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MIL-H-46170 Hydraulic Fluid Recycling: Field Demonstration

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This final report documents the results of laboratory and field evaluations of commercially available recycling units for recycling MIL-H-46170 hydraulic fluid. Previous laboratory efforts demonstrated used hydraulic fluid could be restored to specification performance by removing water and particulate contaminants and mixing with 25% new fluid. The field demonstration confirmed this by demonstrating fluid performance in test vehicles. Used fluid was drained from the vehicles, processed through approved recycling equipment, mixed with 25% new fluid, and returned to vehicle service. The vehicle performance was monitored for six months with satisfactory results. In addition, other batches of used fluid were processed through the recycling equipment and analyzed for performance. Results of these additional analysis confirm that used fluid retains most of its additive performance with the exception of anti-foaming ability, but that the addition of the 25% new fluid restored the cleaned up used fluid to specification performance. Lessons learned during the demonstration are identified in the report with the most important lesson being the need for clean processing containers. Hydraulic fluid contaminated by other types of fluids (engine oils, brake fluid, gear oil, etc) cannot be recycled. Used drums must be free of these types of fluids or they risk contaminating the hydraulic fluid. A total of five units were approved for use with MIL-H-46170 hydraulic fluid. The units vary significantly in the technology employed and cost as well as throughput capability, but all satisfactorily remove water and particulate contaminants. Experience with the approved units reveals that recycling hydraulic fluid would be easier if the units contained on-line fluid condition monitoring which would provide a clear indication of when contaminants have been removed.

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Section 1 Introduction

The US Army Mobility Technology Center (MTC-B) recently concluded a 3 year effort to develop and validate a methodology for recycling used military hydraulic fluid. The effort was conducted in two phases. The first phase focused on determining if used fluid could be restored to specification performance through recycling processes and was conducted predominantly in the laboratory. Investigations revealed that used hydraulic fluid retained almost all of its performance capabilities with little to no loss of additive performance. The predominant reason for changing and discarding used hydraulic fluid was the presence of water and particulate contamination, not the loss of fluid performance. Removal of the contaminants and mixing the cleaned-up used fluid with 25% new fluid proved to be sufficient in restoring the fluid to specification performance. The results of the laboratory investigation are detailed in TARDEC Technical Report, "Recycling MIL-H-46170 Hydraulic Fluid to Extend Fluid Service Life", No. TR-13619.

The second phase of the effort focused on evaluating the performance of commercially available recycling units to determine if they could sufficiently remove the contaminants from military hydraulic fluid. The effort consisted of two parts: first, the recycling units were evaluated against identified performance criteria. Those units that met the criteria received a "Pre-Certification" and were invited to participate in the second part of the effort, the field demonstration. The demonstration was conducted at three different sites with various armor units participating. The field demonstration consisted of removing used fluid from the vehicles, recycling, mixing with 25% new fluid, installing the reusable fluid in the vehicles, and monitoring the performance of the recycling equipment. The demonstration aimed to determine filter life and processing times for recycling the fluid, ease of use of the recycling units, as well as monitoring the performance of the test vehicles. Fluid samples were collected at the time of vehicle changeover to recycled fluid, three months into the demonstration and at the end of the six months. Analysis was performed to determine if any fluid degradation occurred during service in the vehicles. This report discusses the results of the field demonstration and the accompanying fluid analysis.

Section 2 Background

The chosen demonstration sites were Ft. Carson, Colorado because of its exposure to cold temperatures, Ft. Hood, Texas because of its dry, dusty environment, and Anniston Army Depot (AAD), Alabama because of its high temperature and humidity conditions. The same test procedure was implemented at each site (see Appendix A for test plan) and involved test and control vehicles as well as processing of used fluid by the recycling units. Each of the test sites had the added incentives of offering different levels of fluid usage. By far the largest user in this demonstration of MIL-H-46170 hydraulic fluid is Anniston Army Depot, followed by Ft. Hood then Ft. Carson. Anniston and Ft. Hood have fully equipped laboratories on-site which are capable of performing needed fluid analysis. Ft. Carson, although it has an oil analysis laboratory does not have the equipment to analyze hydraulic fluid. Each site was able to provide test and control vehicles for the duration of the demonstration. Anniston Army Depot was able to coordinate with the Alabama Army National Guard, located at Ft. McClellan, Alabama, to provide the vehicles while the depot performed the fluid recycling.

Ft. Carson provided three M1A1 tanks as control vehicles and three tanks as test vehicles. The test and control vehicles were drained of their hydraulic fluid which was collected in 55 gallon drums. The control vehicles were refilled with new fluid from sealed cans. The test vehicles were required to sit empty overnight while the used fluid was processed through the recycling unit. The used fluid drained from the tanks contained copious amounts of water and particulate contamination. The particulates were so high, particle counts could not be determined. Water contents were as high as 0.4%. Although the fluid was heavily contaminated, the vehicles were functioning without any degradation in hydraulic system performance. It is not known how long the fluid has been in the vehicles with such severe contamination. Because of the high water content and particulate contamination, the vehicles were vulnerable to corrosion and excessive wear. Some corrosion and wear may already have been present but not yet exhibited itself in the form of hydraulics malfunction.

Although the fluid in the vehicles was in poor condition it provided an excellent test of the recycling equipment. Based solely on visual appearance, it would be reasonable to assume the fluid was beyond redemption. It was, however, recycled (the conditions of the used and recycled fluid will be discussed later in this report), mixed with 25% new fluid (see TARDEC Technical Report No. TR-13619), and returned to the test vehicles. As part of the demonstration, Ft. Carson originally agreed to continue collecting and recycling used fluid to provide an indication of typical fluid processing times and the filter capacity of the equipment. The transfer of an Armored Division to

Ft. Carson prevented this additional recycling. All available manpower was utilized in accommodating the new Division.

Ft. Hood also provided 3 test and 3 control M1A1 tanks. Although initial coordination with the AMC FAST science advisor from Ft. Hood indicated full cooperation in the demonstration, when MTC-B personnel showed up for the initial vehicle fluid conversion, they were informed that manpower was not available to recycle fluid beyond what was needed for the vehicles. Although fluid samples would be collected from the vehicles, Ft. Hood would not be providing any data regarding recycling other collected used MIL-H-46170 fluid.

The final site of the demonstration was Anniston Army Depot, Alabama. The depot is the largest user of fluid of the three sites. During FY94, the depot used close to 10,000 gallons of MIL-H-46170 fluid. At an average cost of $10/gallon, the depot's fluid procurement required nearly $100,000 in funding. Use of recycled fluid can potentially decrease this expenditure by 75%. Since the depot does not own any of its own vehicles, the Alabama National Guard, Anniston, Alabama, agreed to provide 3 test and 3 control tanks and to support the vehicle testing portion of the demonstration. Used fluid was collected from the Guard vehicles, transported to and recycled at the depot. Once the fluid completed its processing in the recycling unit, it was transported back to the Guard and introduced into the test vehicles. The depot agreed to process a minimum of six additional 55 gallon drums of used fluid throughout the six months. By the end of the first three months, the depot had already recycled seven drums of used fluid. A total of 21 drums were recycled by the depot during the demonstration.

At the beginning of the field demonstration evaluation effort, seven manufacturers expressed interest in participating. A "Pre-Certification" procedure was established which required the manufacturers to recycle new fluid that had been "doped" (see Appendix B for procedure and doping instructions). This standard test fluid allowed each unit to be evaluated based on the same conditions. The doping procedure called for the fluid to be contaminated with 0.5% water and enough ISO A-2 Fine Test Dust to provide a Class 10 level of contamination in accordance with SAE Aerospace Standard AS4059, "Aerospace Cleanliness Classification for Hydraulic Fluids". New fluid which meets the particle count requirements in MIL-H-46170 has an approximate equivalent level of contamination between Class 3 and Class 4 and a water content below 500 ppm. Those manufacturers that passed the pre- certification and agreed to participate in the demonstration entered into a Cooperative R&D Agreement (CRDA) with MTC-B which allowed the Army to use their equipment for six months at the designated sites.

