ESTCP
Executive Summary Report

(WP-0305)

Validation of Alternatives to High Volatile Organic Compound Solvents Used in Aeronautical Antifriction Bearing Cleaning

June 2007

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE *(DD-MM-YYYY)*
04-20-2007

2. REPORT TYPE
Cost and Performance Summary

3. DATES COVERED *(From - To)*
Jan–Apr 07

4. TITLE AND SUBTITLE

COST AND PERFORMANCE SUMMARY FOR VALIDATION OF ALTERNATIVES TO HIGH VOLATILE ORGANIC COMPOUND SOLVENTS USED IN AERONAUTICAL ANTIFRICTION BEARING CLEANING

5a. CONTRACT NUMBER
WP-0305

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Environmental Security Technology Certification Program
901 North Stuart Street, Suite 303
Arlington, VA 22203

10. SPONSOR/MONITOR'S ACRONYM(S)
ESTCP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This demonstration and validation project evaluates a soybean oil derivative (SoyGold 1000) as an alternative to high VOC containing solvent for the rinsing of aeronautical antifriction bearings during DoD Depot level maintenance cleaning. Data analysis and interpretation are based on analytical test results as well as visual inspections performed on test bearings that were processed through the bearing cleaning process. Analytical test results are mixed. SG1000 passed all environmental, occupational, safety and health related tests, but failed a number of the materials compatibility tests including total immersion corrosion for a number of substrate materials, hydrogen embrittlement, nonvolatile residue, and nonvolatile residue with isopropyl alcohol rinse. SG1000 also failed the rinse efficiency test under performance related tests as well as the acidity test under chemical properties. Analytical test results did not meet the acceptance criteria to be qualified as an alternative to MIL-PRF-680 in the rinse step of the bearing cleaning process. During the demonstration, a nonvolatile residue resulted in a film that remained on the bearing surfaces. The demonstration results did not meet the defined acceptance criteria to be qualified as an alternative to MIL-PRF-680 in the rinse step of the bearing cleaning process. Overall SG1000 did not meet the acceptance criteria for analytical testing or the demonstration. SG1000 does not qualify as an alternative to MIL-PRF-680 in the bearing cleaning process.

15. SUBJECT TERMS
SoyGold 1000, SG1000, soybean oil derivative, alternate solvent, bearing cleaning, MIL-PRF-680

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Brad L Hollann
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
U	U	U	U	12	(805) 982-1320

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

EXECUTIVE SUMMARY REPORT
ESTCP Project: WP-0305

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ACRONYMS AND ABBREVIATIONS

APCD	Air Pollution Control District
ATC	U.S. Army Aberdeen Test Center
CAA	Clean Air Act
CAS	Clean Air Solvent
CHPPM	Center of Health Promotion and Preventative Medicine
DI	deionized
DoD	Department of Defense
ESTCP	Environmental Security Technology Certification Program
GC/MS	Gas Chromatography/Mass Spectrometry
g/L	grams per liter
HAP	hazardous air pollutant
IPA	isopropyl alcohol
JTP	Joint Test Protocol
KB	Kauri-Butanol
NADEP	Naval Aviation Depot
NAVAIR	Naval Air Systems Command
NEHC	Navy Environmental Health Center
NESHAP	National Emission Standards for Hazardous Air Pollutants
NFESC	Naval Facilities Engineering Service Center
QPL	Qualified Products List
RO	reverse osmosis
SCAQMD	South Coast Air Quality Management District
SG1000	SoyGold 1000
VOC	volatile organic compound

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ACKNOWLEDGEMENTS

This report was prepared by the Naval Facilities Engineering Service Center (NFESC) Pollution Prevention Technology Development Branch under Contract Number WP-0305 for the Environmental Security Technology Certification Program (ESTCP).

We wish to acknowledge the invaluable contributions provided by the following organizations involved in the creation of this document:

Naval Facilities Engineering Command
Naval Air Systems Command (NAVAIR)
Naval Aviation Depot (NADEP), North Island
Air Force Materiel Command
Air Force Research Lab
Air Force Warner Robins Air Logistics Center
U.S. Army Aberdeen Test Center (ATC)
U.S. Army Research Lab
U.S. Army Tank Automotive Research, Development, and Engineering Center
U.S. Army Aviation and Missile Command
National Defense Center for Environmental Excellence
Concurrent Technologies Corporation
AG Environmental Products L.L.C.
United Soybean Board

Technical material contained in this report has been approved for public release.

