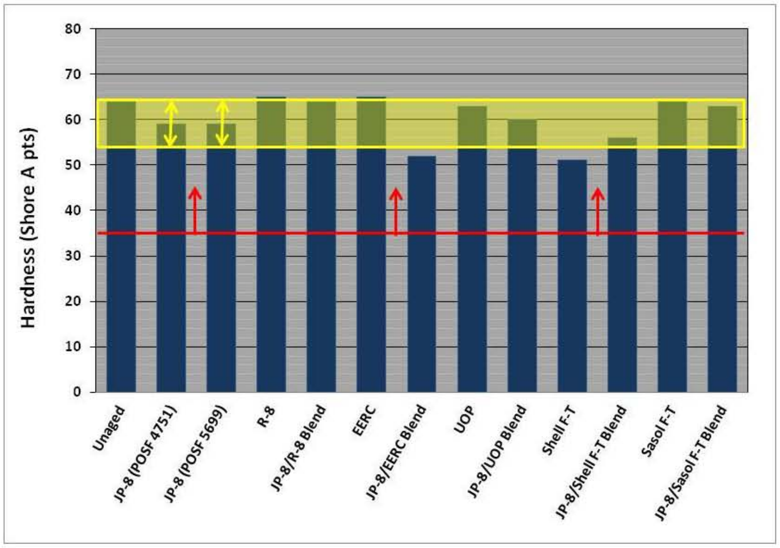

Figure 7. Shore A Hardness Results for the AMS-S-8802 Polysulfide Sealant

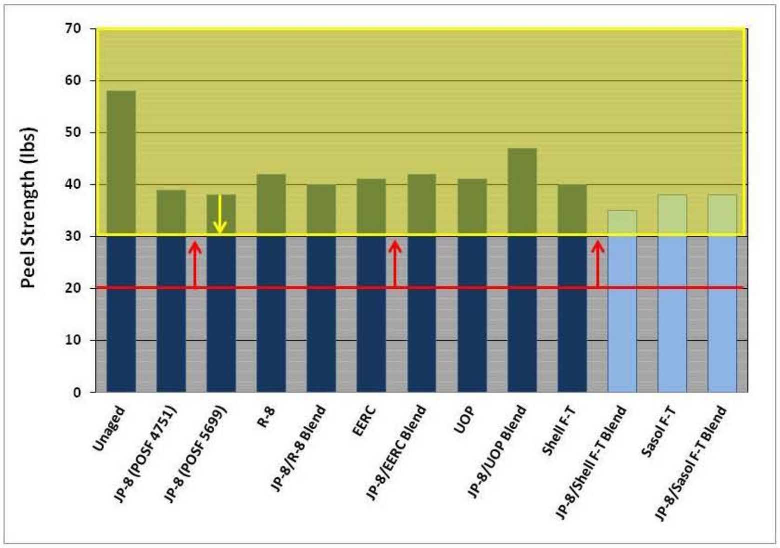

Figure 8. Peel Strength Results for the AMS-S-8802 Polysulfide Sealant (last three data points appear in lighter blue since they did not fail 100 percent cohesively)

Table 5 contains the test results for the AMS 3277 polythioether sealant. Results met the test requirements with the exception of elongation after aging in JP-8 (POSF 4751 only), EERC, UOP, the JP-8/UOP blend, Shell F-T, and Sasol F-T. However, all of these results were within the allowable variation from the JP-8 baseline. There were no tensile strength, elongation, or volume swell results outside of the allowable variations from the JP-8 baseline. For Shore A hardness, the variations from both JP-8s are listed to show that all of the results after aging in the alternative fuels and blends were within the allowable variation from one or both of the JP-8 baselines. As was the case with the AMS-S-8802 sealant, the data are presented in graphs in Figures 9-13 to provide a visual perspective of the results. As noted previously for the AMS-S-4383 material, there were instances in which the AMS 3277 results after aging in the two JP-8s were outside of the allowable variation from one another. These occurred for tensile strength, elongation, and Shore A hardness.

To better clarify and analyze these results, graphs of the data are contained in Figures 9, 10, 11, 12, and 13. The red line (or red shaded area if the requirement is a range) on each graph represents the test requirement, and the yellow shaded region represents the allowable variation from one (or both) of the JP-8 aged test results. As the graphs depict, most of the test results were relatively consistent and were within the allowable variation from at least one of the JP-8 baseline fuels.

