COST, OPERATIONAL READINESS, AND ENVIRONMENTAL BENEFITS FOR THE REUTILIZATION OF USED HYDRAULIC OIL

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ABSTRACT

The U.S. Army, in cooperation with industry, recently developed and demonstrated a methodology for returning used hydraulic fluid to vehicle service. The effort was conducted in three phases: First, a laboratory investigation to determine the viability of restoring used fluid to military specification performance. Second, a field investigation designed to identify commercially available equipment that could successfully process the used fluid and also demonstrate the performance of the restored fluid in military vehicles. Third, the Army entered into Cooperative Research & Development Agreements (CRADA's) with commercial companies that manufacture the certified hydraulic oil recyclers to test on-line diagnostics aimed at automating and optimizing the process.

Under the aegis of the afore mentioned CRADA, industry developed technology that automates the process of restoring used hydraulic fluid to military specification performance. Testing and demonstration results indicate that the process of restoring used hydraulic fluid can be automated to require less labor and eliminate possible incomplete restoration. This paper briefly explains the recommended process developed by the Fuels and Lubricants Team as presented in the "User's Guide For Recycling Military Hydraulic Fluid". Recent military implementation of hydraulic oil restoration programs, studies, and field demonstrations within the U.S. Army, Navy, and Air Force are discussed.

The on-site reutilization of used hydraulic fluid with a certified hydraulic oil recycler can have a significant impact on meeting pollution prevention goals. The benefits include reduced fluid disposal costs, reduced procurement costs for new fluid, increased operational readiness, increased durability of systems, and an uncomplicated avenue for conservation of natural resources. Procedures and certifications for this program are now in place. The implementation of a hydraulic oil recycling program will save Millions of dollars per year for each of the U.S. military services, as well as contribute to operational readiness.

1.0 LABORATORY INVESTIGATION

The approved methodology of returning used hydraulic fluids to Mil-spec performance, developed jointly by the Army and industry, involves the removing of contaminants from the fluids and revitalizing fluid additives. Field investigations have shown that the most common reason for used hydraulic fluid being drained from vehicles and discarded is because it has become contaminated to such a degree that damage to the hydraulic system could result. Laboratory studies have determined that even though the hydraulic fluid may be heavily contaminated, its ability to perform has not been lessened. Analysis during the laboratory phase of this effort revealed that used MIL-H-46170 fluid (FRH) retained nearly all of its required performance capabilities, i.e. viscosity, corrosion protection, etc. The used fluid exhibited satisfactory performance in all but low temperature stability, water content, foaming characteristics, fire point, particle count, and evaporation loss. By removing the contaminants, laboratory studies have shown that the fluid properties can be restored to as good or better than MIL-specification requirements, except for in some cases, the foaming characteristics.

TABLE 1: Specification Requirements and Analysis of Used & Recycled Fluid

TEST	REQUIREMENTS	USED FRH	RECYCLED FRH
Oxidation Stability	PASS	PASS	PASS
Rust Protection	100 hours	PASS	PASS
Galvanic Corr	10 days	PASS	PASS
Low Temp Stab	PASS	FAIL	PASS
Viscosity @ -40° C	< 2,600 cSt	2506 cSt	2494 cSt
Viscosity @ 40 °C	< 19.5 cSt	15.7 cSt	16.4 cSt
Viscosity @ 100°C	> 3.4 cSt	3.8 cSt	4.2 cSt
Pour Point	< -54 °C	< -60 °C	< -60 °C
Flash Point	>218 °C	211 °C	208 °C
Fire Point	> 246 °C	233 °C	224 °C
Water Content	< 500 ppm	728 ppm	278 ppm
Foaming	< 60/0 ml	80/0, 30/0, 60/0	90/0, 30/0, 60/0
4 - Ball Wear	< 0.65 mm	0.382 mm	0.355 mm
Acid Number	< 0.20	0.25	0.15
Particle Count	<10,000 <250 <50 <10	127,347 32 2 0	1,257 19 1 0
Evaporation Loss	< 5%	5.95%	4.36%
Elastomer Swell	15% - 25%	21%	18%

It is essential that particulate and water contamination be removed from used fluid, because contamination can lead to premature wear as well as possible malfunction of hydraulic components. Particulate contamination has been shown to cause pump wear, valve spool sticking, seal wear, cylinder scoring, and erosion of system components. Particulate contamination can be removed from used hydraulic oil to prevent these problems and return the hydraulic fluid to its original performance specification levels.

