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27 SEP 1996

From: Commanding Officer, Naval Research Laboratory
To: Commander, Naval Facilities Engineering Service Center (Code ESC-421 R Lee), 560 Center Drive, Port Hueneme CA 93043-4327

Subj: ENVIRONMENTAL AND EFFICACY TESTS FOR AFFF SEPARATOR USING ACTUAL FIREFIGHTING WASTEWATERS

Encl: (1) Two copies of subject report

1. Enclosure (1) is forwarded for your information and retention. This work is being conducted under PE DBOF, Work Request N6830596WX00024.

2. There is concern about the potential environmental harm when Aqueous Film Forming Foam (AFFF) constituents spread to the environment or are discharged to waste water treatment plants. NRL has developed a prototype AFFF separator. The AFFF separator reduces the AFFF surfactants from typical firefighting waste waters. The presence of contaminants that would typically be found in firefighting wastes, such as petroleum hydrocarbons and aromatic compounds, do not appear to adversely affect the mechanism or the efficiency of the process. In addition, the separator reduces the other pollutants in the waste as measured by BOD_5, COD, VPH, BTEX and TPH. The concomitant reduction can be significant, e.g., 95 to 100%, particularly for the more volatile species. The overall results are extremely encouraging and continued development of the AFFF separator is recommended.

3. The NRL Point of Contact is Dr. F. W. Williams, Code 6180, (202) 767-2002; email, fwilliams@itd.nrl.navy.mil. For furher information about the Navy Technology Center for Safety and Survivability visit the NRL WEB Site at http//chemdiv-www.nrl.navy.mil/6180.htm.

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24 September 1996

Environmental and Efficacy Tests for AFFF Separator using Actual Firefighting Wastewaters

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3905
Ser 6180/0572

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Environmental and Efficacy Tests for AFFF Separator Using Actual Firefighting Wastewaters

1.0 INTRODUCTION

The U.S. Navy is one of the world's largest consumers of aqueous film-forming foam (AFFF). AFFF is currently the agent of choice for suppressing combustible/flammable liquid fuel fires resulting from aviation and shipboard accidents and battle induced damage. The Naval Air Systems Command (NAVAIR) uses AFFF in essential fire suppression systems protecting aircraft assets. Mobile vehicles (both shipboard and shore side) use AFFF which is discharged through turrets and hand lines. Aircraft carrier flight deck wash down systems can discharge AFFF in the event of a serious flight deck mishap.

NAVAIR is not the sole Navy user of AFFF. The Naval Sea Systems Command, the technical manager for the AFFF procurement specification, MIL-F-24385 [1], specifies AFFF to protect surface ship and submarine machinery spaces through hand lines and fixed sprinkler systems. Deluge sprinkler systems are used to protect aircraft carrier hangar decks. The Naval Facilities Command (NAVFAC) specifies AFFF sprinklers for shore side hangars and other flammable liquid hazards. In addition, AFFF is used by the U.S. Air Force and the civil sector for aircraft crash, fire and rescue, and in hanger applications.

There is concern about the potential environmental harm when the AFFF constituents spread to the environment with run-off from fire fighting operations or are discharged to wastewater treatment plants [2]. The primary component of AFFF solution is water. Other components include non-fluorinated surfactants (e.g., hydrocarbon surfactants), glycol ethers, and fluorinated surfactants. The environmental issues which have been raised include persistence of AFFF fluorosurfactants, discharge of glycol ethers used in foam formulations, and the potential for upsetting the balance of biodegradation mechanisms in wastewater treatment facilities when foams are discharged and treated in this manner. It is suspected that some of the compounds used to create the highly effective characteristics of AFFF do not readily breakdown in the environment. Thus, the very elements which apparently make AFFF an effective agent have a detrimental, or at least an unknown, impact on the environment.
Based on these perceived problems, local authorities may severely restrict or prohibit the discharge of AFFF into the local wastewater stream. This is currently the case with several wastewater treatment plants in the Maryland/Virginia area.