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Table 5

AMS 3277 Polythioether Sealant

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS 3277 (Polythioether)	Tensile Strength	Unaged	> 200 psi	436 psi	~	~
		28d/200°F/JP-8 (POSF 4751)	> 200 psi	258 psi	~	~
		28d/200°F/JP-8 (POSF 5699)	> 200 psi	392 psi	35 psi decrease	~
		28d/200°F/R-8	> 200 psi	386 psi	35 psi decrease	+ 128 psi
		28d/200°F/[JP-8/R-8 Blend]	> 200 psi	323 psi	35 psi decrease	+ 65 psi
		28d/200°F/EERC	> 200 psi	311 psi	35 psi decrease	+ 53 psi
		28d/200°F/[JP-8/EERC Blend]	> 200 psi	289 psi	35 psi decrease	+ 31 psi
		28d/200°F/UOP	> 200 psi	349 psi	35 psi decrease	+ 91 psi
		28d/200°F/[JP-8/UOP Blend]	> 200 psi	256 psi	35 psi decrease	- 2 psi
		28d/200°F/Shell F-T	> 200 psi	253 psi	35 psi decrease	- 5 psi
		28d/200°F/[JP-8/Shell F-T Blend]	> 200 psi	339 psi	35 psi decrease	+ 81 psi
		28d/200°F/Sasol F-T	> 200 psi	270 psi	35 psi decrease	+ 12 psi
		28d/200°F/[JP-8/Sasol F-T Blend]	> 200 psi	350 psi	35 psi decrease	+ 92 psi
	Elongation	Unaged	> 150%	231%	~	~
		28d/200°F/JP-8 (POSF 4751)	> 150%	143%	~	~
		28d/200°F/JP-8 (POSF 5699)	> 150%	184%	25% decrease	~
		28d/200°F/R-8	> 150%	170%	25% decrease	+ 27%
		28d/200°F/[JP-8/R-8 Blend]	> 150%	164%	25% decrease	+ 21%
		28d/200°F/EERC	> 150%	123%	25% decrease	- 20%
		28d/200°F/[JP-8/EERC Blend]	> 150%	163%	25% decrease	+ 20%
		28d/200°F/UOP	> 150%	141%	25% decrease	- 2%
		28d/200°F/[JP-8/UOP Blend]	> 150%	133%	25% decrease	- 10%
		28d/200°F/Shell F-T	> 150%	149%	25% decrease	+ 6%
		28d/200°F/[JP-8/Shell F-T Blend]	> 150%	155%	25% decrease	+ 12%
		28d/200°F/Sasol F-T	> 150%	146%	25% decrease	+ 3%
		28d/200°F/[JP-8/Sasol F-T Blend]	> 150%	164%	25% decrease	+ 21%

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Table 5 (Continued)

AMS 3277 Polythioether Sealant

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS 3277 (Polythioether)	Volume Swell	Unaged	~	~	~	~
		28d/200°F/JP-8 (POSF 4751)	0% to 25%	8%	~	~
		28d/200°F/JP-8 (POSF 5699)	0% to 25%	6%	5% increase	~
		28d/200°F/R-8	0% to 25%	1%	5% increase	- 5%
		28d/200°F/[JP-8/R-8 Blend]	0% to 25%	4%	5% increase	- 2%
		28d/200°F/EERC	0% to 25%	2%	5% increase	- 4%
		28d/200°F/[JP-8/EERC Blend]	0% to 25%	5%	5% increase	- 1%
		28d/200°F/UOP	0% to 25%	1%	5% increase	- 5%
		28d/200°F/[JP-8/UOP Blend]	0% to 25%	3%	5% increase	- 3%
		28d/200°F/Shell F-T	0% to 25%	2%	5% increase	- 4%
		28d/200°F/[JP-8/Shell F-T Blend]	0% to 25%	5%	5% increase	- 1%
		28d/200°F/Sasol F-T	0% to 25%	2%	5% increase	- 4%
		28d/200°F/[JP-8/Sasol F-T Blend]	0% to 25%	3%	5% increase	- 3%
	Hardness, Shore A	Unaged	> 35 pts	63	~	~
		28d/200°F/JP-8 (POSF 4751)	> 35 pts	43	~	~
		28d/200°F/JP-8 (POSF 5699)	> 35 pts	50	± 5 pts	~
		28d/200°F/R-8	> 35 pts	46	± 5 pts	+ 3 / - 4
		28d/200°F/[JP-8/R-8 Blend]	> 35 pts	46	± 5 pts	+ 3 / -4
		28d/200°F/EERC	> 35 pts	49	± 5 pts	+ 6 / -1
		28d/200°F/[JP-8/EERC Blend]	> 35 pts	41	± 5 pts	- 2 / -9
		28d/200°F/UOP	> 35 pts	48	± 5 pts	+ 5 / - 2
		28d/200°F/[JP-8/UOP Blend]	> 35 pts	47	± 5 pts	+ 4 / -3
		28d/200°F/Shell F-T	> 35 pts	50	± 5 pts	+ 7 / 0
		28d/200°F/[JP-8/Shell F-T Blend]	> 35 pts	47	± 5 pts	+ 4 / -3
		28d/200°F/Sasol F-T	> 35 pts	50	± 5 pts	+ 7 / 0
		28d/200°F/[JP-8/Sasol F-T Blend]	> 35 pts	50	± 5 pts	+ 7 / 0

Table 5 (Continued)

AMS 3277 Polythioether Sealant

Material Description	Test	Conditioning	Test Requirements	Test Results	Allowable Variation from Baseline (JP-8)	Variation from JP-8
AMS 3277 (Polythioether)	Peel Strength	Unaged	>20 lbs / 100%	55 lbs / 100%	~	~
		28d/200°F/JP-8 (POSF 4751)	>20 lbs / 100%	23 lbs / 100%	~	~
		28d/200°F/JP-8 (POSF 5699)	>20 lbs / 100%	28 lbs / 100%	~	~
		28d/200°F/R-8	>20 lbs / 100%	42 lbs / 100%	8 lbs decrease	+ 19 lbs
		28d/200°F/[JP-8/R-8 Blend]	>20 lbs / 100%	38 lbs / 100%	8 lbs decrease	+ 15 lbs
		28d/200°F/EERC	>20 lbs / 100%	38 lbs / 100%	8 lbs decrease	+ 15 lbs
		28d/200°F/[JP-8/EERC Blend]	>20 lbs / 100%	44 lbs / 100%	8 lbs decrease	+ 21 lbs
		28d/200°F/UOP	>20 lbs / 100%	45 lbs / 100%	8 lbs decrease	+ 22 lbs
		28d/200°F/[JP-8/UOP Blend]	>20 lbs / 100%	42 lbs / 100%	8 lbs decrease	+ 19 lbs
		28d/200°F/Shell F-T	>20 lbs / 100%	36 lbs / 100%	8 lbs decrease	+ 13 lbs
		28d/200°F/[JP-8/Shell F-T Blend]	>20 lbs / 100%	46 lbs / 100%	8 lbs decrease	+ 23 lbs
		28d/200°F/Sasol F-T	>20 lbs / 100%	34 lbs / 100%	8 lbs decrease	+ 11 lbs
		28d/200°F/[JP-8/Sasol F-T Blend]	>20 lbs / 100%	40 lbs / 100%	8 lbs decrease	+ 17 lbs