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1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

The use of solvents for cleaning various parts and equipment is widespread. Historically, Department of Defense (DoD) vehicle, equipment, aircraft, and ship maintenance activities have used petroleum-based solvents to remove dirt, grease, soot, and burned-on carbon. Most of these solvents contain photo reactive volatile organic compounds (VOC), which react with oxides of nitrogen to form ground-level ozone, the primary component of smog. Some solvents have been identified in the Clean Air Act (CAA) as potentially toxic compounds and are listed as hazardous air pollutants (HAP).

In recent years, DoD has increasingly relied on aqueous-alkaline cleaners to comply with emerging environmental regulations. However, these cleaners are not adequate for some applications, as they have been found to have material compatibility issues such as corrosion of metal surfaces and hydrogen embrittlement. Due to these limitations, DoD continues to use large quantities of petroleum-based solvent cleaners. With the environmental concerns related to petroleum-based solvent cleaners and performance issues of aqueous-alkaline cleaners, it is desirable to validate a new class of organic solvents. These environmentally friendly alternative solvents must be HAP-free, not contribute to emissions of VOC, and meet DoD material compatibility and performance criteria.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objective of this effort was to evaluate a low VOC, HAP-free, bio-based solvent for the rinse step of the aeronautical antifriction bearing cleaning process (Step 7 in Table 1). SoyGold 1000 (SG1000) was selected for the demonstration. This solvent, produced by AG Environmental Products, LLC, is a derivative of soybean oil.

Cleaning aeronautical antifriction bearings is a well-defined process that involves a sequence of steps that ensures appropriate bearing cleanliness. The current MIL-PRF-680 solvent-based bearing cleaning process includes demagnetization, preclean, degrease, carbon removal, hot water rinse, water displacing oil immersion, solvent rinse, drying, inspection, fingerprint neutralization, and preservation and packaging. Details of the bearing cleaning process are included in Table 1.

It is important to note that the objective of this demonstration was not to obtain a comprehensive DoD-wide replacement for MIL-PRF-680, Type II, but an evaluation of an alternative solvent for the specific task of rinsing aeronautical antifriction bearings during DoD depot-level maintenance cleaning.

Table 1. Solvent-Based Aeronautical Antifriction Bearing Cleaning Process for Used Bearings.

Stage	Function	Equipment	Material	Minimum Time Required
1	Demagnetize	Demagnetizer	None	30 sec
2	Preclean	Fluid agitated tank	MIL-PRF-6081 (1010) (180° F)	30 min
3	Degreaser	Fluid agitated tank	Xxcel XLS-52	As needed (5 min typical)
4	Carbon removal	Fluid agitated tank	Turco 5668 (140° F)	20-30 min
Optional	Ultrasonic agitation (optional step)	Ultrasonic tank	Turco Caviclean	5 min (maximum)
5	Rinse	Fluid agitated tank	Deionized (DI) or reverse osmosis (RO) water w/Turco Rust Bloc Inhibitor (176° F)	1 min
6	Water displacing oil	Fluid agitated tank	MIL-PRF-32033	3-5 min
7A	Rinse—Step 1	Fluid agitated tank	MIL-PRF-680 (filtered –100 μ)	5 min
7B	Rinse—Step 2	Fluid agitated tank	MIL-PRF-680 (filtered –50 μ)	5 min
7C	Rinse—Step 3	Fluid agitated tank	MIL-PRF-680 (filtered –10 μ)	5 min
8	Dry	Isopropyl alcohol dryer	Isopropyl alcohol	As required
9	Inspection	None	None	As required
10	Neutralize fingerprints	Fluid agitated tank	MIL-C-15074	5 min
11	Preserve/package	As required	As required	As required

1.3 REGULATORY DRIVERS

Emissions from organic solvents are regulated by both federal (40 CFR 51.100) and state air quality regulations. Local air quality districts also may establish regulations that are even more stringent than the state or federal limits. In California, the San Joaquin Valley Air Pollution Control District (APCD) has established regulations limiting the VOC content of degreasers at 50 grams per liter (g/L). South Coast Air Quality Management District (SCAQMD) has set even more restrictive limits of 25 g/L for degreasers using halogenated solvents. It is expected that other jurisdictions countrywide will promulgate similar limits.

CAA Title III, National Emission Standards for Hazardous Air Pollutants (NESHAP) National Emissions Standards for Aerospace Manufacturing and Rework Facilities, described in 40 CFR 63 Subpart GG, require the use of solvents with a vapor pressure less than 7mm Hg containing no HAPs.

