

NON ODC AIRCRAFT OXYGEN LINE CLEANING SYSTEM

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ABSTRACT

Tinker Air Force Base, OK, in conjunction with the Environmental Security Technology Certification Program (ESTCP) and the Joint Group on Pollution Prevention (JG-PP) coordinated efforts with Versar Inc., in regard to pollution prevention issues identified during a defense system's acquisition process. The primary objectives of this task were to reduce or eliminate the use of CFC-113, a Hazardous Material (HazMat), and to avoid duplication of efforts in action required to reduce or eliminate HazMats through joint service cooperation and technology sharing. The Scope of work was to design, develop and construct a prototype oxygen line cleaning system (POLCS), and cleaning process, to precision-clean the critical life support oxygen distribution system for the Air Force B-1B weapon system (and other aerospace vehicles) while all equipment and tubing remains installed onboard the aircraft. The POLCS design will provide the Air Force with a suitable and applicable fluid system that will meet or exceed special operation and cleanliness requirements in accordance with Government and non-Government documents for maintaining on-board aerospace vehicle oxygen tubing. This effort also included testing, troubleshooting and the validation of a selected solvent solution on various aerospace vehicles using the POLCS. Laboratory testing began in October 1999; field-testing was conducted during fall 2001.

INTRODUCTION

The specific problem motivating replacement of many chlorofluorocarbon (CFC) solvents is their effect on ozone. Depletion of ozone layer in the upper atmosphere increases the intensity and range of harmful radiation transmitted to the earth surface. For this reason, the use of chemicals with known ozone depleting potential (ODP) is being phased out of industrial and commercial use. Although CFC's are still in limited commercial use, the Montreal Protocol phased out their production by year 2000, and Executive Decision Number 12856 has tasked the United States Air Force, as well as other government agencies, to identify a cleaning solvent to replace CFC-113, which is currently used for cleaning oxygen system of all military aircrafts.

Of the many manufacturing and processing activities affected by this decision, one has been the cleaning of oxygen distribution lines and storage systems in several military aerospace vehicles. Tinker Air Force Base (AFB), Oklahoma, in conjunction with Environmental Security Technology Certification Program (ESTCP) and the Joint Group for Pollution Prevention (JG-PP), coordinated efforts with Versar, Inc. to identify a suitable solvent system that can eliminate the use of CFC-113 for this application. Furthermore, by sharing technology through joint service cooperation, duplication of effort in actions required to reduce or eliminate the CFC-113 is avoided.

BACKGROUND

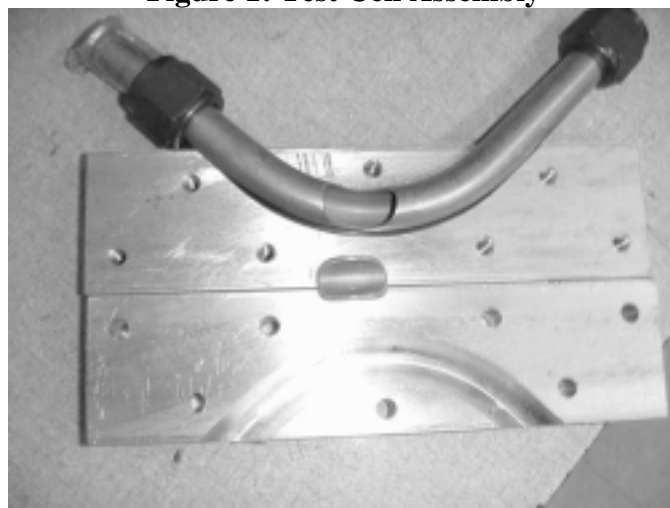
OXYGEN LINES

The oxygen lines on-board military aircraft consist of a series of tubing that are connected between a Liquid Oxygen (LOX) converter, low or high pressure cylinders, or Molecular Sieve Oxygen Generating (MSOG) system and an oxygen regulator. The regulator is connected to the oxygen mask of the crewmember. Many oxygen system components (i.e., pressure transducers, pressure relief valves, check valves, toggle switches...etc.) are placed strategically between the LOX converter, cylinder, or MSOG unit and the masks. The first objective of the project was to identify materials used within these components (metals, elastomers and plastics) and to find a solvent that causes minimal changes to these materials. The second objective was to design, develop and construct a Prototype Oxygen Line Cleaning System (POLCS) flexible enough to meet the cleaning requirements of all oxygen line systems (smallest to the largest).

The initial focus was to create a system that would successfully clean B1-B oxygen lines without costly removal of the lines. Potential risks involved with cleaning an actual B1-B aircraft initiated an effort to design and construct a full-scale replica of the B1-B oxygen system. This allowed experimental testing which was used to verify and validate that the POLCS can successfully clean all areas within the oxygen lines.