Water can prove to be a very damaging contaminant in a hydraulic system. The presence of water can lead to decreased lubricity, viscosity, load-carrying ability, and dynamic film thickness; as well as cause acid formation. Free water in hydraulic systems that experience low temperatures (below the freezing point of water) can degrade system performance and cause malfunctions due to formation of ice crystals. Water contamination can be removed from used hydraulic fluid to prevent these actions and return the hydraulic fluid to specification performance levels.

During the laboratory testing phase, one concern was the occasional foaming of used hydraulic fluid. This can be attributed to the depletion of anti-foaming additives over long term use. It is this loss of foaming resistance in the fluid that prevents simple removal of contaminants from being the only treatment required to restore the used fluid to like new condition. In order to restore the used fluid to service, additional anti-foaming additive is required. Virgin hydraulic fluid contains less than 0.1% anti-foaming agent. Trying to blend very small amounts of additional additives into the used fluid outside a laboratory or manufacturing facility is not a viable technique for the soldier. Thus another solution was required in order to reuse waste hydraulic fluid. The Fuels and Lubricants Technology Team determined that the addition of new hydraulic fluid in the appropriate amount was sufficient to restore decontaminated, used fluid to specification performance. After an investigation into the optimum amount of new fluid to mix with used fluid, a mixture of 25% new fluid with used fluid freed of water and particulate contaminants exhibited satisfactory performance.

2.0 FIELD INVESTIGATION

The second phase of the hydraulic oil recycling effort involved identifying and/or developing commercial technology that would satisfactorily remove the contaminants from the military hydraulic fluid, without altering the physical and chemical properties of the reconditioned fluid. While a variety of technologies exist to clean up used oils in the commercial world, the Army's investigation revealed that not all of the technologies are appropriate to clean up military hydraulic fluid. MIL-H-46170 fluid in particular, poses an extra challenge in the removal of excess water. The fluid is formulated with an organic ester additive that has a strong propensity to absorb water. Commercially available fluid purifiers that depended strictly on special absorbent filters and/or coalescers typically were unsuccessful in removing the water from used military hydraulic fluid. In addition, the use of heat may cause fluid oxidation, coking, or charring; high vacuum may strip the fluid of light ends, changing its viscosity; and desiccants may strip out fluid additives and add hard particulate contamination. These processes need to be avoided to maintain the physical and chemical properties of the fluid being recycled.

The Fuels and Lubricants Technologies Team sought out commercial manufacturers of oil purifiers to develop processing units utilizing multiple technologies that were capable of removing water and particulate contaminants from

hydraulic oils at different throughput capacities. Once commercial units were identified and/or developed that successfully cleaned-up the used fluid during laboratory testing, they were employed in a six month field demonstration to assess both the performance of the processing units themselves as well as monitor the performance of the hydraulic systems on the vehicles using the restored fluid. The results of the field demonstration highlighted the need to explore means of automating the process of recycling hydraulic fluid.

FIGURE 1: Pall Automated Hydraulic Oil Recycling Unit Demonstrated at Fort Irwin, CA.

The field demonstration validated what had already been proven in the laboratory: used military hydraulic fluid can be processed such that it is restored to like new condition and successfully used in military vehicles. Experience with the recycling units, however, revealed that the process of recycling used fluid was somewhat cumbersome. The units available for use in the demonstration had no means of determining when the used fluid had been sufficiently processed to remove the water and particulate contaminants to below the Mil-spec. levels. The only means available for determining when used fluid had been sufficiently processed was to collect and analyze samples for water content and particle count or to simply process the fluid for an extended period of time to ensure all contaminants were removed.