Using MIL-PRF-680 solvent in open-tank parts washers will not meet these regulations. Compliance can be met by installing emission control equipment or by using alternative low VOC, HAP-free solvents. This demonstration attempts to qualify an alternative solvent for rinsing aeronautical antifriction bearings that is HAP-free, contains low VOC, and will allow continued use of open-tank parts washers without the addition of emissions control equipment.

1.4 TEST RESULTS

The alternative solvent was tested in three phases to evaluate the product's potential throughout the evaluation. Results from each phase were evaluated prior to proceeding to the next phase. Test methods, performance requirements, and acceptance criteria are clearly defined in the Joint Test Protocol (JTP) and Demonstration Plan. The complete JTP can be found in the final report for this project.

The acceptance criteria are the gauge used to determine whether the alternative solvent passes or fails the tests identified in the JTP. The alternative must pass all tests identified in the JTP and pass the demonstration/validation phase to qualify as an acceptable alternative to MIL-PRF-680 in the rinse step of the aeronautical antifriction bearing cleaning process. In addition, the Demonstration Plan also requires that any alternative solvent must meet all performance, compatibility, and safety requirements; be cost effective; and provide measurable environmental benefit.

1.4.1 Phase I Screening Test Results

Phase I screening of the alternative solvent included VOC, flash point, vapor pressure, Kauri-Butanol (KB), toxicity, and rinse efficiency tests. Testing was performed on new SG1000 product as well as SG1000 product that had been held in storage for approximately 1 year.

SG1000 product passed the VOC, flash point, vapor pressure, and toxicity screening tests but failed the KB and rinse efficiency tests as defined by the acceptance criteria in the JTP.

1.4.2 Phase II Analytical Test Results

Phase II analytical testing was performed using fresh SG1000 product and SG1000 product that had been held in storage for approximately 1 year. Test results for each are presented in the following sections.

1.4.2.1 <u>Phase II Analytical Test Results for Fresh SG1000 Product Material</u>

Phase II analytical tests included total immersion corrosion, stress corrosion, titanium stress corrosion, appearance, hydrogen embrittlement, acidity, nonvolatile residue, and nonvolatile residue with isopropyl alcohol (IPA) rinse. The JTP lists all Phase II analytical tests performed using fresh SG1000 product material and includes the specimen materials, coupon configuration, test method used, and acceptance criteria.

Results for total immersion corrosion tests using fresh SG1000 product material are mixed. A total of 21 materials were identified in the JTP to be included in the total immersion corrosion

tests. Of the 21 materials, 13 passed, six failed, and two were not included because the materials were no longer commercially available (have not been produced for several years).

The fresh SG1000 product material passed all stress corrosion tests. Twenty-two materials were identified in the JTP to be included in the stress corrosion tests. Eighteen passed the stress corrosion tests, one material was found to be a duplicate and eliminated; one was not able to be fabricated into the coupon configuration specified in the test method and was eliminated; and two were not included because the materials were no longer commercially available.

The fresh SG1000 product material passed the titanium stress corrosion and appearance tests but failed the hydrogen embrittlement, acidity, nonvolatile residue, and nonvolatile residue with isopropyl alcohol rinse tests.

1.4.2.2 Phase II Analytical Test Results for Stored SG1000 Product Material

Phase II analytical tests included total immersion corrosion, stress corrosion, titanium stress corrosion, appearance, hydrogen embrittlement, acidity, nonvolatile residue, and nonvolatile residue with isopropyl alcohol rinse. The JTP lists all Phase II analytical tests performed using SG1000 product material that had been held in storage for approximately 1 year and includes the specimen materials, coupon configuration, test method used, and acceptance criteria.

Results for total immersion corrosion tests using stored SG1000 product material are mixed. Twenty-one materials were identified in the JTP to be included in the total immersion corrosion tests. Fifteen passed, four failed, and two were not included because the materials were no longer commercially available.

The stored SG1000 product material passed all stress corrosion tests. Twenty-two materials were identified in the JTP to be included in the stress corrosion tests. Eighteen passed the stress corrosion tests; one material was found to be a duplicate and eliminated; one was not able to be fabricated into the coupon configuration specified in the test method and was eliminated, and two were not included because the materials were no longer commercially available.

The stored SG1000 product material passed the titanium stress corrosion and appearance tests but failed the hydrogen embrittlement and acidity tests. Nonvolatile residue and nonvolatile residue with isopropyl alcohol rinse tests for the stored product were not required by the JTP and were not performed.