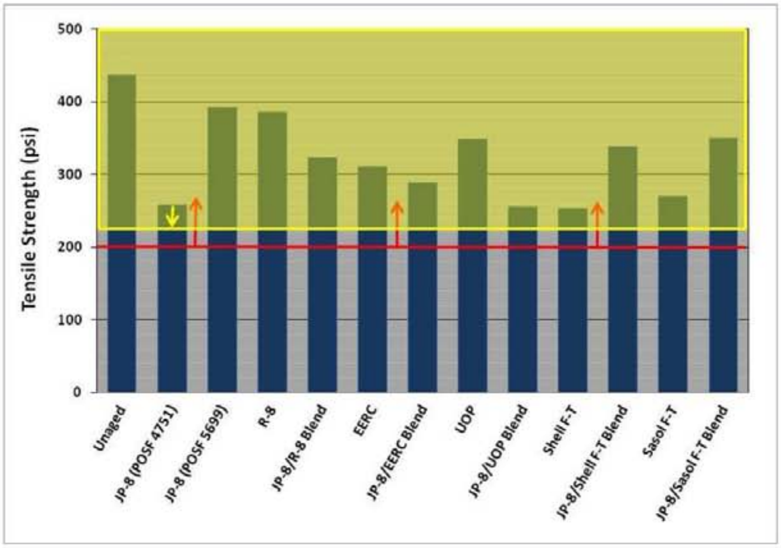

Figure 9. Tensile Strength Results for the AMS 3277 Polythioether Sealant

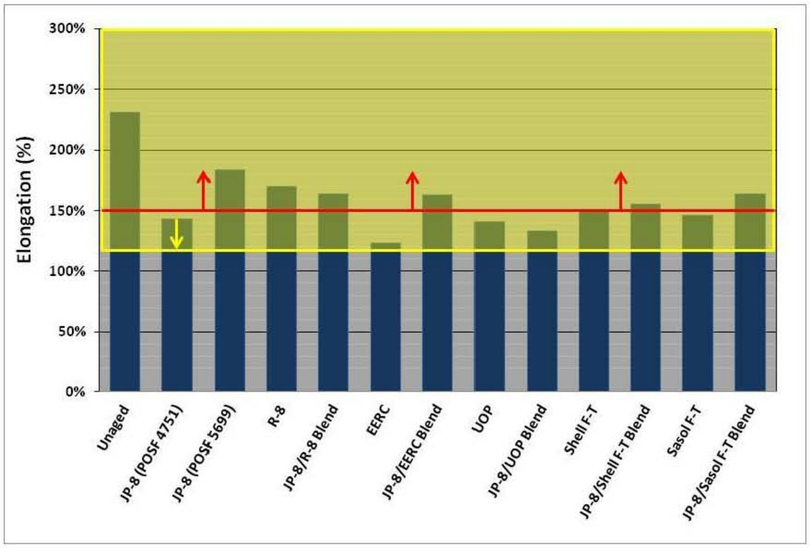

Figure 10. Elongation Results for the AMS 3277 Polythioether Sealant

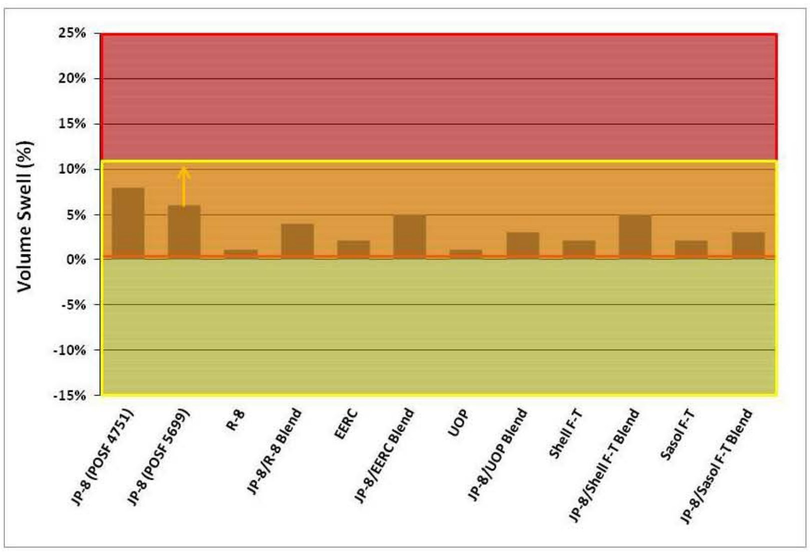

Figure 11. Volume Swell Results for the AMS 3277 Polythioether Sealant

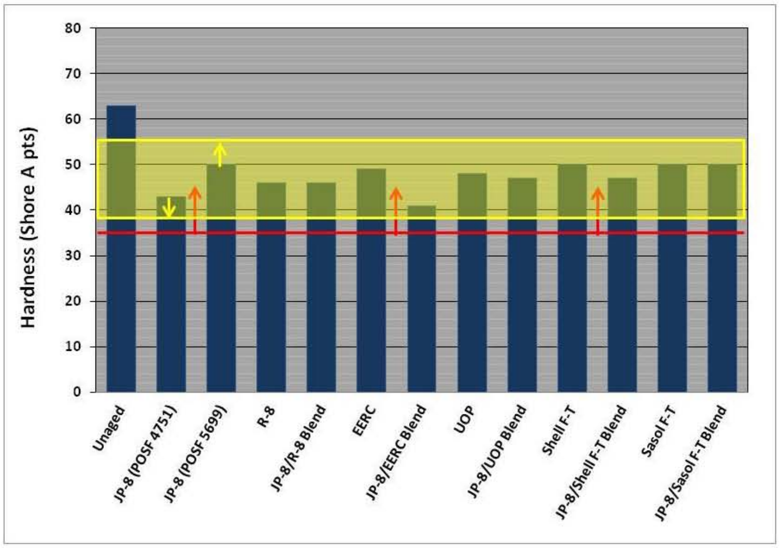

Figure 12. Shore A Hardness Results for the AMS 3277 Polythioether Sealant

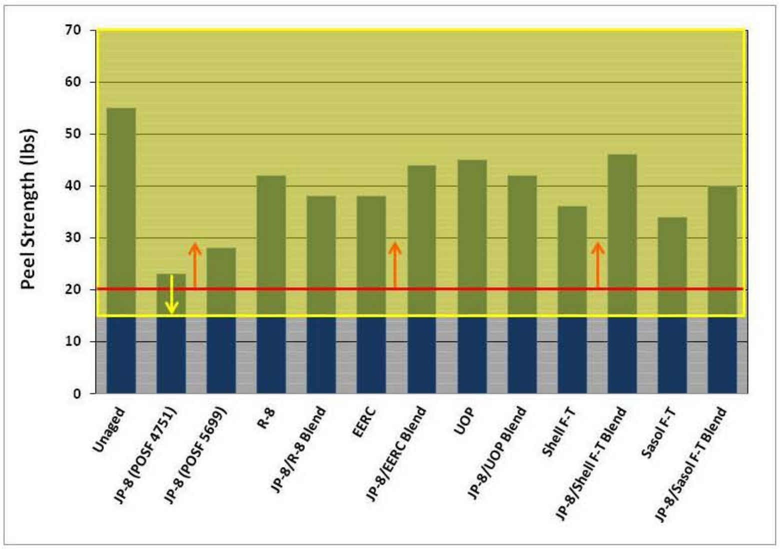

Figure 13. Peel Strength Results for the AMS 3277 Polythioether Sealant

CONCLUSIONS

From the data obtained in this effort, the various alternative fuels whether F-T derived or HRJ-type appear to affect the materials similarly. Likewise, the 50/50 blend of each alternative fuel with JP-8 also appear to affect the various materials similarly. In both cases, this was expected because the hydrocarbon mixture produced by each process (from each feedstock) was said (by AFRL/RZPF fuels engineers) to be very similar. It does not appear the 50/50 blend of any of the alternative fuels degraded the four materials evaluated more than JP-8 alone. However, similar to previous studies, it cannot be concluded that the 100 percent alternative fuels would be suitable for use.

The nitrile bladder innerliner material failed to meet the elongation requirement of 300 percent after aging in all of the fuels. However, all results after aging in the various 50/50 blends were within the allowable variation from the JP-8 baseline, so no further testing is needed at this time. Based on the data and the manufacturer's recommendation, all future testing of this material shoud be performed with relatively new material if possible, and to further reduce variability, baseline data must be obtained whenever an additional alternative fuel is tested.

The AMS-S-4383 nitrile coating does require some further examination because it failed the tape adhesion tests after aging in nearly all of the fuels, including the two JP-8s baselines. It does not appear the 50/50 blend of any of the alternative fuels degraded the coating more than did JP-8 alone, but further evaluation of the specimen preparation and test method is needed.