The replica of B1-B system was also used to determine whether the previous test data for flow velocity and fluid composition was accurate and reproducible and to establish whether the system was capable of effectively removing particulates that have the strongest adhesion to the surface of the lines. Test cells were designed and constructed to visually qualify the cleaning ability of the solvent. A picture of a test cell is shown in Figure 1. After it was established that the POLCS could successfully clean the replica unit, the POLCS was used to clean the oxygen lines on an actual B1-B aircraft.

Figure 1: Test Cell Assembly



CONTAMINATION (Problems)

It is known that particulates and non-volatile residues (NVR) in oxygen systems can cause significant hazards to aircraft and harm to personnel. Particulates may include, but are not limited to, metal shavings, Teflon tape, and dust. NVR can range from Krytox greases to hydraulic oils. Particulates impinging on surfaces of concentrated oxygen streams can be a source of ignition and fire on military aircraft. Contaminates can plug pressure relief valves or foul regulators and result in system malfunctions, or even worse, catastrophic failure. Particulates can also pose a significant threat to the health of personnel in oxygen systems, as emphasized in EPA's revised guidelines for particulate matter. Personnel with health problems and/or aircraft malfunctions can lead to mission degradation, loss of combat readiness and, in some instances, loss of aircraft and/or personnel. In today's environment of pollution minimization, regular maintenance on these aircraft life support systems must incorporate environmentally acceptable solvents and processes that are efficient, yet safe to humans and the environment.

MATERIALS (Previous Studies)

The initial concept of this project was to combine the cleaning properties of a solvent and surfactant. However, laboratory testing had shown that using an adequate solvent and sufficient flow velocity would result in adequate cleaning without the introduction of additional chemicals into an aircraft system. The results of our early studies involving a solvent/surfactant solution are described in this section.

Surfactant Associates Inc. conducted primary studies for the solvent/surfactant selection for the POLCS. They identified three fluorosurfactants and five fluorosolvents (three perfluorocarbon solvents and two hydrofluorocarbon solvents) based on their ability to enhance particle removal. In their studies, they evaluated and compared the baseline fluid, CFC-113, to the above fluorosolvent and fluorosurfactants. Their studies showed that any of the solvent surfactant solutions far exceeded the cleaning ability of CFC-113. The three surfactants identified as test candidates were Krytox Alcohol (a nonionic fluorosurfactant), Zonyl UR (an anion fluorosurfactant) and Krytox 157 FSM (a nonionic fluorosurfactant). The perfluorocarbons tested in their study were FC-72, FC-77, and FC-43. The hydrofluorocarbon solvents tested were HFE 7100 and HFC-236 FA. All of the solvents and surfactants were made available by 3M or Dupont.

The contaminated sample surfaces were characterized using scanning electron microscopy (SEMs). These surfaces were initially marked to allow re-examination of the same area for direct comparison both before and after cleaning. Their results indicated that HFE 7100 was the appropriate solvent. The solvent is essentially non-toxic, non-flammable, non-ozone depleting, non-aqueous, and resistant to thermal breakdown which are all characteristics needed in oxygen service equipment. HFE-7100 has been tested and is LOX compatible.

The solvent/surfactant solution recommended for replacing CFC-113 was a mixture of the **solvent**, hydrofluoroether (HFE-7100) made by 3M, and the **surfactant**, Krytox

alcohol (Hexafluoropropylene Oxide Homopolymer Alcohol) made by Dupont. The solvent and the surfactant are both fluorocarbons. A fluorocarbon compound has all its hydrogens on its carbon backbone replaced by fluoride. Fluorocarbons are unique in having the lowest surface tensions of any fluid. This allows the fluorocarbon molecules to quickly wet surfaces and penetrate pores and cracks that exist between particles and their supporting substrate. By lowering the surface tension, less energy is required to remove particles that have adhered to the surface. The force to remove the particles is supplied by passing a high velocity solvent/surfactant mixture across the contaminated surface. Prior testing has shown that the required velocity (energy) to overcome particulate adhesion forces is reduced with addition of a fluorosurfactant.

ADDITIONAL TESTING

Versar Inc. used the test data from earlier work by Surfactant Associates Inc. as a starting point to identify an optimum solvent/surfactant combination and flow velocity to target the worst realistic oxygen line contaminate and focus on its removal. The reason being that if the worst contaminate can be detached with acceptable results, the other contaminates will easily be removed. To identify the worst-case contaminant, hundreds of fluid velocity tests were conducted using various contaminates and solvent/surfactant mixtures.