Initially, only three manufacturers were able to pass the pre-certification. These manufacturers were Pall Aerospace, Clarus Technologies/SESCO, and Petronetics. Two other manufacturers failed to pass either the water content limit or the particle count limit on their first attempt. After adjustment to their equipment, both Next Step Filtration and TF Purifier also passed the pre-certification. Pall Aerospace, Clarus Technologies/Sesco, and Petronetics were all given the opportunity to participate in the demonstration. Only Pall Aerospace and Clarus Technologies/Sesco actually entered into R&D Agreements. Petronetics indicated a desire to participate, but scheduling problems prevented them from doing so. Next Step Filtration and TF Purifier were unable to participate in the demonstration because their equipment could not be pre-certified until well after the demonstration had started. Participation in the demonstration is not a reflection of the relative abilities of the equipment as all five manufacturers provided equipment which met all requirements.

The Pall Aerospace unit (referred to from now on as the Pall unit) makes use of spinning disc and vacuum dehydration technologies. The water is removed from the fluid via vacuum dehydration and 3 micron filters are used to remove particulate contamination. The Pall unit was shipped to Ft. Carson, Colorado and remained at this site until December 1995. During this time period a total of 110 gallons of fluid was processed by the unit. Although Ft. Carson originally intended to participate to a greater extent, events on Post prevented manpower from being available to recycle more fluid. During the initial conversion of the test and control vehicles, the unit required six hours, thirty minutes to bring the fluid to specification level particulates and to 760 ppm water. The requirement for the fluid allows up to a maximum 500 ppm water, but time constraints due to the lack of on-site fluid analysis prevented further processing of the fluid to remove the final amount of water. The recycled fluid was mixed with 25% new fluid and returned to the vehicles. Water content for the test vehicles ranged from 404 ppm to 866 ppm. Since each of the vehicles was filled from the same batch of recycled fluid, the vehicle with the high water content may have still contained moisture in the hydraulic system.

The Clarus Technologies/Sesco unit (hereafter referred to as the Clarus/SESCO unit) utilizes proprietary thin film vacuum distillation and multistage depth filtration technology to remove contaminants. The unit was originally scheduled for Ft. Hood, Texas. The unit was shipped to Ft. Hood and used to process the fluid drained from the test and control vehicles. The used fluid from these vehicles was considerably cleaner than at Ft. Carson and the Clarus/SESCO unit was able to restore the fluid to specification cleanliness after 2.5 hours. Again the fluid was mixed with 25% new fluid, to restore anti-foaming capability, and returned to the three test vehicles. The three control vehicles received new fluid from sealed containers. Since Ft. Hood could not provide manpower to continue recycling used fluid, the Clarus/SESCO unit was transferred to Anniston Army Depot. At Anniston, the unit recycled two drums of previously collected used fluid and two drums of fluid collected from the Guard vehicles. The used fluid at Anniston was also considerably less contaminated than the fluid at Ft. Carson and the processing time was 3.5 hours for each drum.

One problem which surfaced at Anniston which should be noted was the condition of the drums in which the used fluid was collected. The drums provided by the Guard for collecting the used fluid had been "triple rinsed". This process of cleaning the drums involved using detergent, then rinsing the drums three times in order to remove all traces of previous fill. Even with the triple rinse procedure, it was found that the drums still retained traces of detergent. One 55 gallon drum into which fluid was collected had to be discarded because it was discovered after filling the drum that it still contained residual detergent. The importance of collecting used fluid in CLEAN drums cannot be stressed enough. If fluid is to be successfully recycled, it cannot be mixed with any other hydraulic fluid or other liquid substance. Any foreign contamination in the fluid such as detergent, other types of oil, or other types of hydraulic fluid will render the fluid unfit for recycling. This lesson as well as others learned during the field demonstration have been incorporated into a User's Guide. This document, **"User's Guide for Recycling Military Hydraulic Fluid"** (a copy may be obtained by contacting The Mobility Technology Center - Belvoir, ATTN AMSTA-RBF, 10115 Gridley Rd., STE 128, Ft. Belvoir, VA 22060-5843) provides detailed instructions for conducting a used fluid recycling program as well as discussions of each of the approved recycling units.

Analysis Results & Discussion

The initial used fluid samples collected from Ft. Carson, Ft. Hood and Anniston Depot were subjected to water content, viscosity at 40°C, and total acid number. Particle counts for Ft. Hood and Anniston Depot were not included due to non-availability of functioning equipment. As mentioned earlier, the samples of used fluid from Ft. Carson were so contaminated with particulates, particle counts could not be determined. Results are summarized in Table 1 below. The fluid samples obtained from Anniston are much less contaminated than those from Ft. Carson. None of the samples evaluated from Anniston (see Table 2) revealed contamination levels comparable to Ft. Carson and since the fluid comes from vehicles that are stationed across the country, it is reasonable to assume that the fluid samples from Anniston Depot are more representative of the entire Army than those from Ft. Carson. It should be noted, however, that it is certainly possible other vehicles in the fleet contain fluid as severely contaminated as the fluid at Ft. Carson.

Table 1: Used and Initial Recycled Fluid From Field Demonstration

Sample	Process Time	H_2O Content	Vis @ 40°C	Total Acid No. (TAN)
Ft. Carson: Used	N/A	4700 ppm	14.81 cSt	0.08 mg KOH/g
Ft. Carson: Recycled	7.5 hrs	760 ppm	14.86 cSt	0.03 mg KOH/g
Ft. Hood: Used	N/A	no sample	no sample	no sample
Ft. Hood: Recycled	3 hrs	427 ppm	15.66 cSt	0.01 mg KOH/g
Anniston Depot: Used	N/A	2246 ppm	15.36 cSt	0.10 mg KOH/g
Anniston Depot: Recycled	3 hrs	411 ppm	15.24 cSt	0.08 mg KOH/g

N/A = Not Applicable

With Ft. Carson representing a worst case, results from Table 1 show that recycling hydraulic fluid is certainly a viable process. The processing time required to remove fluid contamination is a direct function of the amount of initial contamination in the fluid. The samples from Ft. Hood and Anniston Depot required less than half the processing time required for the Ft. Carson samples. Examination of the data collected during vehicle conversion and Pre-Certification indicates that the processing time for cleaning the fluid is dependent on the amount water present in the fluid. Based on data from Pre-Certification, each of the units was able to remove the particulate contamination early during the recycling process. It is the water removal which determines the time required to process the fluid. It should also be noted that visual inspection alone will not indicate when the fluid is clean. Typically the fluid turned from cloudy to clear between 1300 and 1000 ppm which is double the maximum water allowed in the fluid. Simply judging fluid cleanliness based on its clarity is misleading and not recommended. The fluid should be analyzed for water and particulate contamination prior to reuse.

Table 2 shows the analysis of samples collected during processing of the other drums of used fluid collected at Anniston Army Depot. These samples were analyzed for complete specification performance to include foaming characteristics, oxidation-corrosion stability, corrosion protection, and viscosities at high and low temperatures. Analysis of the fluid reveals no loss of additive performance or degradation in the fluid (there are two exceptions which will be discussed later in this report). All of the drums exhibited high water content and Drums 1,2 and 5, 6 and 7 exhibited high particle counts. These high contamination levels do not in any way imply that the recycling unit failed to process the fluid. The drums were each processed for 2.5 to 3 hours and samples taken. The results of the sample analysis simply indicate that for these drums of used fluid, the processing time needed to be longer. An additional hour of processing would probably be sufficient to render the particulates and water content to acceptable levels. The important point of the analysis is that even without the addition of the 25% new fluid, performance properties for the most part still meet specification requirements. The low flash and fire points exhibited by Drum 3 are due most likely to the new fluid from the can exhibiting values below specification requirements, which is known to happen occasionally. Ultimately over time, additive depletion and loss of performance will occur, but the fluids are formulated so robustly that this loss of performance is minimal and not enough to prevent the recycled fluid from passing specification performance requirements. Adding 25% new fluid to the recycled fluid not only restores the fluid's foaming characteristics, it also acts as a hedge against eventual additive depletion, ensuring that fluid returned to service meets all specification performance requirements.