All of the results for the AMS-S-8802 manganese dioxide cured polysulfide and AMS 3277 polythioether sealants were relatively consistent, and it does not appear the HRJ alternative fuels and blends degraded their properties and more than did the JP-8s, F-Ts, and JP-8/F-T blends.

It is notable that there were some instances in which the results after aging materials in the two JP-8 fuels were outside of the allowable variation from one another. This potentially indicates the allowable variation values used for these materials are too restrictive However, further studies should continue to use the same test requirements and allowable variations for these materials to ensure any potentially increased degradation is identified. It is important to remember a material failing to meet the test requirement and/or allowable variation for one particular test does not necessarily mean there is a compatibility issue. The overall test results and potential on-aircraft implications of the results must always be considered before a final determination on compatibility is made.

RECOMMENDATIONS

- Based on the test results, it appears the JP-8/R-8 blend has a similar effect on the evaluated materials as does JP-8 and the 50/50 blends of the various other alternative fuels tested. The potential concerns mentioned in AFRL/RXS 10-002 have been addressed, so further testing of these materials is not recommended. There do not appear to be any serious compatibility concerns for these materials with the 50/50 blend of any of the alternative fuels tested.

- It is however recommended that the general application and tape adhesion test method for the AMS-S-4383 nitrile coating be examined to better understand the failures after aging in all of the fuels. Lastly, it is recommended all future analysis of the nitrile bladder innerliner material include baseline testing using the same batch of material, with the orientation of the test specimens held constant.

AFRL/RXS 10-003

REVIEWED BY

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PUBLICATION REVIEW: This report has been reviewed and approved.