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Correlate Drain times & Surface tension } To determine AFFF conc. in solution

1.1 Review of Previous Work

In response to these problems, the Naval Facilities Engineering Service Center sought an economical way to separate AFFF from the wastewater at fire training facilities. The project resulted in a proof-of-principle device that lowered the AFFF in water solutions [3]. A brief summary of that work follows.

The first task was to develop a simple test that could be performed in the field that would correlate with the AFFF concentration. The method developed is based on drain times. The AFFF MILSPEC requires that drain time be determined for all AFFF solutions [1]. The drain time is defined as the amount of time required for a specific amount of generated foam to return to a specific amount of liquid. The MILSPEC test required specific procedures and equipment that was not readily adaptable to a small-scale field test. An inexpensive test to measure drain time was developed. Drain time is measured using a 2.54 cm(1-in) diameter by 10.2 cm(4 in) high test tube with a screw cap. The tube is filled with 5.2 cm(2 in) of solution and shaken 50 times. The time to reduce 90 percent of the foam back to liquid is recorded. Several problems still exist with this manual method: sensitivity to how vigorously the sample is shaken, the temperature and the amount of liquid. To overcome some of these problems a single operator was used. Acceptable repeatability was then achieved.

The drain time results were correlated against a property of the AFFF that could be accurately measured, surface tension. The results were in excellent agreement and provide a good measure of the relative decrease in the amount of AFFF in the solution. This proof-of-principle work only used one AFFF concentrate, 3M brand 6% MILSPEC AFFF foam concentrate (FC-206 CF).

With a method to measure the relative concentration of AFFF in solution, a series of breadboard AFFF separators were developed. The basic design concept was to use air bubbles to create a foam. Water alone can not form a bubble, but the surfactants in the AFFF allow a foam to form. The foam should be rich in surfactants compared with the average water solution. This effectively concentrates the surfactants into the foam which can be subsequently removed by mechanical means. The method was shown to be capable of separating the surfactants from AFFF-water solutions down to a concentration of 1000 ppm, or lower, of surfactants.

In summary, previous development work proved 1) the feasibility for using foam creation to concentrate and remove the AFFF fluorosurfactants, 2) the basic design features for the separator unit, and 3) a simple field test that correlates the reduction in surfactant levels to a laboratory measurement technique. All of these results, however, were obtained on 'standard' or pure AFFF-water solutions that would be typical from AFFF discharge tests, e.g., testing fire trucks. There are two other scenarios for creating wastewater containing AFFF that still needed to be evaluated in the separator unit:

- Standardized Fire Tests (e.g., AFFF MILSPEC Qualification Tests)
- Actual Fire events (Firefighter Training)

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1.2 Environmental Requirements

In addition to the other types of wastewaters, the effluent from the separator needed to be evaluated in terms of environmental impacts. Seven tests were chosen based on requirements of Hampton Road Sanitation District and the wastewater treatment plant at the Chesapeake Beach Detachment (CBD) of the Naval Research Laboratory (NRL) [4,5]:

1. Biological (Biochemical) Oxygen Demand, 5 day (BOD_5)
2. Chemical Oxygen Demand (COD).
3. Volatile Petroleum Hydrocarbons (VPH)
4. Total Petroleum Hydrocarbons (TPH)
5. Benzene, Toluene, Ethylbenzene and Xylenes (BTEX)
6. Methylene Blue Active Substances (MBAS)
7. pH

The BOD test measures the amount of dissolved oxygen that is consumed by bacteria in breaking down the organics present in the sample. The higher the BOD the greater the extent of pollution. The COD test measures the amount of oxygen that is required to oxidize the organics present under certain conditions of oxidizing agent, temperature and time. It is a separate measure from the BOD test and has no direct relationship to the results of the BOD test [5,6]. The ratio of BOD to COD however, is often used as an indication of the degree of biodegradability of a sample. A BOD/COD ratio equal to one means that all of the organics that can be oxidized, as indicated by the COD test, are oxidized by the microbes in the water, as indicated by the BOD test.