Table 2: Analysis of Anniston Army Depot Used Fluid

(Specification Requirement Values are given in Parenthesis under "Test" Column)

Test		Drum 1	Drum 2	Drum 3	Drum 4	Drum 5	Drum 6	Drum 7	Drum 8
VIS @ 40° C (<19.5)	B	15.2	14.3	15.1	15.0	14.8	15.3	N/A	N/A
	A	15.2	14.8	15.0	15.1	14.5	14.8	15.35	15.32
VIS @ 100° C (>3.4)	B	3.6	3.6	3.6	3.6	3.7	3.8	N/A	N/A
	A	3.7	3.6	3.6	3.6	3.6	3.6	3.74	3.69
VIS @ -40° C (<2,600)	B	2,449	2,381	2,418	2,422	2,406	2,492	N/A	N/A
	A	2,452	2,307	2,332	2,395	2,423	2,487	1,786	1,785
EVAP LOSS (<5%)	B	3.541%	3.204%	3.459%	3.547%	3.369%	3.393%	N/A	N/A
	A	3.074%	3.267%	3.225%	3.192%	3.435%	3.760%	3.212%	3.347%
FLASH POINT (>218°C)	B	222°	228°	228°	224°	224°	226°	N/A	N/A
	A	220°	228°	222°	224°	228°	220°	230°	228°
FIRE POINT (>246°C)	B	246°	248°	**244°**	248°	246°	246°	N/A	N/A
	A	246°	246°	**244°**	248°	246°	246°	250°	252°
POUR POINT (<-54°C)	B	< -54	< -54	< -54	< -54	< -54	< -54	N/A	N/A
	A	< -54	< -54	< -54	< -54	< -54	< -54	< -54	< -54
% H_2O (<0.05%)	**B**	**0.107%**	**0.080%**	**0.070%**	**0.094%**	**0.082%**	**0.083%**	**N/A**	**N/A**
	A	**0.064%**	**0.076%**	**0.067%**	**0.069%**	**0.058%**	**0.054%**	**0.055%**	**0.053%**

Test		Drum 1	Drum 2	Drum 3	Drum 4	Drum 5	Drum 6	Drum 7	Drum 8
TAN (<0.20)	B	0.15	0.01	0.07	0.11	0.02	0.04	N/A	N/A
	A	0.13	0.04	0.06	0.08	0.11	0.05	0.16	0.09
GALVANIC CORROS FTM 791- 5322	B	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
	A	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS
CORR & OX STABILITY FTM 791-5308	B	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
	A	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS
LOW TEMP STABILITY (CLEAR)	B	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR	N/A	N/A
	A	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR	CLEAR
HUMIDITY CABINET	B	PASS	PASS	PASS	PASS	PASS	PASS	N/A	N/A
	A	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS
Seal Swell (15%-25%)	B	21%	16%	16%	19%	19%	20%	N/A	N/A
	A	18%	17%	16%	18%	19%	20%	15%	15%
PARTICLE COUNT 10,000 250 50 10	B	**10,755** 81 9 3	**38,053** **1,295** **70** 10	4,365 60 7 0	3,809 35 5 1	**19,595** **1,670** **125** **13**	7,915 **1,098** **192** **40**	N/A	N/A
	A	1288 14 2 0	**10,435** **760** 42 5	**40,207** **1,670** **150** **5**	1,549 58 9 0	**26,740** **2,145** **170** **13**	**7,676** **249** **23** **2**	**19,550** 87 25 8	5,892 92 20 4
FOAMING 1- 65/0 2- 65/0 3- 65/0	**B**	**1- 480/0** **2- 90/0** **3- 400/0**	1- 0/0 2- 30/0 3- 0/0	1- 20/0 2- 40/0 3- 20/0	N/A	N/A	N/A	N/A	N/A
	A	**1- 440/0** **2- 100/0** **3- 470/0**	1- 10/0 2- 50/0 3- 30/0	1- 20/0 2- 40/0 3- 20/0	1- 50/0 2- 50/0 **3- 70/0**	1- 40/0 2- 50/0 3- 10/0	1- 40/0 2- 50/0 **3- 110/0**	**1- 440/0** **2- 70/0** **3- 380/0**	1- 20/0 2- 30/0 3- 20/0
4-BALL WEAR @ 40 kg (< 0.65mm)	B	0.390	0.426	0.414	0.407	0.402	0.355	N/A	N/A
	A	0.418	0.409	0.415	0.421	0.549	0.408	0.416	0.409
Gravimetric (<0.5MG per 100ML/15Min)	B	0.0555	0.0560	0.0559	0.0492	0.0442	0.0344	N/A	N/A
	A	0.0450	0.0628	0.0519	0.0532	0.0515	0.0325	0.0468	0.0543

B = Before Recycle, A = After Recycle, Bold = Out of Specification
N/A = Test Sample not Available

The two exceptions mentioned earlier in this report are printed in bold in Table 2 and concern foaming. Both Drum 1 and Drum 7 exhibit extremely high levels of foaming even after being mixed with 25% new fluid. The initial tendency is to conclude that used fluid cannot always be restored to specification performance even with the addition of 25% new fluid. Because the foam levels are so extraordinarily high, contamination of the fluid was suspected. During the initial conversion of the test vehicles for the demonstration, drums that were inspected prior to use were found to be contaminated. It is entirely possible that Drums 1 and 7 were not clean at the time the fluid was transferred to the drum. This lab is not equipped with the analytic capability to explicitly identify a contaminant so a different method of analysis was utilized to determine the cause of the excessive foaming. The samples of recycled Hydraulic fluid is typically formulated with 0.1% anti-foaming additive to keep the foam volume to 65 ml or less. If formulated without anti-foamant, the fluid can exhibit a foam volume of up to 120 ml. Drums 1 and 7 exhibited foam volumes of greater than 400 ml which is far beyond what one would expect if the anti-foaming additive had been depleted completely. The technique employed to determine if the suspect fluid was indeed contaminated was to add successive greater amounts of the fluid to a sample of new fluid. If a majority of new fluid is insufficient to overcome the foaming caused by the recycled fluid, then a pro-foamant contaminant is indicated. Testing reveals that even with 60% new fluid, the mixture of fluid still exhibited foaming above specification limits (see Table 3).

Table 3: Foaming Characteristics of Mixed Fluid

Foaming	Spec Limit	New Fluid	Suspect Fluid	75% Suspect 25% New	50% Suspect 50% New	40% Suspect 60% New	35% Suspect 65% New	25% Suspect 75% New
Sequence I	65/0	10/0	470/0	300/0	220/0	160/0	30/0	20/0
Sequence II	65/0	20/0	110/0	90/0	50/0	65/0	50/0	45/0
Sequence III	65/0	10/0	350/0	290/0	160/0	85/0	40/0	25/0

Samples collected from the vehicles at the demonstration sites after three months of service were subjected to gravimetric analysis, viscosity and total acid number (TAN) determination, foaming water content, and particle count (see Table 4). Ft. Carson was unable to collect fluid samples at the 3 month mark due to a lack of available manpower. The samples collected from test vehicles at Ft. Hood exhibit some increase in water content above initial conditions and significant increases in particle count. The increase in particle count is to be expected, given the dusty conditions at Ft. Hood. The values obtained however, probably reflect more than just the particulate contamination. Analysis with a new, recently acquired automatic particle counter reveals that the sensor is sensitive to water in the fluid. A study conducted to ascertain the effect of water in hydraulic fluid revealed that the particle count increased significantly with the amount of water in the fluid (for results of study, see Appendix C). The results of the gravimetric analysis (a method which determines the mass of particulates in the fluid) indicate that the particulate contamination is still within specification limits (0.5 mg/100ml). Although the particle count is high, an examination of the viscosity, TAN, and foam characteristics shows that the fluid continues to exhibit performance within specification requirements. The fluid is starting to become dirty, but additive performance is well within requirements. The Alabama National Guard did not collect samples in the bottles provided, thus insufficient sample was received to perform all analyses. Sufficient fluid was available however, to conduct water content, viscosity and TAN determinations. The test vehicles exhibit slight increases in water content above initial results (see Table 1), but the viscosity and TAN remain well within specification requirements.