1.4.2.3 Phase II Toxicity Clearances

In addition, the Navy Environmental Health Center (NEHC) and the U.S. Army Center for Health Promotion and Preventative Medicine (CHPPM) performed toxicity evaluations to identify any occupational safety and health risks associated with worker exposure. These evaluations are performed and clearances are conditionally approved based on the solvent application or use condition. Clearance for any potentially hazardous product to be used by the DoD is granted or denied independently by each Service.

An administrative health hazard assessment of SG1000 was performed and clearance was granted on May 16, 2005, by NEHC. A toxicological evaluation of SG1000 was conducted and a toxicity clearance was granted on February 23, 2005, by CHPPM approving SG1000 as a degreaser. An additional toxicity clearance was also granted by CHPPM on January 31, 2006, approving SG1000 as a cleaner.

It should be noted that these assessments were "paper studies" and that no analytical testing was performed by NEHC or CHPPM. Assessments were based on Material Safety Data Sheets and product literature provided by the SG1000 manufacturer.

1.4.3 Phase III Demonstration/Validation Test Results

The Phase III demonstration and validation portion of this project evaluated SG1000 as an alternative to MIL-PRF-680 for rinsing aeronautical antifriction bearings during DoD Depot-level maintenance cleaning. The demonstration was performed at the Naval Aviation Depot (NADEP) North Island bearing cleaning shop and was designed to duplicate the normal bearing cleaning process as specified in the tri-service technical manual *Maintenance of Aeronautical Antifriction Bearing Cleaning for Organizational, Intermediate, and Depot Maintenance Levels (NAVAIR 01-1A-503, TM55-1500-322-24, T.O. 44B-1-122)*. Henceforth, this document will be referred to as the *Bearing Cleaning Technical Manual*. Section 5 of the manual prescribes the cleaning procedures, equipment, methods, and solvents required to accomplish the bearing cleaning process.

There are no established analytical testing methods used during the bearing cleaning process to determine cleanliness. Bearing cleanliness is determined through visual inspections performed by the bearing artisans during the cleaning process. The demonstration test results are therefore qualitative rather than quantitative. However, quantitative data collected during Phase II analytical testing supports qualitative results observed during the Phase III Demonstration.

During the Demonstration Phase, it was found that SG1000 solvent successfully removed the chemical agents used to clean the bearings prior to the rinse step of the bearing cleaning process. On close examination, bearing inspectors noted that for both MIL-PRF-680 and SG1000 processed bearings some residual grease and thickeners remained in the crevices and difficult areas of the bearings. The amount of residual grease varied with the type of grease applied and was virtually the same for either rinse process.

For example, bearing Series-2, was contaminated with MIL-PRF-27617 grease. Inspector notes report that both MIL-PRF-680 and SG1000 rinsed bearings contained "negligible" remaining grease. For bearing Series-6, which was contaminated with Rheotemp 500 grease, inspectors note that both MIL-PRF-680 and SG1000 rinsed bearings contained "some" residual grease.

The amount of residual grease varied with grease type but was virtually independent of the rinse process. This observation is logical as grease type and formulation was purposely not the same for each bearing series. Some grease was heavier and more substantial than others and therefore more difficult to remove. Since both the MIL-PRF-680 and SG1000 rinsed bearings were cleaned for the same amount of time using the same cleaning agents, it is expected that the level of cleanliness achieved prior to the rinse step would be the same.

Bearings processed using MIL-PRF-680 in the rinse step were found to be cleaner than those processed using SG1000. MIL-PRF-680 is clearly a better solvent that SG1000. Rinse efficiency tests performed during the analytical testing found that SG1000 had a low solvent cleaning power of 30% as compared to 85% solvency for MIL-PRF-680. Theoretically, bearings should be completely clean prior to entering the rinse step of the bearing cleaning process. However, many of the greases and thickeners are difficult to remove, and on occasion, not all of the material is removed during the cleaning steps of the bearing cleaning process. Bearings may be returned for additional soak or agitation time in the previous cleaning stages. In the bearing cleaning process, small amounts of grease that remain in the crevices and difficult areas of the bearings are further removed during the agitation of the rinse step using MIL-PRF-680. The three-stage MIL-PRF-680 rinse provides additional cleaning capability in addition to removing the bearing cleaning chemicals. The SG1000 rinse step does not provide this additional cleaning capability due to low solvent cleaning power identified during analytical testing.