These tests were conducted implementing a Waukesha model 60 positive displacement pump with a variable frequency drive to adjust the flow rate. A Hedland Flow meter with a range of 0 to 50 gallons-per-minute was implemented to observe the flow rate. A Test Cell was constructed to qualify the cleaning efficiencies of the solvent/surfactant solutions. In order to document results of solvent/surfactant cleaning using the Test Cell technology, a Sony Digital Camera was used to store images. Figures 2 & 3 show before and after cleaning using HFE-7100.

Figure 2: Before Cleaning



Figure 3: After Cleaning with HFE 7100



The results of the evaluations performed to identify the worst-case contaminant are provided in table 1.

Table 1: Average Flow rate required remove contaminates using HFE 7100

Contaminates	Solvent & 0.05 wt% Krytox	Flow Rate liter/min	Flow Time (Minutes)	Cleaning Efficiency (Range)
Hydraulic Oil & A.C. Fine Test Dust	HFE 7100	10	15	85 to 100 Percent
Hydraulic Oil & Powdered Zeolite	HFE 7100	10	15	85 to 100 Percent
Hydraulic Oil & A.C. Fine Test Dust	HFE 7100	10	15	85 to 100 Percent
Krytox Grease & Powdered Zeolite	HFE 7100	10	15	85 to 100 Percent
Krytox Grease & A.C. Fine Test Dust	HFE 7100	10	15	85 to 100 Percent
Acetone & Powdered Zeolite	HFE 7100	14	15	85 to 100 Percent
Acetone & A.C Fine Test Dust	HFE 7100	18.5	15	85 to 100 Percent
HFE-7100 & Powdered Zeolite	HFE 7100	14	15	85 to 100 Percent
HFE-7100 & A.C Fine Test Dust	HFE 7100	18.5	15	85 to 100 Percent
Tap Water & Powdered Zeolite	HFE 7100	16	15	85 to 100 Percent
Tap Water & A.C Fine Test Dust	HFE 7100	56	15	85 to 100 Percent
Distilled Water & Powdered Zeolite	HFE 7100	16	15	85 to 100 Percent
Distilled Water & A.C Fine Test Dust	HFE 7100	56	15	85 to 100 Percent

Results of these tests identified that the greases and hydraulic oils required the least amount of energy (flow rate) for removal. The most adhesive compound is a mixture of distilled water and A.C. Fine Test Dust from the Duke Scientific Company. Since this compound was the most difficult to remove, it became the target contaminate of the cleaning process. Flow rates were varied through a 5/8” test cell ranging from 2 to 20 gallons per minute for 10 to 20 minutes. Surfactant concentration varied from 0.05 to 0.15 wt. Percent. Data results indicated that the optimum concentration to-date was a ratio of 0.05 wt. percent surfactant in the solvent mixture and a flow rate of 56 liter per min in 5/8” line for 15 minutes.

In order to reduce the risk of inserting additional chemicals into an aircraft oxygen system, then having to remove it, further testing was accomplished using the HFE-7100 solvent alone for cleaning. Testing proved that similar and adequate cleaning could be achieved using the solvent alone with a flow velocity of 18-20 feet per second. A solvent/surfactant solution works well for some applications, but the addition of a surfactant only complicates the removal verification process and increases the risks involved in cleaning a human breathing system such as onboard an aircraft. From this stand point it was determined to operate the system with solvent only for the purpose of cleaning aircraft oxygen systems, while maintaining surfactant capability for other potential applications.

PROTOTYPE OXYGEN LINE CLEANING SYSTEM (POLCS)

DESIGN AND CONSTRUCTION PARAMETERS

The POLCS was constructed for testing and evaluation. The system is designed to meet or exceed the cleaning ability of CFC-113. To verify cleanliness levels, an in-line particle counter is implemented, and laboratory proof of concept test procedures have validated the removal of non-volatile residues. Safety and efficiency of the cleaning process is improved by fully automating the system and by distilling the solvent so that it can be reused for future cleanings. By recycling the solvent, a substantial amount of cost saving is realized. The process can also be modified to recycle a surfactant, if used, by implementing an in-line filtration unit. The filtration unit would separate the particulates from the surfactant molecules and organic materials (non-volatile residues). The surfactant must be periodically checked to assure that the accumulation of non-volatile residues does not exceed a specified level.

Another design parameter for the POLCS was to be fully transportable and operable in climatic conditions ranging from 40 to 120 °F (target). The system was designed with dimensions to fit in a trailer measuring 12' (long) x 7' (width, fender to fender) x 7' (high), with all sides having fold up or open panels for ease of maintenance and operation.