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- **Failure Analysis/Accident Investigation**
  - **- Structural**
  - **- Electronic**
  - **- Chemical**
- **Consultations on**
  - **- Materials/Process Specifications**
  - **- Physical and Mechanical Metallurgy**
  - **- Materials and Component Failure Analysis**
  - **- Electronics and Packaging**
  - **- Bonded Repair of Metals/Composites**
  - **- Nonmetallic Materials**
  - **- Welding, Joining and Adhesive Bonding**
  - **- Electrostatic Discharge Control and Process Specs/Standards**
- **Nondestructive Inspection**
- **Electrostatic Discharge (ESD) Testing**
- **ESD Material Qualifications/Acceptance Testing**
- **Composites Supportability**

APPENDIX K
Aircraft Performance Model Results

Impact of Alternative Fuels on aircraft mission range (% change) when compared to JP-8 PQIS average.

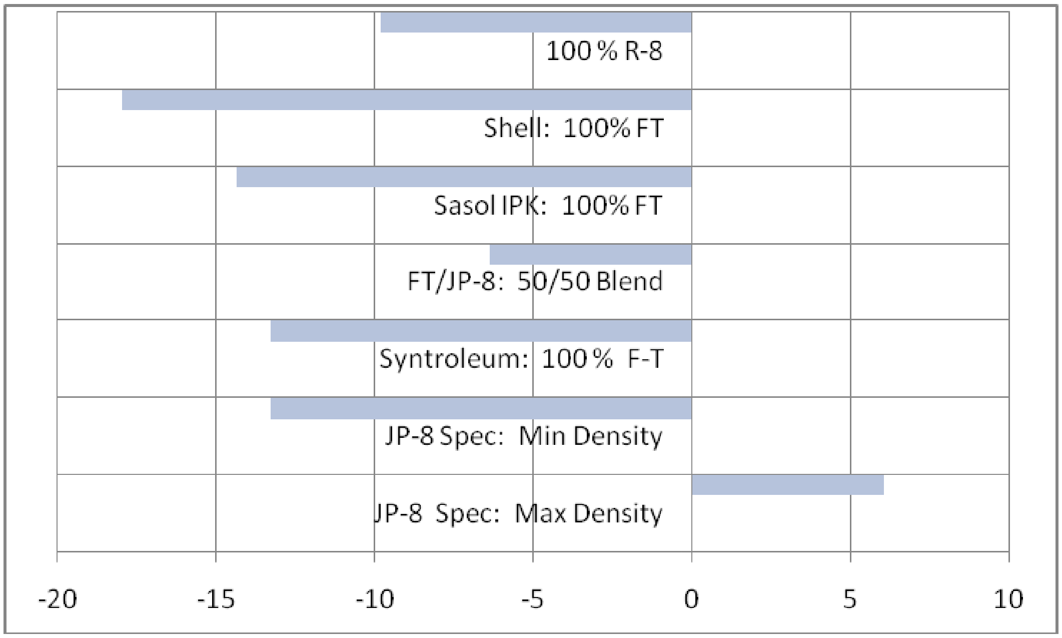

Figure K-1. Fighter/Air-Air Model – R-8 100%

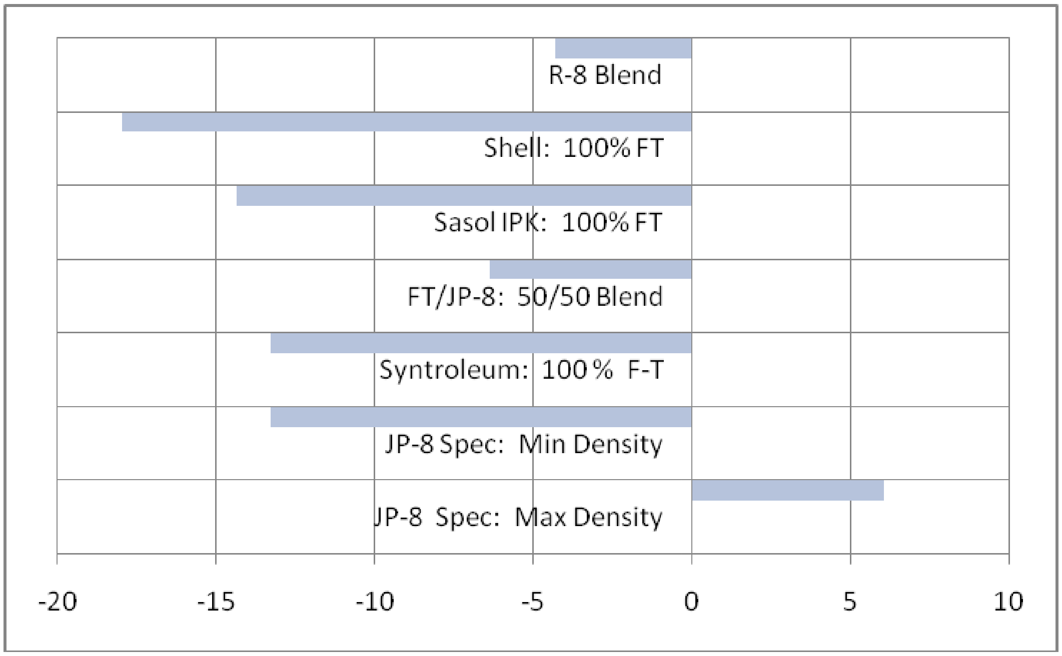

Figure K-2. Fighter/Air-Air Model – R-8 50% Blend

APPENDIX K
Aircraft Performance Model Results

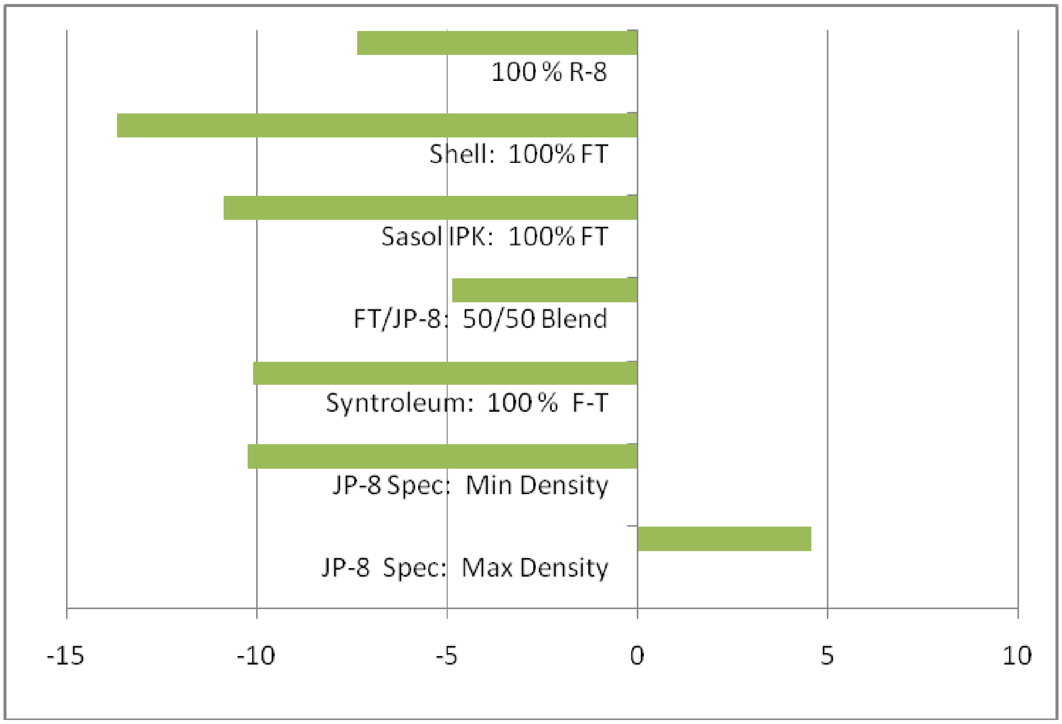

Figure K-3. Fighter/Air-Ground Model – R-8 100%

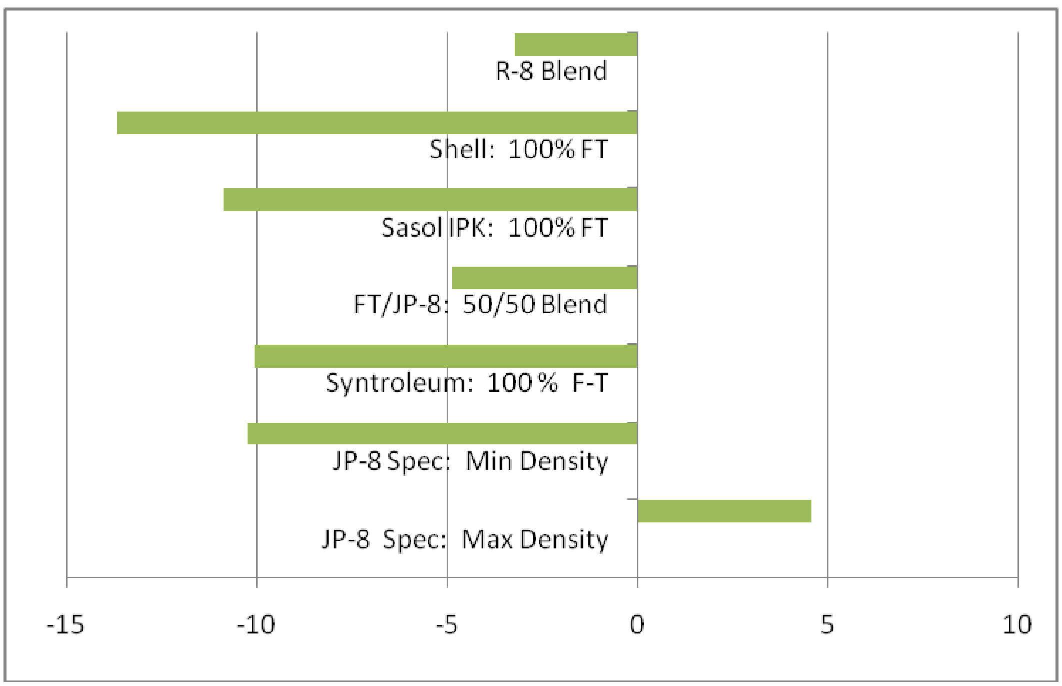

Figure K-4. Fighter/Air-Ground Model – R-8 50% Blend

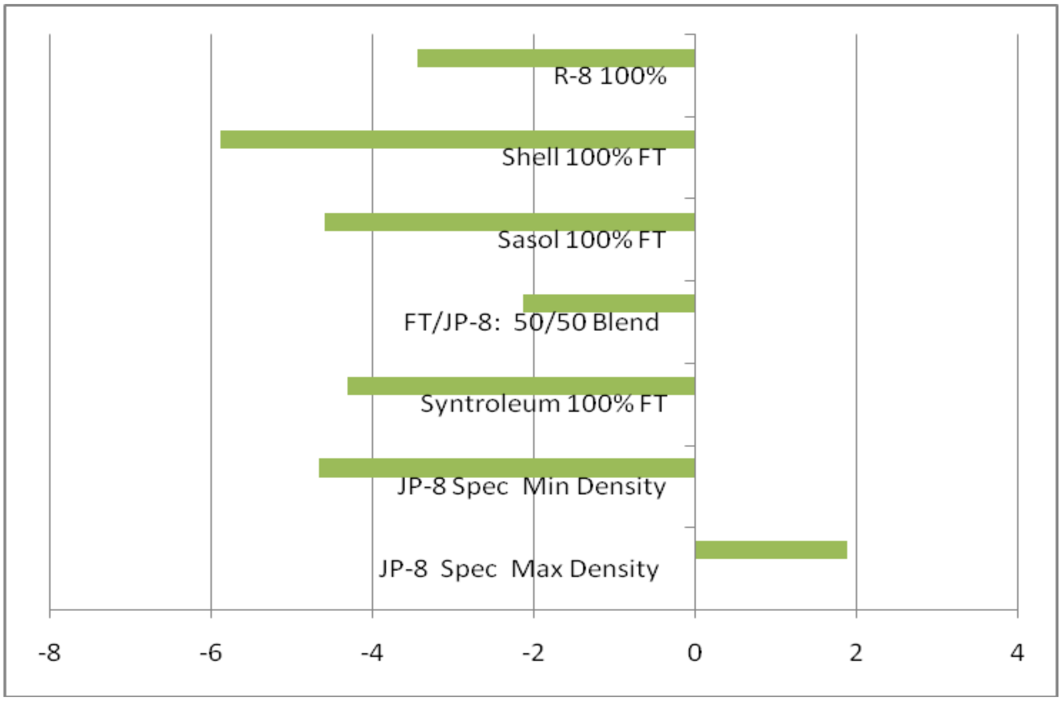

Figure K-5. Cargo Model – R-8 100%

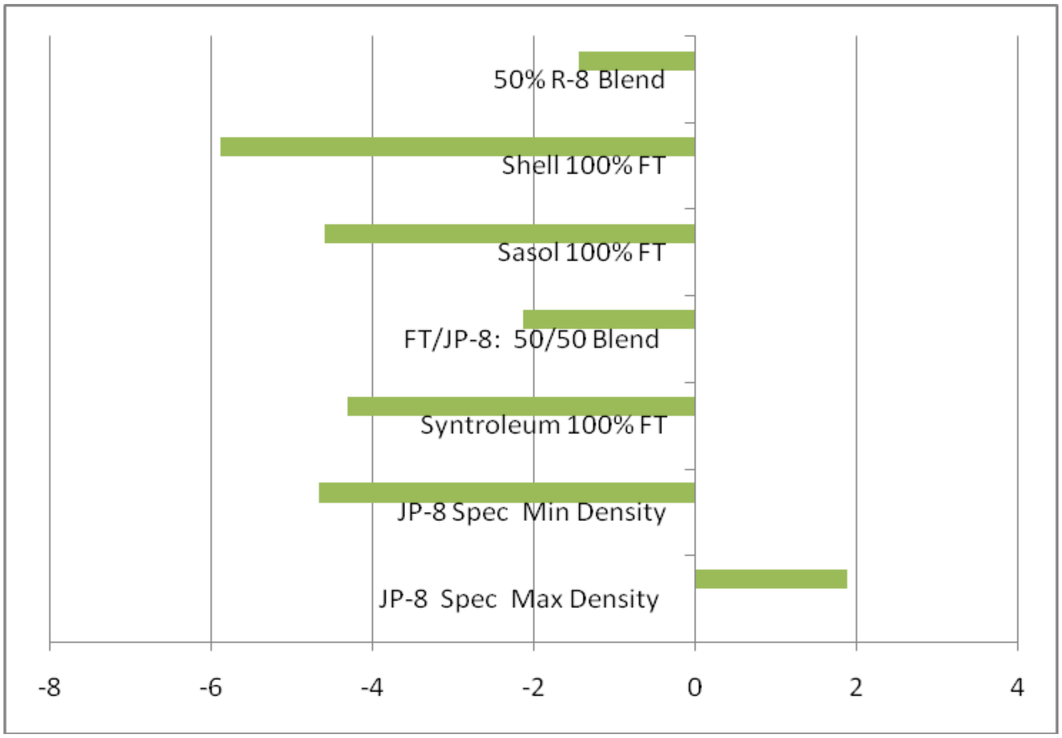

Figure K-6. Cargo Model – R-8 50% Blend

APPENDIX K
Aircraft Performance Model Results

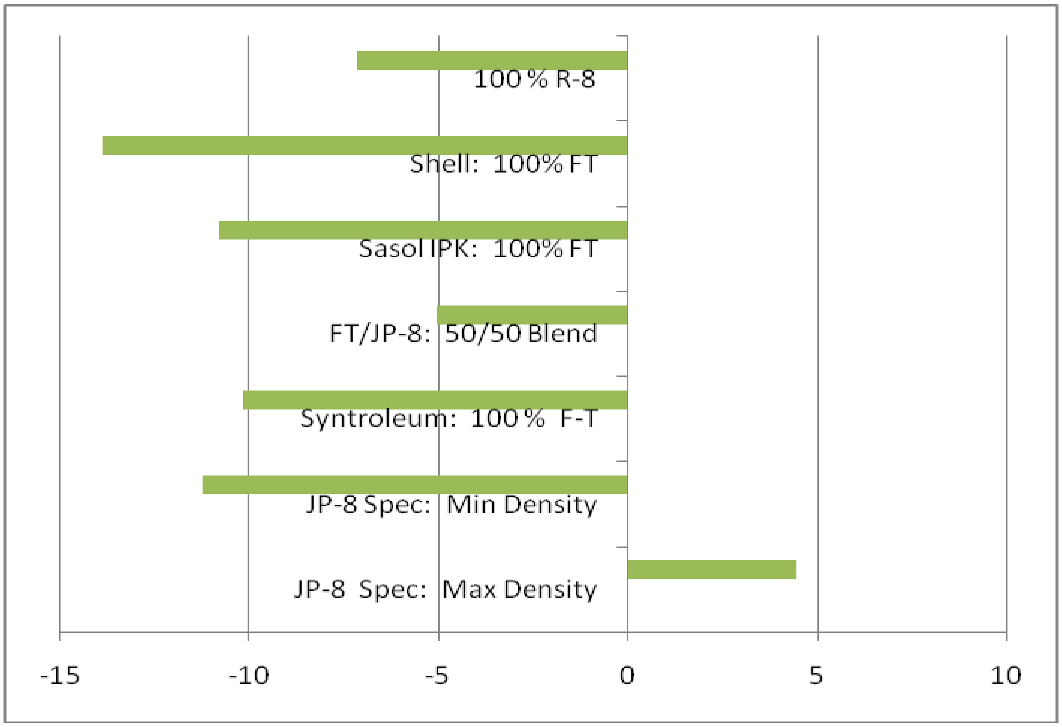

Figure K-7. Strike Aircraft Model – R-8 100%

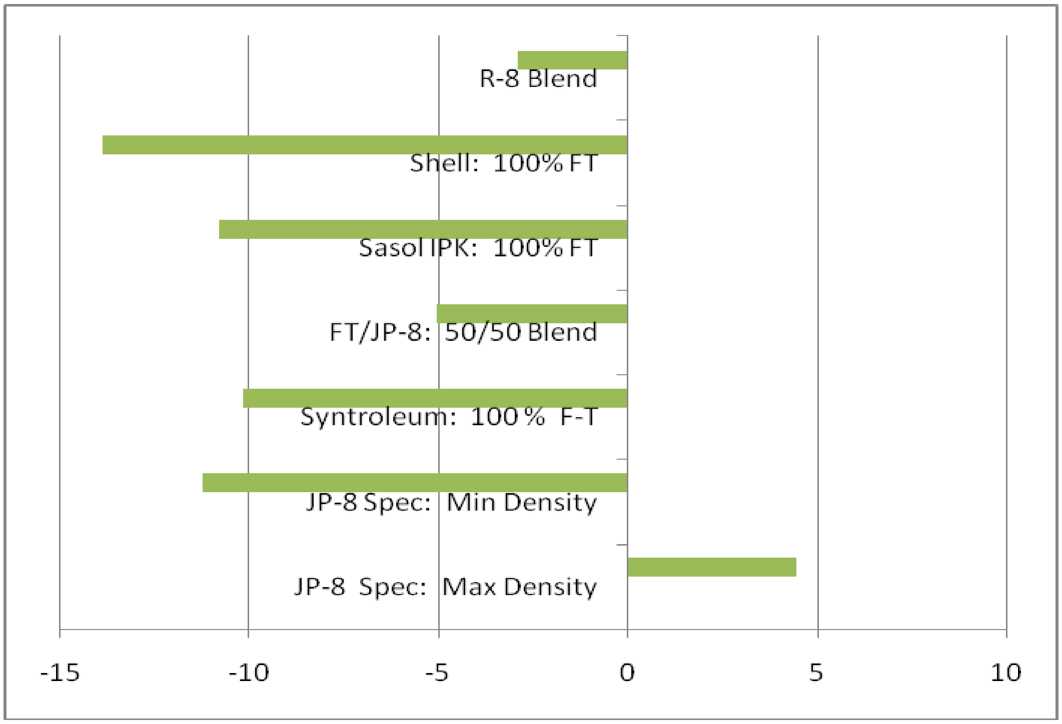

Figure K-8. Strike Aircraft Model – R-8 50% Blend

LIST OF ACRONYMS, ABBREVIATIONS AND SYMBOLS