Table 4: 3 Month Processing Samples

Sample (Veh ID#)	% H_2O	Particle Count	Vis@ 40°C	TAN	Gravim	Foam
FT CARSON	**No 3 month vehicle samples were received from Ft Carson.**					
FT HOOD						
Cont: C-12	0.038	2,872 **1,056** **222** **40**	15.02	0.01	0.0479	0/0 10/0 0/0
Cont: C-23	0.040	4,190 **2,038** **228** **20**	14.93	0.01	0.0519	0/0 20/0 0/0
Cont: C-32	0.041	2,602 **1,154** **124** **22**	14.90	0.01	0.0640	0/0 0/0 0/0
Test: D-11	0.043	**93,634** **13,168** **2,158** **214**	14.5	0.05	0.0523	0/0 20/0 0/0
Test: D-12	0.062	**440,406** **91,576** **8,428** **360**	15.11	0.05	0.0648	0/0 30/0 0/0
Test: D-13	0.096	**29,248** **7,492** **2,740** **7,404**	15.06	0.04	0.0591	0/0 30/0 0/0
AAD						
Cont: A-14	0.289		15.0	0.04		
Cont: A-23	0.075		15.2	0.05		
Cont: A-24	0.090		15.2	0.06		
Test: A-13	0.059		14.5	0.05		
Test: A-33	0.048		15.1	0.01		
Test: A-6	0.063		14.9	0.01		

Blank Spaces = no analysis due to insufficient test sample quantities, Bold = Out of Specification, AAD = Anniston Army Depot

Table 5 shows the same analysis on samples collected at the end of the six month demonstration. Once again a slight increase in water content is exhibited for all three demonstration locations, and as expected, particle counts also increased. When comparing the particle counts for the Ft. Hood test vehicles, Test Vehicle D-11 and D-12 exhibit a decrease in particle count from the 3 month analysis to the six month analysis. There is no on-line filtration in the vehicles causing the counts to decrease, thus it is most probable that the particle count data from the 3 month analysis is in error. As insufficient sample remained after the original analysis to repeat a particle count, there is no way to confirm the numbers. A comparison of the 6 month gravimetric analysis to the 3 month gravimetric analysis, shows very little change, thus it is likely the 6 month particle counts are a more accurate reflection of the actual particulate contamination. Again, however, viscosity, TAN, and foam characteristics are all well within specification limits, further supporting the efficacy of recycling military hydraulic fluid. Although the fluid continues to become contaminated, the recycled fluid continues to exhibit the desired performance characteristics while in service in the vehicles. The fluid analysis is further verified by the vehicle crews. No difference in performance of the vehicle was reported for those vehicles using recycled fluid.

Table 5: 6 Month Processing Samples

SAMPLE	%WATER	COUNT	VIS@40°C	TAN	GRAVIM	FOAM
FT CARSON						
CONTROL A-12	0.0657	**24,660 9,305 1,722 165**	14.6	0.07	0.0664	N/A
CONTROL B-13	0.0409	**17,008 1,730 237 32**	15.2	0.02	0.0645	N/A
CONTROL B-14	0.257	**44,604 3,316 460 126**	14.7	0.07	0.0679	N/A
TEST B-12	0.0315	**44,720 6,632 2,316 4,156**	15.4	0.02	0.0619	N/A
TEST A-14	0.0735	**86,768 18,165 2,090 135**	15.0	0.05	0.0703	N/A
TEST A-24	0.0566	**88,385 5,695 425 50**	14.9	0.07	0.0674	N/A

SAMPLE	%WATER	COUNT	VIS@40°C	TAN	GRAVIM	FOAM
FT HOOD						
CONTROL C-12	0.0608	**165,523** **5,345** **272** **32**	15.0	0.07	0.0367	0/0 0/0 0/0
CONTROL C-23	0.0398	**28,373** **2,152** **127** 10	15.1	0.04	N/A	0/0 0/0 0/0
CONTROL C-32	0.0469	**204,158** **7,166** **778** **160**	15.0	0.12	N/A	0/0 0/0 0/0
TEST D-11	0.0553	**60,218** **3,352** **145** 2	15.7	0.16	0.0629	0/0 30/0 0/0
TEST D-12	0.0600	**71,610** **3,805** **118** 10	15.2	0.09	0.0478	0/0 30/0 0/0
TEST D-13	0.1020	**15,384** 152 48 **12**	15.4	0.07	N/A	0/0 60/0 10/0
AAD						
CONTROL A-14	0.0910	**32,440** **3,790** **716** **766**	15.3	0.04	0.0508	20/0 30/0 10/0
CONTROL A-23	0.0668	**14,245** **1,666** **248** **60**	15.1	0.04	0.0546	20/0 30/0 0/0
CONTROL A-24	0.1000	**17,783** **2,006** **261** **37**	15.2	0.04	0.0632	20/0 20/0 0/0
TEST A-13	0.0542	**62,913** **6,528** **788** **124**	15.0	0.08	0.0661	0/0 0/0 0/0
TEST A-33	0.0468	**18,376** **5,836** **1,156** **256**	13.8	0.09	0.0510	0/0 0/0 0/0
TEST A-6	0.0600	**32,176** **2,064** **288** **54**	15.1	0.10	0.0436	0/0 0/0 0/0

Bold = Out of Specification

Analysis of the collected samples reveals that used hydraulic fluid can be successfully recycled and returned to service. Although the field demonstration was conducted entirely using MIL-H-46170 hydraulic fluid, it is reasonable to assume the MIL-H-6083 hydraulic fluid can also be recycled. A study was conducted in 1990-1991 (Belvoir Research, Development & Engineering Center Technical Report TR-2512) to determine the service limits of MIL-H- 6083. The study concluded that no deterioration in fluid performance could be detected (fluid was left in vehicles for up to 3 years) although the fluids exhibited high water and particulate contamination. Because MIL-H-6083 is formulated using almost identical additives as MIL-H- 46170, and previous study indicates, it is as robustly formulated as MIL-H-46170, this fluid is also a strong candidate for recycling. To maintain the desired level of performance with MIL- H-6083 if it is recycled, it is still recommended that 25% new fluid be mixed with the recycled fluid. Care must be taken, however, if an installation intends to recycle both types of fluid, that they be collected and processed separately. If MIL-H-6083 is mixed with MIL-H-46170 or vice versa, then the fluid cannot be recycled and reused.

One condition must be placed on recycling MIL-H-6083. Because the fluid is petroleum based, it exhibits a significantly lower flash point than MIL-H-46170. It is also more prone to high evaporation when subjected to high temperature conditions. Some of the certified recycling units (TF Purifiner and Next Step Filtration) subject used fluid to high temperatures as a means of driving off excess water. These units are not approved for use with MIL-H-6083 because of the safety hazard created by an operating temperature above the flash point of MIL-H-6083 and because of the potential for the evaporation characteristics of the fluid to negatively impact low temperature performance. The units not approved for use with MIL-H- 6083 were not part of the field demonstration. A detailed discussion of recycling MIL-H-6083 can be found in the planned "User's Guide for Recycling Military Hydraulic Fluid".