Bearing inspectors also noted that a slight noticeable film remained on the bearing surfaces after the IPA rinse in all but two of the SG1000 bearing series. The MIL-PRF-680 rinse left no noticeable film on the bearing surfaces. This observation was quantified during nonvolatile residue and nonvolatile residue with IPA rinse tests that were performed during Phase II analytical testing. SG1000 failed both the nonvolatile residue and nonvolatile residue with IPA rinse tests. MIL-PRF-680 passed both the nonvolatile residue and nonvolatile residue with IPA rinse tests.

Based on the SG1000 demonstration, the NADEP North Island bearing inspector and materials engineer concluded that SG1000 *does* meet the minimum requirements to be used as an acceptable replacement for MIL-PRF-680 as a rinse agent in the bearing cleaning process. These conclusions and comments address nonvolatile residue left on bearing surfaces but do not address material compatibility issues or other acceptance criteria related to analytical tests performed during Phase I and Phase II. NADEP North Island conclusions and comments regarding the results of the demonstration phase are included in their test report dated January 19, 2006, which is included in Appendix E of the Final Report for this effort.

The JTP defines the acceptance criteria for all phases of the effort, including the Phase I screening tests, the Phase II analytical tests, and the Phase III demonstration. The detailed acceptance criteria specified in the JTP was developed by a joint group led by the NFESC and consisted of technical representatives and process stakeholders that identified engineering performance and testing requirements for aeronautical antifriction bearing cleaning. This group reached consensus on the test conditions and acceptance criteria to qualify alternatives against critical, technical, and performance requirements.

The JTP specifies that SG1000 must meet all acceptance criteria and perform as well as or better than MIL-PRF-680 in all phases of the demonstration to be considered a success. Demonstration results clearly indicate that SG1000 does not perform as well as MIL-PRF-680 in the rinse step of the bearing cleaning process. Nonvolatile residue results in a film remaining on the bearing surfaces. In addition, SG1000 failed several of the analytical tests performed in Phase I and II, which also indicate that SG1000 does not perform as well as MIL-PRF-680. The SG1000

demonstration results do not meet the defined acceptance criteria to qualify as an alternative to MIL-PRF-680 in the rinse step of the bearing cleaning process.

1.5 STAKEHOLDER/END-USER ISSUES

All DoD activities are under increasing pressure to reduce VOC and HAP emissions from component cleaning lines. Unfortunately, many of the alternative solvents do not meet performance requirements or they produce undesirable side effects such as flash corrosion or hydrogen embrittlement. Any alternative solvent must meet all performance, compatibility, and safety requirements, be cost effective, and provide measurable environmental benefit.

SG1000 is produced by AG Environmental Products, LLC and is a derivative of soybean oil. AG Environmental Products, LLC was granted the SCAQMD Clean Air Solvent (CAS) certificate for SG1000 in May 2000. Analysis was performed by the SCAQMD Laboratory using the most recent version of SCAQMD Method 313, *Determination of Volatile Organic Compounds (VOC) by Gas Chromatography/Mass Spectrometry (GC/MS)*. This specification is described in the SCAQMD Clean Air Certification Protocol Planning Rule Development and Area Sources document dated September 2003. To be awarded the CAS certificate, the solvent must not contain more than 25 g/L VOC, and is used to perform solvent cleaning, finishing, or surface preparation operations.

Company product testing has also demonstrated that SG1000 is readily biodegradable, nontoxic, has low evaporative emissions (less than 0.0005 at 76° F relative to an n-butyl acetate rating of 1), has a “normal” health rating, a flash point above 200° F, and is reactively stable. This would indicate that it is excellent solvent from an emissions and safe-to-use standpoint for use in the bearing cleaning operation.

For any solvent to be qualified as an alternative to MIL-PRF-680 in the bearing cleaning process, it must meet the rinsing requirements of the process and meet all environmental, occupational safety, health, chemical properties, materials compatibility, and performance requirements defined in the JTP and Demonstration Plan. If successful, the alternative could be substituted for MIL-PRF-680 in the rinse step of the aeronautical antifriction bearing cleaning process at all DoD depots.