Acronym	**Description**
AFB	Air Force Base
AFCO	Air Force Certification Office
AFRL	Air Force Research Laboratory
AFPET	Air Force Petroleum Agency
AO	Antioxidant additive
ASTM	American Society for Testing and Materials
BOCLE	Ball On Cylinder Lubricity Evaluation
°C	Celsius
CI/LI	Corrosion Inhibitor/Lubricity Improver additive
CRC	Coordinating Research Council
CU	Conductivity Units
DARPA	Defense Advanced Research Projects Agency
DiEGME	DiEthylene Glycol Monomethyl Ether
DOD	Department of Defense
FFP	Fit for Purpose
FOG	Fats, Oils, and Greases
FSII	Fuel System Icing Inhibitor
FT	Fischer-Tropsch
GC	Gas chromatograph
GSE	Ground Support Equipment
HRJ	Hydroprocessed renewable jet
IPK	Iso-paraffinic kerosene
IPT	Integrated Product Team
JP-8	Aviation, Kerosene Fuel produced to MIL-DTL-83133
LT	Low Temperature
LW	Rolls-Royce LibertyWorks
MSEP	Microseparometer
MSDS	Material Safety Data Sheet
OEM	Original Equipment Manufacturer
PARC	Intertek PARC, Pittsburgh PA

PID	Program Introduction Document
POSF	Air Force Fuels Branch Fuel Sample Designator
PQIS	Petroleum Quality Information System
R&D	Research and Development
R-8, R-8HRJ	Designation for Syntroleum Corporation hydroprocessed renewable jet fuel from fats and greases
R-8X, R-8X HRJ	Designation for Syntroleum Corporation hydroprocessed renewable jet fuel from oils (sea plants)
RZPF	Fuels and Energy Branch (Energy, Power, and Thermal Division, AFRL)
SAE	Society of Automotive Engineers
SDA	Static Dissipater additive
SPK	Synthetic Paraffinic Kerosene
SPO	System Program Office
SSJF	Semi-Synthetic Jet Fuels
SwRI	Southwest Research Institute
TM	Technical Memorandum
UDRI	University of Dayton Research Institute
UTC	Universal Technology Corporation