Conclusions

The successful conclusion of the field demonstration strongly suggest that recycling military hydraulic fluid is indeed a viable option to disposal. There are some items for consideration in implementing a hydraulic fluid recycling program. In using commercially available equipment, the user is obligated to pursue one of two options. The user can collected sample after an initial processing time and have them analyzed for water content and particle count or the fluid can be processed for an extended period of time (12 hours) which is assumed to be enough time to remove sufficient contamination to render the fluid serviceable again. While both options are possible, neither is ideal. The first option requires either in- house capability to perform samples analysis or reliance on an outside lab. In any event, the processed fluid cannot be returned to service until after the results of the analysis have been received. The other downfall to this approach is that the fluid sample may reveal that water and/or particulates are still too high and the fluid must be processed further which requires the sampling and analysis procedures be repeated. This can be a time consuming process which artificially increases the price of recycling fluid. The second option, while it eliminates the sampling and analysis, is also less than optimum because it leads to the possibility of processing the fluid for longer periods of time than is truly necessary (Ft. Hood and Anniston fluid was processed in three hours) again artificially increasing the price of recycling. Although these two options are not ideal , either one of them can be implemented such that significant fluid usage and attendant costs savings can be realized by recycling hydraulic fluid.

The best of all possible worlds would be for the manufacturers of this recycling equipment to incorporate on-line fluid condition monitoring into their units. Technology exists which can monitor water content and particle count on-line while the fluid is being processed. If this technology were incorporated into the recycling units. users could process the fluid long enough such that the on-line sensors indicate cleanliness levels have been reached. The units could even be automated to automatically shut off when the sensors indicate the appropriate cleanliness has been achieved, thereby reducing the manpower required to monitor the recycling process. Conceivably, an operator could start the equipment and leave it unattended knowing it will shut down automatically when the fluid has been clean sufficiently to meet performance requirements.

One other aspect to note when recycling fluid is the Army recommendation to add 25 % new fluid to the recycled fluid to insure adequate anti-foaming. This can be a cumbersome procedure because either the new fluid must be mixed in the same drum as the recycled fluid or new cans of fluid must be added one at a time to the vehicle directly to achieve the appropriate mix of recycled fluid to new fluid. One possible answer to this is to have the equipment process the fluid in an internal processing tank which is large enough to accommodate the addition of new fluid after the processing has been completed thus the mixed fluid can be pumped directly into the vehicle without the cumbersome transfer of containers in the mixing process. Although some effort is involved in recycling military hydraulic fluid (collecting used fluid in separate containers, sampling and analysis, long processing times, mixing new fluid with recycled fluid, etc) the procedure is not so complex or expensive that it is not worth the effort. Recycling hydraulic fluid making use of commercial equipment as it exists presently is still significantly cost effective. In the case of Anniston Army Depot. If they were to purchase one of the approved units at a cost of $30,000, they would still save $45,000 in their first year of operation. If they chose to sample and analyze the fluid and had to purchase equipment to do so (at an approximate cost of $35,000) they would still save $10,000 the first year. By recouping capital investment in the first year, each succeeding year of recycling hydraulic fluid will yield a cost savings of $75,000 annually (which does not take into account any costs of disposing of used fluid only costs saved by not purchasing additional fluid). These costs savings would be more significant if the units were modified to include on-line monitoring and automatic shut-off. Currently, MTC-B is involved in a Cooperative R&D agreement with one of the manufacturers to develop a recycling unit that incorporates on-line monitoring and automatic shutoff. With the successful completion of this program, the Army will be able to achieve even more cost savings.

References

a. MIL-H-46170, Hydraulic Fluid, Fire Resistant, Rust Inhibited, Synthetic Hydrocarbon.

b. MIL-H-6083, Hydraulic Fluid, Operational and Preservative, Petroleum Base.

c. Purdy, Ellen M., Rutkowski, Donna M., Sterling, Franklyn D., "Recycling MIL-H-46170 Hydraulic Fluid to Extend Fluid Service Life", TARDEC Technical Report No. 13619, March 1995.

d. Purdy, Ellen M., "User's Guide for Recycling Military Hydraulic Fluid", October 1996.

e. Van Brocklin, Constance, "Determination of MIL-H-6083 Hydraulic Fluid In-Service Use Limits for Self Propelled Artillery", USA-BRDEC-TR//2512, 1991.

f. Cuellar, Jr., J.P., "Hydraulic Fluid Reuse/Recycle Study", Final Report No. SwRI-1944, Fuels and Lubricants Research Division, Southwest Research, Institute, 1988.

Appendix A: MIL-H-46170 Fluid Service Life Extension: Field Demonstration

1. Introduction

1.1 Purpose

The purpose of this demonstration is 1) to validate the performance of commercially available recycling equipment under long-term conditions and with various levels of fluid contamination, and 2) to demonstrate the performance of reclaimed MIL-H-46170 hydraulic fluid in actual vehicle operation.

1.1.1 Definition Of Terms

* New Hydraulic Fluid - Fluid obtained from sealed container.
* Used Hydraulic Fluid - Fluid collected from vehicles.
* Reclaimed Hydraulic Fluid - Used fluid processed through commercial reclamation equipment.
* Reusable Hydraulic Fluid - Reclaimed fluid mixed with new fluid which can be returned to service.

1.2 Background

In an attempt to reduce the waste stream and disposal costs generated by the US Army and US Marine Corps, the Defense General Supply Center funded the Fuels and Lubricants Division of the US Army TACOM's Mobility Technology Center - Belvoir to develop a means of reclaiming MIL-H-46170, Hydraulic Fluid, Fire Resistant, Rust Inhibited, Synthetic Hydrocarbon Base so that its useful service life could be extended. Reclamation of hydraulic fluid results in a significant reduction of fluid consumed and disposed of over the life cycle of military hydraulic equipment. Laboratory analysis reveals that used hydraulic fluid, while often heavily contaminated, usually retains sufficient additive strength to provide continued service. Reclamation of military hydraulic fluid predominantly involves removal of water and particulate contamination. Although the fluid additive package remains relatively intact, used hydraulic fluid tested to date mainly exhibits a loss of anti-foaming capability. Testing revealed that the addition of 1 part new MIL-H-46170 to 3 parts reclaimed fluid will sufficiently re- inhibit the fluid to prevent excessive foaming. Mixing new fluid with the reclaimed fluid allows the reclaimed fluid to be brought back to full specification performance without becoming involved in attempting to introduce additives in the field which would create numerous operational and logistical problems.

Removal of the water and particulate contamination commonly found in used fluid can be accomplished using commercially available equipment. MIL-H- 46170 allows a maximum moisture content of 500 ppm and a particulate level roughly equivalent to Class 4 Cleanliness as designated by SAE Aerospace Standard AS4059 (see Attachment A). When these particulates are removed from the fluid and the fluid mixed as explained above, it will meet all specification requirements and can be returned to full service.

1.3 Scope

The field demonstration will encompass three sites, Ft. Hood, Texas, Ft. Carson Colorado, and Anniston Army Depot. At least one pre-certified reclamation unit will be set up at each site. A second vendor's equipment may also be demonstrated at the site. The reclamation units will be brought in by the manufacturers who will provide personnel to train military personnel in the operation of the equipment. The equipment will remain at each site for a minimum of 6 months during which time it will be operated such that it meets the reclamation needs of each site. In addition to demonstrating the performance of the reclamation equipment from a user's operational perspective, a minimum of 3 vehicles from each site will be converted to the reclaimed MIL-H-46170 fluid and operated as normally required. Three additional vehicles will be designated as control vehicles and will continue to use new MIL-H-46170. The test and control vehicles will be monitored for performance throughout the duration of the demonstration.