The petroleum hydrocarbon content is tested in three ways. The BTEX test is exactly as its name implies. It measure the concentration of benzene, toluene, ethylbenzene and xylenes. The VPH test covers the organic range C4 through C12, commonly referred to as the gasoline range. The BTEX and gasoline range tests can be run together. The TPH tests measures organics C10 and up. This effectively covers the diesel range (C10 to C24) and the oil and grease range. These three tests in combination, should adequately characterize the fuel concentration/contamination of the wastewater [6].

The MBAS test is used to measure the concentration of detergents and surfactant type materials that react with methylene blue to form a blue colored salt. It is only applicable to anionic surfactants measured as linear alkyd sulfonates (LAS) [5].

2.0 APPROACH

Wastewater from a standard AFFF QPL test, and from the 660,000 l (20,000 gal) wastewater tanks at CBD were tested using the AFFF separator to determine the ability to reduce

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the AFFF surfactants. The drain time versus concentration plots developed under the previous work were used to determine the effectiveness of the separator with these wastewaters [3].

Before and after samples of the two wastewaters were sent to an EPA approved environmental laboratory for the required tests. All samples were tested for BOD, COD, pH, MBAS, BTEX, and VPH. Only the wastewater from the storage tanks was tested for TPH. The wastewater from the QPL test uses gasoline so there should not be any heavy hydrocarbons present that would require the TPH tests.

Standard samples of AFFF-water solution were prepared for 1000 ppm, 500, ppm, 100 ppm and 10 ppm. These 'standards' were sent to the same environmental laboratory to undergo MBAS tests to determine how well the MBAS results compare with the drain time results.

3.0 EXPERIMENTAL

3.1 Source of Firefighting Test Waters

The test waters came from the live-fire facilities at the CBD. The complex consists of office, laboratory, and indoor and outdoor fire testing spaces. All of the live-fire testing facilities use potable water, generally from the fire hydrant system, and are designed to collect and store all resulting wastewater. There are three basic scenarios for fire tests run at CBD that result in wastewater:

- Qualified Purchase List (QPL) test for Aqueous Film Forming Foam (AFFF), as described by MIL-F-24385[1,7]
- Small-scale tests performed in Burn Building.
- Mid-scale and large-scale tests performed on the flight simulation outdoor fire mat or other outdoor fire test areas.

3.1.1 MILSPEC Test Water

The waste from the QPL fire tests is the easiest to characterize because there is a specific standard test method. The purpose of this test is to determine if the specific product meets the requirements for AFFF listed in the MILSPEC. The resulting waste, hereafter referred to as MILSPEC TEST will contain gasoline and AFFF, and may also contain products from the fire. The fire products of concern are the aromatic hydrocarbons such as those measured by the BTEX test. The AFFF concentrates and, therefore, the resulting solutions used in these tests will contain fluorinated surfactants, hydrocarbon surfactants, and glycol ethers. The precise make-up of each AFFF concentrate is proprietary and will vary from vendor to vendor. The QPL test requires using salt water to simulate the effects of using ocean water. The waste may also contain the salts used to generate the artificial sea water.

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3.1.2 Waste Tank Water

The two waste tanks collect all of the effluents from the three types of testing: QPL Tests, Small-scale tests in the Burn Building, and Medium- and Full-scale Tests. The resulting waste, hereafter referred as WASTEWATER can contain any or all of the constituents used: heptane, JP-5, JP-4, Diesel, AVGAS, MOGAS, fire combustion products, MILSPEC and non-MILSPEC AFFF, CLASS A foam extinguishing agents, PKP and salt (used to simulate sea water). There is no way to predict the concentrations of the various elements. Samples taken at different times may result in considerably different composition depending upon the fire testing that is taking place at any given time.