The method of determining the end point of the reconditioning process by collecting samples for analysis by a laboratory is both time consuming and labor intensive. In addition, if samples are collected too soon, the used fluid has to be processed an additional amount of time and samples collected and analyzed all over again. This increases the amount of time for the process, particularly if there is no supporting laboratory on the installation and the samples have to be shipped to an off site laboratory. This extra time is accompanied by the cost of labor to perform the sampling and analysis.

The method of processing the used fluid for an extended period of time, although less costly than sampling and analysis, poses additional risks. Because the processed fluid is not analyzed for water content and particle count, there is no means of determining when the fluid has been cleaned sufficiently. To overcome this uncertainty, the fluid must be processed for an extended period of time, even though it is likely that the fluid is cleaned long before the time has elapsed. Much of the used fluid processed during the field demonstration was adequately cleaned in less than three hours, but a significant margin of error must be built into the processing time unless on-line diagnostics are available.

The solution is to automate the certified processing units such that the recycling units perform in-line analysis and a "go/no-go" indication is given to the operator. Two of the vendors that participated in the field demonstration phase entered into CRADAs with the Fuels and Lubricants Technology Team to accomplish in-line fluid condition monitoring on a recycling unit. The challenge was to incorporate affordable technology into the processing unit without impeding processing unit performance.

3.0 AUTOMATED RECYCLER DEVELOPMENT

To date, one company, Pall Aeropower Corporation, has successfully developed affordable technology married to the processing units to provide the in-line diagnostics needed. The technology employed in the Pall Automated Hydraulic Fluid Recycling Unit (depicted in Figure 1 above) removes particulate contamination consistently, based on the number of passes of fluid that the system sees. The water contamination removal rate is dependent on a number of factors including oil type, temperature, water content, ambient humidity, etc. Because the Pall recycling unit particulate removal rate is consistent and predictable and typically the particulate contaminants are removed long before all of the water is removed,

Pall Aeropower Corporation opted to incorporate a water sensor into its recycling unit as a means of detecting water content of the fluid. After a time delay, set to ensure particulate clean-up, the automation package interrogates the water sensor to determine when the relative humidity level of the fluid being reconditioned drops to a level corresponding to less than 500 PPM water (for MIL-H-46170, other fluids are set for the specific MIL-spec.). Once all of the criteria are met, the recycler shuts-off automatically (recycled fluid meets the MIL-spec.).

FIGURE 2: Pall Automation Package Including Water Sensor

The Pall Aeropower Corporation hydraulic oil recycler, with its water sensor and automation package, provides an automated unit that makes the process consistent, repeatable, and economical in terms of time and labor required. The automation package for the Pall unit is set at the factory for a specific hydraulic oil. By following the procedures developed by the U.S. Army, and using a certified automated recycler, the recycling process can be accomplished automatically. The automation package shuts the recycler off when the fluid being recycled is cleaner and dryer than the MIL-spec. requirements.

Another cost, operational readiness, and environmental benefit obtained as a result of the water sensor development under this program, is Pall's new portable water sensor which is currently being used as a portable lab device, a direct readout on certain problem applications, and as a device in the lab to replace coulimetric titration. The portable lab device is being used to bring the water tester to the application, preventing the need for bottle sampling (reducing costs and oil disposal while increasing accuracy). The direct readout on problem applications has increased operational readiness

through ability to know when a system is becoming contaminated with instant response possible. The potential errors and the chemical usage associated with coulometric titration in the lab, have been eliminated through the implementation of the new water sensor. All of these benefits have been further enhanced by the low cost of the water sensor, which is saving the US Military and commercial applications worldwide, millions of dollars per year, over previous ways that water contamination was identified.