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2.0 COST ASSESSMENT

2.1 COST REPORTING

The objective of this effort was to evaluate and demonstrate SG1000 as a drop-in replacement for MIL-PRF-680 solvent in the aeronautical antifriction bearing cleaning process. Implementing a drop-in replacement would require minimal capital investment. Holding tanks for virgin and spent alternative solvent material are the only significant capital that would be required. Existing bearing cleaning parts washers, pumps, filtration, and piping systems would not be replaced. Minor components such as pump seals, filtration system seals, and filter elements would have to be replaced with product compatible materials. Differences in solvent cost and hazardous waste disposal fees would also be included in the overall cost of implementing any drop in replacement.

2.2 COST ANALYSIS

A detailed cost analysis was not performed because the demonstration solvent material did not meet the acceptance criteria defined in the JTP.

2.3 COST COMPARISON

A cost comparison was not performed because the demonstration solvent material did not meet the acceptance criteria defined in the JTP.

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3.0 IMPLEMENTATION ISSUES

3.1 ENVIRONMENTAL PERMITS

The JTP specifies that the alternative solvent material must be HAP-free and contain less than 50 g/L VOC, be VOC-exempt, or be a SCAQMD certified CAS. These requirements were selected to facilitate the use of the alternative solvent material in the aeronautical antifriction bearing cleaning process without any environmental permits.

3.2 OTHER REGULATORY ISSUES

Emissions from organic solvents are regulated by both federal (40 CFR 51.100) and state air quality regulations. In addition, local air quality districts may also establish regulations that are even more stringent than the state or federal limits. In California, the San Joaquin Valley APCD has established regulations limiting the VOC content of degreasers at 50 g/L. SCAQMD has set even more restrictive limits of 25g/L for degreasers using halogenated solvents. It is expected that other jurisdictions countrywide will promulgate similar limits.

CAA Title III, NESHAP National Emissions Standards for Aerospace Manufacturing and Rework Facilities, described in 40 CFR 63 Subpart GG, require the use of solvents with a vapor pressure less than 7mm Hg that contains no HAPs.

Using MIL-PRF-680 solvent in open-tank parts washers will not meet these regulations. Compliance can be achieved by using alternative low VOC or HAP-free solvents or by installing emission control equipment. This demonstration attempted to qualify an alternative solvent for rinsing aeronautical antifriction bearings that is HAP-free, contains low VOCs, and will allow continued use of open-tank parts washers without the addition of emissions control equipment.

3.3 SCALE-UP

The demonstration solvent material did not meet the acceptance criteria defined in the JTP and will not be implemented.

3.4 OTHER SIGNIFICANT OBSERVATIONS

Materials compatibility and performance are the major factors that affect implementation of any alternative solvent material for the aeronautical antifriction bearing cleaning process. Because this is a critical process, the alternative solvent must be evaluated carefully to eliminate products that may result in materials compatibility or performance issues. However, it is also as important to gauge the success or failure of the alternative with a reasonable set of acceptance criteria. The process stakeholders must be fair when developing the JTP and defining the acceptance criteria to include only those parameters that are absolutely necessary. Tests and acceptance criteria must be thoroughly scrutinized to determine if they are reasonable and necessary requirements.

3.5 LESSONS LEARNED

The demonstration solvent material did not meet the acceptance criteria defined in the JTP and will not be implemented.

3.6 END-USER/ORIGINAL EQUIPMENT MANUFACTURER ISSUES

As previously stated, SG1000 did not meet the acceptance criteria for several of the tests prescribed in the JTP. The solvent left a visible film on bearing surfaces that was observed during bearing inspection at the end of the bearing cleaning process. Product reformulation may eliminate this problem but would not likely eliminate problems such as hydrogen embrittlement and corrosion issues that were identified during analytical testing. It should also be noted that any product reformulation would require that *all* tests identified in the JTP be repeated.

The stakeholders of the bearing cleaning process identified the analytical tests to be performed and defined the acceptance criteria for each test that any alternative solvent must meet to qualify as a replacement in the rinse step of the bearing cleaning process. The end users are authorized to use only products that have been approved by the process stakeholders and that are on the Qualified Products List (QPL). SG1000 did not meet these criteria and therefore will not be added to the QPL for the aeronautical antifriction bearing cleaning process.

3.7 APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE

The reason for selecting the demonstration solvent material was to allow continued use of open-tank parts washers in the bearing cleaning process without the addition of costly emissions control equipment. The approach was to qualify a HAP-free, low VOC solvent material to eliminate compliance issues associated with the current MIL-PRF-680 solvent material. The SG1000 product selected for the demonstration is HAP-free and was granted the SCAQMD's CAS certificate in May 2000.

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APPENDIX A

POINTS OF CONTACT

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