1.4 Objectives

The objectives of this endeavor are as follows:

- Determine the suitability of commercially available equipment to reclaim used military hydraulic fluid
- Establish replacement rates for filter elements
- Confirm usability of reclaimed MIL-H-46170 fluids in actual vehicles by monitoring performance over a six month period
- Develop a Hydraulic Fluid Reclamation User's Guide

1.4 Schedule.

Milestone	Completion Date
Ft. Carson Equipment installation & personnel training; vehicle fluid conversion	5-9 Jun 1995
Ft. Hood Equipment installation & personnel training; vehicle fluid conversion	10-14 July 1995
Anniston Equipment installation & personnel training; vehicle fluid conversion	24-28 July 1995
Ft. Carson vehicle fluid sample collection	7 Aug 1995
Ft. Hood vehicle fluid sample collection	5 Spt 1995
Anniston vehicle fluid sample collection	18 Spt 1995
Ft. Carson field demo wrap up; 6-month fluid sample collection	13-16 Nov 1995
Ft. Hood field demo wrap up; 6-month fluid sample collection	27-30 Nov 1995
Anniston field demo wrap up; 6-month fluid sample collection	11-14 Dec 1995
Recycled fluid analysis drums 1-8	8 Jan - 26 Apl 1996
3-month fluid analysis (all sites)	1 May - 28 Jun 1996
6-month fluid analysis (all sites)	1 July - 30 Aug 1996
Field Demonstration Final Report	30 Spt 1996

2. Demonstration Concept And Procedures

2.1 Concept

The demonstration is intended to characterize the performance of the recycling equipment and verify the performance of the reclaimed fluid in test vehicles. Characterization of the equipment involves developing a profile of filter life based on the level of contamination of the fluid. Each batch of fluid to be reclaimed will first be analyzed for contamination and assigned a cleanliness class in accordance with SAE Aerospace Standard AS4059 (see Attachment A). From this data, as well as performance monitoring by equipment operators, the equipment will be evaluated on ease of use and cost to reclaim fluid. Performance of the reclaimed fluid in the vehicles will be evaluated based strictly on vehicle monitoring and fluid sample analysis (3 month and 6 month samples). Miles traveled, hours operated, and rounds fired will be logged for each test and control vehicle. Each vehicle crew will be asked to complete a performance evaluation survey at the end of 3 months and 6 months.

2.2 Procedures

Fluid reclamation will take place in 55-gallon increments regardless if the used fluid is collected in drums or large volume storage tanks. Each batch of used fluid will be characterized for water content, particulate contamination, and flash point. Any fluid suspected of contamination with other types of oils will not be recycled. Prior to the start of the field demonstration, each site is requested to provide a 1 Liter sample from each container of fluid to be recycled. If fluid is collected in a holding tank, it must be transferred to 55 gallon drums and samples taken from each drum. These samples will be analyzed at Ft. Belvoir to characterize the level of contamination and detect the presence of contamination by oils other than used FRH. Sample bottles can be provided upon request and must be mailed to Ft. Belvoir at least 3 weeks prior to the scheduled start date of the demonstration. Pre-characterization of the fluid prior to actual start-up will reduce the time required to reclaim the fluid and convert the test vehicles. Fluid samples should be mailed to the following address:

Mobility Technology Center - Belvoir
ATTN AMSTA-RBF (E. Purdy, Bldg 362)
10115 Gridley Rd., STE 128
Ft. Belvoir, VA 22060-5843

After the used fluid has been characterized, 40 gallons will be transferred to a clean drum using the recycling equipment. After this first pass, a sample will be drawn and again checked for water content and particulate contamination. This sample will provide an indication of the time required before the fluid is restored to specification cleanliness standards. After the fluid has been transferred to the clean drum, it will be recycled through the equipment and back into the same drum until the contamination level has been reduced to the specification limits. This procedure will be repeated for a minimum of 4 drums to allow sufficient fluid to be reclaimed for use in the test vehicles.

After 40 gallons have been restored to specification cleanliness standards, 15 gallons of new fluid will be mixed with the reclaimed fluid using an agitator attached to the drum. The drum will then be sealed for future re-use of the fluid.

The test vehicles will be converted to the reclaimed fluid by the procedure in the Technical Manual or Lubrication Order for replacing old fluid. Prior to drainage of the old fluid, the hydraulic system should be exercised to allow adequate suspension of any particulate contamination in the hydraulic system to occur. The old fluid is drained and the hydraulic system is flushed with the reclaimed fluid until clear fluid comes through the bleed valve. The system is then brought to prescribed level. The control vehicles, which are the same type of vehicle as the test vehicles, will also have the hydraulic fluid changed. The old fluid will be replaced with new MIL-H-46170 fluid. Fluid changes shall be conducted in accordance with Technical Manual specifications. After each vehicle has been converted to its appropriate fluid, the hydraulic will again be exercised to insure no air remains in the lines. Test and control vehicles will then be monitored while performing regularly scheduled activities.

2.3 Data Collection

The data collected will be the results of the used fluid characterizations (water content, particle count, flash point), interim fluid sample analysis (water content, particle count), final fluid results (water content, particle count), and number of filters used (see Attachment B). The initial characterization data will be evaluated to assign a Cleanliness Class to the used fluid. Vehicle performance data will be collected in the form of vehicle crew and maintenance personnel surveys (see Attachment C). The initial demonstration may be photographed for documentation purposes. Sites are requested to provide photo documentation, if possible, of any unusual occurrences or problems that arise, particularly during the vehicle trial when MTC-B personnel are not present. Fluid service samples will be analyzed against MIL-H-46170 specification performance requirements and a lab report will be prepared for each evaluation. All data associated with the field demonstration will be assembled in a Final Report.

3. Management And Responsibilities

3.1 Relationships

The Fuels and Lubricants Division of the US Army TACOM Mobility Technology Center - Belvoir (MTC-B) has oversight responsibility for the field demonstration. Personnel from MTC-B will be responsible for overall coordination with each participating site and each participating recycling equipment manufacturer. Each site's participation in this hydraulic fluid recycling demonstration is voluntary.

3.2 Points Of Contact

MTC-B	Mrs. Ellen M. Purdy Mobility Tech TRC - Belvoir ATTN AMSTA-RBF 10115 Gridley Rd., Ste 128 Ft. Belvoir, VA 22060-5843 DSN 654-3722, COM (703) 704-3722 FAX (703) 704-1822
Ft. Hood,TX	Mr. R. J. Holly Ft. Hood Science Advisor DSN 737-7145 FAX (817) 287-2478
Ft. Carson, CO	Mr. Mike Davis HQ Ft. Carson 4th Infantry ATTN AFZC-ECM-EC (M Davis), Bldg 302 Ft. Carson, CO 80913-5000 DSN 691-2014, COM (719) 526-8005 FAX (719) 526-5404
Anniston Army Depot, AL	Mr. Ralph Usrey DEPT OF ARMY Anniston Army Depot ATTN SIOAN (DPE-MED R. Usrey)) 7 Frankfort Ave Anniston, AL 36201-4199 DSN PH 571-6265 COM (205) 235-6265 DSN FX 571-7128 CFX (205) 235-7128

3.3 Responsibilities

MTC-B personnel are responsible for conduct and coordination of field demonstration. Participating sites are responsible for providing personnel to operate the recycling equipment, personnel to perform vehicle hydraulic fluid changeovers, and vehicles and crews for 3 test and 3 control vehicles. Site personnel must ensure the availability of clean drums to store recycled fluid and arrange with an oil analysis lab to provide sample analysis of recycled fluid which at a minimum must include Particle Counts (MIL-H-46170), Karl Fisher Water Content (ASTM D1744), and Flash Point (ASTM D92). (If sites do not have local oil analysis support, arrangements can be made with MTC-B to provide sample analysis support to verify fluid cleanliness after recycling.) Sites must also provide sufficient used and new MIL-H-46170 hydraulic fluid. Participating equipment manufacturers are responsible for shipping their equipment to the designated site, training military personnel in the operation and maintenance of the equipment and providing initial filters and required tools, spare parts (in case of equipment malfunctions) for the duration of the six month demonstration. Participating sites are responsible r providing support personnel and demonstration equipment. Additional filters will be purchased by MTC-B to the extent funding is available.