FIGURE 3: Pall Portable Water Sensor

4.0 CONTAMINATION REMOVAL PROCESS:

The Pall Automated Hydraulic Fluid Recycling Unit is based on a proven technology that Pall has been providing to the U.S. Military since 1965. The current purifier incorporated in the recycler includes the latest improvements, while keeping the system simple to use and safe to operate. The purifier employs spinning disk, mass transfer dehydration, and

high efficiency / high dirt capacity membrane filtration technologies; which are processes that effectively remove the contaminants while not degrading the hydraulic fluid.

The detailed removal process is as follows: Contaminated hydraulic oil is drawn into the vacuum chamber through a mesh strainer. A float valve regulates the inlet flow, keeping it equal to the output of the discharge pump. The oil entering the vacuum chamber impinges on the center of a spinning disk. As the disk rotates, oil flows outward to the edge of the disk, progressively decreasing in film thickness. The oil is thrown off of the disk and breaks into very small droplets yielding a large surface area for the oil. Maximizing the surface area of the oil directly increases the water removal rate.

Ambient air is drawn into the vacuum chamber through an air breather filter. The air expands to approximately five times its former volume, resulting in an 80% reduction in relative humidity. The dry air is passed over the contaminated oil droplets and the water, air, and solvent contamination is transferred to the air stream from the oil. The water, air, and solvent contamination are carried from the vacuum chamber within the air stream exhaust.

The dehydrated and deaerated hydraulic oil from the vacuum chamber is pumped through a proprietary, synthetic media, 3-micron absolute non-bypass filter. This filter removes particulate contamination quickly and effectively, while exhibiting an extremely high dirt holding capacity. The purified hydraulic oil exits the purifier, returning it to a storage container, system reservoir, or application.

5.0 RECENT IMPLEMENTATION PROGRAMS

The U.S. Army Environmental Center and Aberdeen Proving Ground have been supporting technology transfer by collecting important cost and performance information and hosting field demonstrations. The Pall Automated Hydraulic Fluid Recycling Unit was successfully demonstrated at Ft. Irwin, CA. and numerous other Military facilities. The U.S. Army Environmental Center estimates that the cost to recycle FRH using the Pall recycler is less than $3.00 per gallon

depending on site conditions, fluid contamination, and available workforce. The typical procurement cost of new MIL-H-46170 (FRH) is many times this cost per gallon. Disposal costs vary greatly from near $0.00 to as much as $30.00 per gallon (depending on how hazardous the local authorities consider the oil). The Pall unit is now certified by the Army and is commercially available. Due to the reasonable cost of the Pall recycling unit, the reutilization of hydraulic oil process has the potential for a very short payback period with a great deal of long-term cost savings.

Other implementations within the U.S. Army are looking at cleaning-up hydraulic oil directly on the application, rather than draining the oil and cleaning-up a barrel. A recent implementation is the U.S. Army's CH-47 (cargo helicopter) program, which has successfully implemented the use of the Pall recycling units as part of their maintenance program. By purifying the hydraulic oil directly on the aircraft systems, they gain the added benefit of cleaning the hydraulic systems as well as cleaning the oil (simply draining the system and replacing with new oil does not clean the system). By cleaning the systems (by flushing with purified oil), they get the added benefits of improved system performance, reliability, and reduced maintenance. These translate directly to an increase in operational readiness. In addition to the environmental and cost saving advantages, the aircraft operators are experiencing improved system performance and reliability as a side benefit to utilizing the Pall recycler.

The U.S. Navy Environmental Leadership Program (NELP) investigated purifier systems for removing contaminants from aircraft hydraulic fluid. This study was accomplished at Naval Air Station North Island and Naval Station Mayport. The NELP study concluded that purifying hydraulic fluid will provide a major environmental benefit by reducing the volume of waste fluid with a corresponding decrease in the requirement for new fluid. Information on these tests is available on the Internet via the Tri-Services Pollution Prevention Technical Library (maintained by the Naval Facilities Engineering Services Center) listed as Recycler, Hydraulic Purifier. Additional information can be found in the Pollution Prevention Equipment list (maintained by the Navy Office of the Chief of Naval Operations {N45}) and directly on the Pall website at: www.pall.com/envirosolutions. Pall has been working with the U.S. Navy on hydraulic oil purification since the early 1960's. The initial applications were on submarines, with later developments of more efficient units developed for specific aircraft. A recent implementation by the U.S. Navy is the LCAC (Hovercraft) program. The LCAC's have begun implementation of an oil recycling program for their hydraulic and lubricating fluids, utilizing the Pall recycling unit.