At this time, the POLCS prototype construction is complete and testing has been conducted on the B-1B, F-15, F-16 and C-130 aircraft. The design drawings are complete and the POLCS is a fully functional unit ready for implementation on an aircraft production line. Software programming was accomplished using National Instrument LabView graphical software language. The libraries and functions of this software are specifically designed for data acquisition and instrument control.

PROCESS DESCRIPTION

The cleaning process begins by connecting the lines on the POLCS to oxygen lines on board the aircraft. The aircraft oxygen supply unit is disconnected to provide a plumbing entry point. Oxygen regulators or devices at the end of the branch lines are disconnected as plumbing exit points. To check for leaks, the lines are first pressurized with dry air. This ensures that there will be no solvent loss during the cleaning process. Then a vacuum is applied to ensure a uniform vacuum is applied throughout the system to allow complete removal of solvent after the cleaning process. If the leakage rate is within acceptable guidelines, the cleaning process begins. If not, the location of the leakage must be identified and eliminated prior to starting the cleaning process. The next step is to pump solvent (without the surfactant) into the oxygen lines. The solvent is then circulated through each individual flow path for several minutes. A filter is used in the circulation loop to capture any particulates removed from the system. After the wash cycle is complete, a rinse cycle commences with fresh, pure solvent to insure no contaminant residue is left behind. A sample from the rinse cycle effluent is analyzed with an in-line particle counter. If the appropriate cleanliness level has not been achieved, the computer will initiate a series of steps to re-clean the lines. If the lines meet the cleaning criteria, the process continues with the evaporation cycle. The evaporation cycle consists of applying vacuum to vaporize the remaining solvent from the oxygen lines. Laboratory tests have shown that no detectable quantities of solvent remain in the system at pressures below 0.50 psia. The evacuation cycle continues until

the system pressure has remained below 0.30 psia for five minutes. Upon completion of the evaporation cycle, the dry air purge begins. Dry air flows through the lines for at least 10 minutes. The dry air is then sampled by a halogen detector to measure the quantity of solvent vapor in the dry air stream. If the solvent concentration is above 40 parts per million, the dry air continues to flow through the system until a reading of less than 40 parts per million is achieved. If the solvent level is below 40 parts per million, the cleaning process is complete.

The LabView software program allows the operator to view (on the touch screen monitor) the cleaning cycles, the cycle time, and the cleanliness levels. It also alerts the operator of any problems that may occur and guides the operator (on screen) as to how to correct the problem. When the oxygen lines have been cleaned to an acceptable level, the program starts the distillation cycle to purify the solvent for future use.

This entire cleaning process can be carried out by one operator in less than four hours for an aircraft the size of the B1-B. It is our estimate that the oxygen lines on a B-1 aircraft can be cleaned for less than \$2500. Larger aircraft with more outlets will require a longer time to clean. A manifold must be constructed specifically for the number of outlets on the aircraft being cleaned to regulate the velocity and flow paths of the cleaning fluid. A CD containing software-programming information will be provided for a specific aircraft type to control flow velocities and the operational sequence.

CONCLUSION

Once the Oxygen Line Cleaning system is validated and fielded, we are expecting to realize several benefits in the oxygen-cleaning arena. First and foremost, we will drastically reduce the amount of CFC-113 currently used in cleaning aircraft oxygen equipment and lessen the Air Force's dependence on the ODS. Secondly, laboratory testing has shown that the solvent cleans better than CFC-113. A third benefit is dramatic cost savings realized by not requiring the dismantling of contaminated aircraft in order to accomplish a complete system cleaning. The POLCS is estimated to save approximately \$1,000,000 in labor and materials for each contaminated B-1 aircraft cleaned. We believe additional savings will be realized by increased reliability and by reducing system component failures due to particulate impacts once significant numbers of aircraft oxygen systems have been properly cleaned. This should reduce component failure rates for all weapon systems that employ this cleaning method.

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BIOGRAPHY

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Mr. Herrington is retired from the United States Air Force after serving 20 years active duty. During his tenure, he amassed skills in aircraft maintenance technology, served as an aircraft crewmember, and acquired 10 years experience as a logistics program manager. Immediately following his Air Force Career, Mr. Herrington served 3 years as a project manager for the Joint Group on Pollution Prevention, located at HQ AFMC, Wright-Patterson AFB, OH. For the past year, he has been working for Versar Inc. as a Senior Logistician in order to finalize the Non-ODC Aircraft Oxygen Line Cleaning Project and work toward its implementation in the Air Force and industry.

Mr. Herrington holds an AS Degree in Aircraft Maintenance Technology, and is a government certified acquisition professional in Program Management and Acquisition Logistics. He has attained a vast array of technical and managerial knowledge and certifications in numerous Air Force schools, and also completed numerous logistics courses at the Air Force Institute of Technology.