4. Resources

4.1 Demonstration Items

Each site should designate 3 test vehicles and 3 control vehicles for this demonstration. Each site will operate at least one recycle unit which will be provided by equipment manufacturers. It is possible that more than one recycling unit will be available at a site. The volume of fluid reclaimed will be at the discretion of the participating site once the minimum required amount of fluid has been reclaimed. The minimum volume will depend on the condition of the fluid collected by each site and will be determined during demonstration start up.

4.2 Logistic Support

4.2.1 Support Equipment

Equipment required to support the field demonstration will consist of clean empty drums in which to store reclaimed fluid. For the demonstration, MTC-B will provide test equipment to determine fluid water content, particle count and flash point. This equipment will only be available only during start-up of the field demonstration.

4.2.2 Consumable Supplies

The initial supply of replacement filters will be supplied by MTC-B to the extent that funding is available. Additional filters that may be needed at the discretion of the participating site must be purchased by the site. Sample bottles will be provided by MTC-B and mailing containers for the 3-month samples will also be provided by MTC-B. Participating sites are responsible for providing used fluid and sufficient new fluid to provide for 3 vehicle fluid changes and new fluid to mix with the reclaimed fluid. For every 55 gallon drum of reclaimed fluid, 15 gallons should be new fluid. At a minimum of 3 drums of new fluid should be available for fluid changeover in the control vehicles and 60 gallons will be needed to mix with the 4 drums of reclaimed fluid for use in the test vehicles. Every 40 gallons the site plans to reclaim over the 6 month demonstration period requires 15 gallons of new fluid to make up a 55 gallon drum of reusable fluid.

4.2.3 Transportation

Transportation of recycling equipment and manufacturer personnel will be at the expense of participating equipment manufacturers.

4.2.4 Maintenance.

Participating sites are required to provide maintenance support for participating vehicles. Equipment manufacturers are required to provide maintenance support for their equipment beyond what is required for normal operation of the recycling equipment.

4.3 Personnel

MTC-B will provide 2 field test engineers for the start-up of the demonstration. One engineer will be available during field demonstration wrap- up to collect fluid samples and assist in vehicle re-conversion to new fluid (if sites choose to convert the test vehicles back to new MIL-H-46170).

Equipment manufacturers are invited to participate in the field demonstration to whatever extent they choose provided the minimum start-up responsibilities are met (see paragraphs 3.3 and 4.2.4). Personnel are to be cautioned that this field demonstration is a non-interference demonstration. Activities should be limited to providing support without disrupting regularly scheduled activities.

Appendix B: Hydraulic Fluid Reclamation: Standardized Test Fluid

1. Standardized test fluid consists of new MIL-H-46170 hydraulic fluid contaminated with IS A-2 Fine Test Dust and Deionized water. The level of contamination for the Standardized Test Fluid corresponds to the SAE Aerospace Standard, AS4059, Cleanliness Class 10 for particulates and 0.5% water content.

2. To prepare the Standardized Test Fluid, the following is required:
   - new MIL-H-46170 hydraulic fluid (FRH) minimum 15 gallons
   - ISO A-2 Fine Test Dust @ 5 mg/L (0.0189 g/gal)
   - Deionized water (0.5%)

2.1 The following table provides the treat rates for specified volumes of FRH fluid:

Fluid Volume (gal)	ISO A-2 Fine Test Dust (grams)	Deionized Water (gal)	Deionized Water (liters)	Deionized Water (ml)
15	0.2839	0.075	0.2839	284
20	0.3785	0.100	0.3785	378
25	0.4731	0.125	0.4731	473
30	0.5678	0.150	0.5678	568
35	0.6624	0.175	0.6624	662
40	0.7570	0.200	0.7570	757
45	0.8516	0.220	0.8327	833
50	0.9463	0.250	0.9463	946
55	1.0409	0.275	1.0409	1041

3. To prepare the Standardized Test Fluid, locate the treat rates for the volume of fluid being prepared in the above chart. Measure out the appropriate amount of ISO A-2 Fine Test Dust and Deionized Water.

4. While the new FRH hydraulic fluid is being agitated in the mixing tank (tank must be clean prior to adding fluid), add the ISO A-2 Fine Test Dust. Allow the fluid to agitate for 20 minutes to insure the dust has been dispersed throughout the fluid. Pull a sample of fluid and perform a particle count. The fluid contamination level should correlate roughly with AS4059 Class 10 Cleanliness. Keep a record of the initial count.

5. While the dust contaminated fluid is being agitated, add the water at no more than 150 ml per 5 minutes. A 55 gallon sample of test fluid requires approximately 35 minutes to complete the water contamination. At the end of the appropriate mixing interval, pull a sample of fluid and determine the water content. The fluid contamination level should correspond roughly to 0.5% water. Keep a record of the initial water content.

6. Upon completion of the fluid contamination procedure, begin fluid recycling. Collect fluid samples every 30 minutes and determine particle count and water content. Continue recycling until water content reaches 500 ppm or below and particle count meets the requirements in MIL-L-46170. Keep a record of the amount of time required to fully recycle the fluid.

Appendix C: Particle Count Water Sensitivity Study

	New FRH (no water added)	0.05% Water Added	0.10% Water Added	0.25% Water Added
Baseline	1, 541 26 2 0	131,424 13,328 1,930 109	350,109 44,894 6,704 560	680,141 144,621 25,989 5,414
1% Class 10	5,518 584 111 24	141,968 17,035 3,539 214	458,925 71,172 14,040 1,300	787,356 728,544 129,108 5,968
5% Class 10	15, 057 566 60 8	297,199 41,700 8,297 1,341	633,194 107,904 19,764 1,504	717,787 753,175 144,797 7,559
10% Class 10	26,455 734 68 9	326,769 41,029 6,639 129	551,415 97,596 20,813 1,733	851,978 349,112 86,399 15,165
25% Class 10	56,756 1,460 96 8	235,179 17,333 800 73	749,634 179,872 41,564 5,187	926,938 223,450 33,677 1,486

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APG MD 21005-5071

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CDR ARMY ATCOM
1 ATTN AMSAT I ME (L HEPLER)
1 ATTN AMSAT I LA (V SALISBURY)
1 ATTN AMSAT R EP (V EDWARD)
4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

CDR AVIA APPL TECH DIR
1 ATTN AMSAT R TP (H MORROW)
FT EUSTIS VA 23604-5577

CDR ARMY NRDEC
1 ATTN SATNC US (J SIEGEL)
1 ATTN SATNC UE
NATICK MA 01760-5018

CDR ARMY ARDEC
1 ATTN SMCAR CC
1 ATTN SMCAR ESC S
PICATINNY ARSENAL
NJ 07808-5000

CDR ARMY CRDEC
1 ATTN AMSMC MA
APG MD 21010-5423

CDR ARMY DESCOM
1 ATTN AMSDS MN
1 ATTN AMSDS EN
CHAMBERSBURG PA 17201-4170

DIR AMC LOG SPT ACT
1 ATTN AMXLS LA
REDSTONE ARSENAL
AL 35890-7466

CDR APC
1 ATTN SATPC Q
1 ATTN SATPC QE (BLDG 85 3)
NEW CUMBERLAND
PA 17070-5005

1 PETROL TEST FAC WEST
BLDG 247 TRACEY LOC
DDRW
P O BOX 96001
STOCKTON, CA 95296-0960

CDR ARMY LEA
1 ATTN LOEA PL
NEW CUMBERLAND
PA 17070-5007

CDR ARMY TECOM
1 ATTN AMSTE TA R
1 ATTN AMSTE TC D
1 ATTN AMSTE EQ
APG MD 21005-5006

PROJ MGR PETROL WATER LOG
1 ATTN AMCPM PWL
4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