The U.S. Air Force has been evaluating the Pall Automated Hydraulic Fluid Recycling Unit for use on aircraft for many years. The USAF understand that it is critical that the purification process does not degrade the fluid in any way. The Pall purifier has been tested to ensure that the physical and chemical properties of the oil are not changed during the purification process. Also, multiple tests were performed to ensure that additive packages were not removed as well as multi-year pump wear tests were performed to ensure that there would be no negative side effects to reutilizing hydraulic oil purified with the gentle Pall patented process.

The Airbase and Environmental Technology Division (AFRL/MLQ - Tyndall Air Force Base, Florida), initial investigations provided the impetus for a Memorandum for Record (MFR) released in October 1995. This MFR concluded that the Pall unit purified new and used hydraulic fluids without degrading their working properties. The MFR recommended hydraulic pump wear studies, which have been completed under the auspices of the Air Force Research Laboratory - Nonstructural Materials Branch (AFRL/MLBT) at Wright-Patterson Air Force Base, Ohio. Numerous pump wear tests were conducted with the results indicating that the highly purified fluid (with the gentle process of the Pall unit) did not adversely affect pump life / performance. In addition, the U.S. Air Force Air Mobility Command recently conducted an operational utility evaluation with the Pall automated hydraulic oil recycling unit at McChord AFB. This testing was carried out to verify the feasibility of recycling hydraulic fluids for reuse on aircraft, using MIL-H-83282, MIL-H-87257, and MIL-H-5606. The AFRL/MLQ has estimated that the successful implementation of the hydraulic oil recycling program could save the U.S. Air Force alone, approximately $30 million a year. As a result of these tests, the USAF has begun implementation of Purification of Hydraulic Fluid for Ground Systems and Aircraft. This is an Air Force Wide Program, under direction from AFMC/CEVV Project #s ZHTV01PV06 & ZHTV01OV06. The USAF is currently rewriting their Tech Orders to allow the use of hydraulic oil that has been purified with an approved device proven to not degrade the oil.

The successes mentioned above have spurred many new projects that will look at fluids other than hydraulic oils for reutilization. The U.S. Military services have approved the reutilization of hydraulic oil by cleaning the oil to better than Mil-Spec. performance, by utilizing an approved hydraulic oil recycler. Some of the fluids being looked at for possible future reutilization are: PAO coolants (electronic cooling fluid), lubricating oils, transmission oils, and brake fluid.

6.0 CONCLUSIONS

- Used hydraulic oil can be restored to Mil-spec. performance by utilizing a hydraulic oil recycler certified by each of the U.S. Military Services.

- The use of a certified automated hydraulic oil recycler, incorporating in-line monitoring technology, optimizes processing time and eliminates the labor required to collect and analyze fluid samples.

- Reutilizing hydraulic fluid to specification performance directly relates to less new fluid procured, less fluid required to be kept in stock to meet fluid usage requirements, and less fluid required for deployments (deploy with a small amount of oil and an oil purifier vs. deploying with large quantities of oil).

- Reutilization of hydraulic fluid prevents pollution by reducing the amount of used fluid that must be disposed of.

- Additional benefits of this contamination removal process include increased operational readiness, system performance, reliability, and an uncomplicated avenue for conservation of natural resources.

- Reuse of hydraulic fluid has the potential for very substantial dollar savings throughout the Department of Defense and commercial entities.

- The approved recycling process works consistently and is easily repeatable.

- The implementation of hydraulic oil recycling throughout the U.S. Military will have a significant impact on meeting pollution prevention goals, conserving natural resources, and reducing costs associated with both the procurement of new and disposal of used hydraulic fluids.

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