3.2 AFFF Surfactant Separation

A MILSPEC TEST was performed using Angus MILSPEC 3% foam. Instead of discharging the effluent to the waste collection system it was collected in a 209 l (55 gal) drum. The drum was turned on its side and let stand for seven days. Approximately 57 l (15 gal) was drained from the bottom of the tank and placed into the 35.6 cm(14 in) by 35.6 cm (14 in) by 91.4cm(36 in) high separator unit. Air was supplied at an initial rate of 1132 l/hr (40 SCFH) and the foam was removed every five minutes. The air flow rate was increased to 2264 l/min (80 SCFM) when the drain time dropped to approximately 1.5 seconds to further reduce the surfactant concentration. The test was stopped when the drain time dropped below one second, approximately 5 hours and 40 minutes from beginning of test.

In a second test 76 l (20 gal) of WASTEWATER was removed from the CBD storage tanks and placed into the separator unit. A sump pump with a two stage water filter was also placed into the tank to attempt to remove some of the heavier particles present. Air flow was set at 1132 l/min (40 SCFM) and the foam was initially removed every 4 minutes. The test was stopped when the drain time dropped to about 2.75 seconds, approximately 12 hours and 30 minutes from start of test.

3.3 Environmental Tests

Before and after water samples from the AFFF QPL tests and the storage tank were tested for COD, BOD_5, TPH, BTEX, pH and MBAS. Additionally, standard samples of AFFF solution were also tested for MBAS to determine if the MBAS test was suitable for the AFFF-type surfactants. All of these tests were run in accordance with EPA approved methods as follows:

TEST	EPA METHOD
• BOD_5	405.1 ppm
• COD	410.4 ppm
• MBAS	425.1 ppm
• BTEX	8020 ppb
• VPH	8015-M ppb
• TPH	418.1 ppb
• pH	N/A

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4.0 RESULTS AND DISCUSSION

4.1 AFFF Surfactant Reduction

The concentration of the AFFF surfactants was calculated from the drain time measurements using the drain time versus concentration plots previously developed and provided in Figures 1 and 2 [3]. The drain time at the start of the MILSPEC TEST sample was 10.93 seconds representing a concentration of approximately 1350 ppm. The drain time at the end of the test was 0.83 seconds representing a concentration of approximately 240 ppm. The initial drain time of the WASTEWATER sample was 17.13 seconds or about 1800 ppm. After running through the separator the drain time was reduced to 2.77 seconds corresponding to about 500 ppm of AFFF surfactants. These tests confirmed that the separator adequately reduces the AFFF surfactant concentration with both of these types of firefighting wastes.

4.2 Environmental Tests

The results of the environmental tests and the separator tests are provided in Table 1. The same headings for MILSPEC TEST and WASTEWATER are used. Samples captured for environmental testing just prior to running the AFFF Separator are labeled BEFORE. Samples taken after AFFF separation are labeled AFTER. The values given as 'less than' using the "<" symbol are at or below the detection limits for that analysis, as provided in the Report of Analysis from Gascoyne Laboratories, Inc., Appendix A.

An analysis of the BEFORE and AFTER samples from the MILSPEC TEST and the WASTEWATER indicate that all measured quantities are decreasing. The effluent from the AFFF separator contains considerably less AFFF surfactants and is less polluting as measured by the environmental tests. The reductions can be significant. This is particularly true for the more volatile species measured in the BTEX and VPH tests versus the heavier organics measured in the TPH test. This result is expected with the aeration technique used in the AFFF Separator.

The MILSPEC TEST BEFORE sample was extremely high in VPH and BTEX, and had the highest COD of the group. There is good rationale for the observed high value of the COD test from the results of BTEX and VPH. However, this same reasoning does not hold true for the concentration of BTEX and VPH versus the BOD_5 results. The BOD_5 was not very high which was unexpected based on the composition of the wastewater. Further analysis revealed that the BOD_5 test that is prescribed by the wastewater treatment plants and recommended for this study is not suitable for this type of wastewater . The BOD_{20} test is apparently needed to provide enough time for the particular organics present to react with the bacteria. All future testing should require the 20 day BOD test instead of the 5 day test to more adequately characterize these wastes.