PROJ MGM MOBILE ELEC PWR
1 ATTN AMCPM MEP
7798 CISSNA RD STE 200
SPRINGFIELD VA 22150-3199

CDR
ARMY COLD REGION TEST CTR
1 ATTN STECR TM
1 ATTN STECR LG
APO AP 96508-7850

CDR ARMY ARMOR CTR
1 ATTN ATSB CD ML
1 ATTN ATSB TSM T
FT KNOX KY 40121-5000

CDR ARMY AMCCOM
1 ATTN SMCCR RS
ROCK ISLAND IL 61299-6000

HQ MILITARY DISTRICT OF WASHINGTON
ATTN ANEN-ES
BLDG 42
FT MCNAIR, WASHINGTON, DC 20319

CDR ARMY QM SCHOOL
1 ATTN ATSM PWD
FT LEE VA 23001-5000

CDR
ARMY COMBINED ARMS SPT CMD
1 ATTN ATCL CD
1 ATTN ATCL MS
FT LEE VA 23801-6000

CDR ARMY FIELD ARTY SCH
1 ATTN ATSF CD
FT SILL OK 73503

CDR ARMY TRANS SCHOOL
1 ATTN ATSP CD MS
FT EUSTIS VA 23604-5000

CDR ARMY ENGR SCHOOL
ATTN ATSE CD
FT LEONARD WOOD
MO 65473-5000

CDR ARMY AVIA CTR
1 ATTN ATZQ DOL M
1 ATTN ATZQ DI
FT RUCKER AL 36362-5115

1 DIR
AMC FAST PROGRAM
10101 GRIDLEY RD STE 104
FT BELVOIR VA 22060-5818

CDR ARMY SAFETY CTR
1 ATTN CSSC PMG
1 ATTN CSSC SPS
FT RUCKER AL 36362-5363

CDR ARMY CSTA
1 ATTN STECS EN
1 ATTN STECS LI
1 ATTN STECS AE
1 ATTN STECS AA
APG MD 21005-5059

CDR ARMY YPG
1 ATTN STEYP MT TL M
YUMA AZ 85365-9130

CDR ARMY CERL
1 ATTN CECER EN
P O BOX 9005
CHAMPAIGN IL 61826-9005

CDR
RED RIVER ARMY DEPOT
1 ATTN SDSRR M
1 ATTN SDSRR Q
TEXARKANA TX 75501-5000

PS MAGAZINE DIV
1 ATTN AMXLS PS
DIR LOGSA
REDSTONE ARSENAL
AL 35898-7466

CDR 6TH ID (L)
1 ATTN APUR LG M
1060 GAFFNEY RD
FT WAINWRIGHT
AK 99703

DEPARTMENT OF THE NAVY

CDR
NAVAL SEA SYSTEMS CMD
1 ATTN SEA 03M3
2531 JEFFERSON DAVIS HWY
ARLINGTON VA 22242-5160

CDR
NAVAL SURFACE WARFARE CTR
1 ATTN CODE 632
1 ATTN CODE 859
3A LEGGETT CIRCLE
ANNAPOLIS MD 21401-5067

CDR
NAVAL AIR SYSTEMS CMD
1 ATTN AIR 53623C
1421 JEFFERSON DAVIS HWY
ARLINGTON VA 22243-5360

CDR
NAVAL AIR WARFARE CTR
1 ATTN CODE PE33 AJD
P O BOX 7176
TRENTON NJ 08628-0176

1 CDR
NAVAL PETROLEUM OFFICE
CAMERON STA T 40
5010 DUKE STREET
ALEXANDRIA VA 22304-6180

1 OFC ASST SEC NAVY (I & E)
CRYSTAL PLAZA 5
2211 JEFFERSON DAVIS HWY
ARLINGTON VA 22244-5110

DEPARTMENT OF THE NAVY/U.S MARINE CORPS

HQ USMC
1 ATTN LPP
WASHINGTON DC 20380-0001

1 PROG MGR COMBAT SER SPT
MARINE CORPS SYS CMD
2033 BARNETT AVE STE 315
QUANTICO VA 22134-5080

1 PROG MGR GROUND WEAPONS
MARINE CORPS SYS CMD
2033 BARNETT AVE
QUANTICO VA 22134-5080

1 PROG MGR ENGR SYS
MARINE CORPS SYS CMD
2033 BARNETT AVE
QUANTICO VA 22134-5080

CDR
MARINE CORPS SYS CMD
1 ATTN SSE
2033 BARNETT AVE STE 315
QUANTICO VA 22134-5010

CDR
BLOUNT ISLAND CMD
1 ATTN CODE 922/1
5880 CHANNEL VIEW BLVD
JACKSONVILLE
FL 32226-3404

CDR
MARINE CORPS LOGISTICS BA
1 ATTN CODE 837
814 RADFORD BLVD
ALBANY GA 31704-1128

1 CDR
2ND MARINE DIV
PSC BOX 20090
CAMP LEJEUNNE
NC 28542-0090

1 CDR
1ST MARINE DIV
CAMP PENDLETON
CA 92055-5702

1 CDR
FMFPAC G4
BOX 64118
CAMP H M SMITH
HI 96861-4118

DEPARTMENT OF DEFENSE

ODUSD
1 ATTN (ES) CI
400 ARMY NAVY DR
STE 206
ARLINGTON VA 22202

HQ USEUCOM
1 ATTN ECJU L1J
UNIT 30400 BOX 1000
APO AE 09128-4209

US CINCPAC
1 ATTN J422 BOX 64020
CAMP H M SMITH
HI 96861-4020

ODUSD
1 ATTN (L) MRM
PENTAGON
WASHINGTON DC 20301-8000

DIR DLA
1 ATTN DLA MMDI
ATTN DLA MMSB
CAMERON STA
ALEXANDRIA VA 22304-6100

CDR
DEFENSE FUEL SUPPLY CTR
1 ATTN DFSC Q BLDG 8
1 ATTN DFSC S BLDG 8
CAMERON STA
ALEXANDRIA VA 22304-6160

CDR
DEFENSE GEN SUPPLY CTR
1 ATTN DGSC SSA
1 ATTN DGSC STA
8000 JEFFERSON DAVIS HWY
RICHMOND VA 23297-5678

DIR ADV RSCH PROJ AGENCY
1 ATTN ARPA/ASTO
3701 N FAIRFAX DR
ARLINGTON VA 22203-1714

DIR ADV RSCH PROJ AGENCY
1 ATTN ARPA/ASTO
3701 N FAIRFAX DR
ARLINGTON, VA 22203-1714

12 DEFENSE TECH INFO CTR
CAMERON STATION
ALEXANDRIA, VA 22314

DEPARTMENT OF AIR FORCE

HQ USAF/LGSSF
1 ATTN FUELS POLICY
1030 AIR FORCE PENTAGON
WASHINGTON DC 20330-1030

HQ USAF/LGTV
1 ATTN VEH EQUIP/FACILITY
1030 AIR FORCE PENTAGON
WASHINGTON DC 20330-1030

AIR FORCE WRIGHT LAB
1 ATTN WL/POS
1 ATTN WL/POSF
1 ATTN WL/POSL
1790 LOOP RD N
WRIGHT PATTERSON AFB
OH 45433-7103

AIR FORCE WRIGHT LAB
1 ATTN WL/MLBT
2941 P ST STE 1
WRIGHT PATTERSON AFB
0H 45433-7750

AIR FORCE WRIGHT LAB
1 ATTN WL/MLSE
2179 12TH ST STE 1
WRIGHT PATTERSON AFB
OH 45433-7718

1 AIR FORCE MEEP MGMT OFC
615 SMSQ/LGTV MEEP
201 BISCAYNE DR STE 2
ENGLIN AFB FL 32542-5303

1 SA ALC/SFT
1014 ANDREWS RD STE 1
KELLY AFB TX 78241-5603