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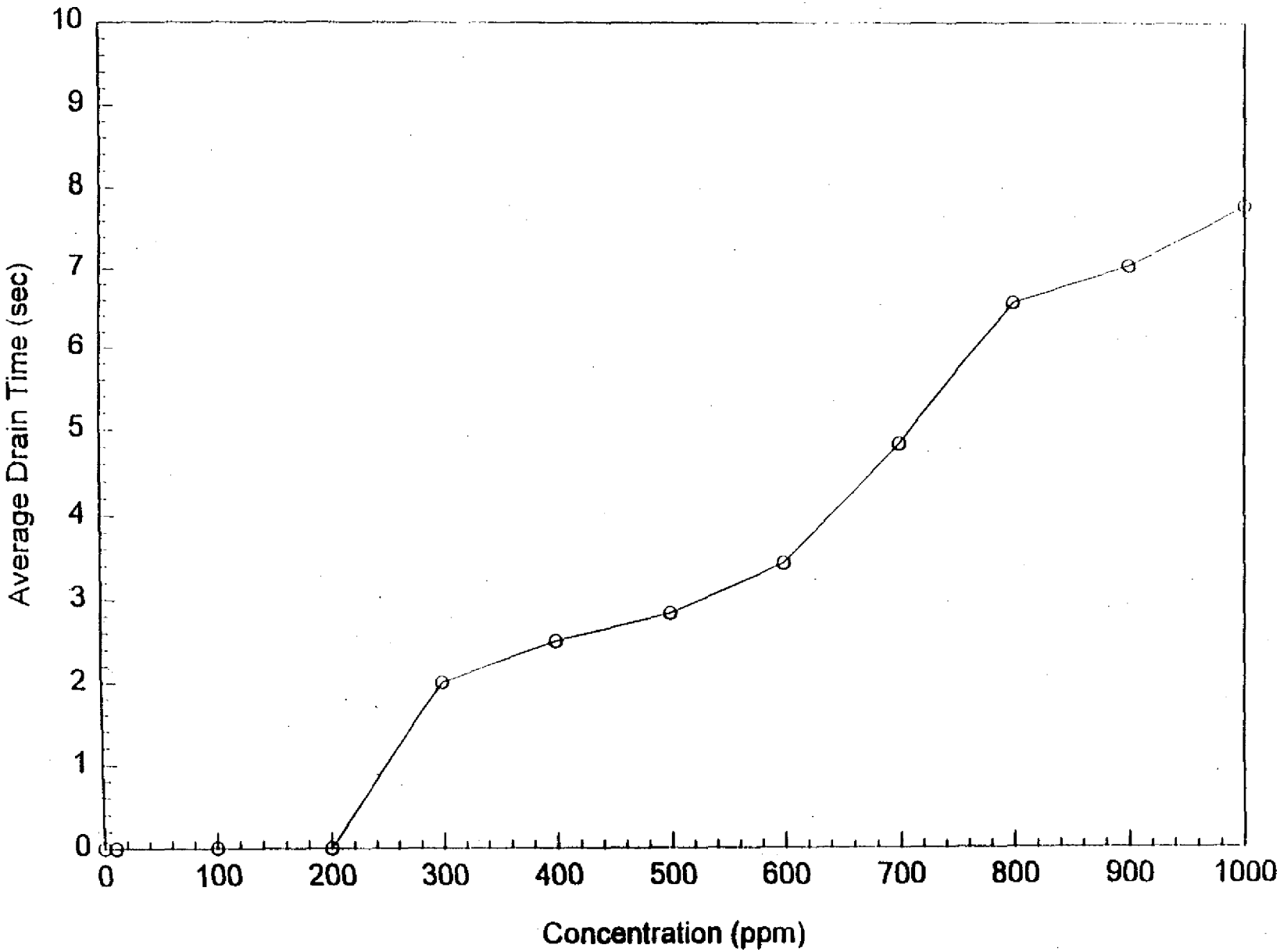

Fig. 1 - Average Drain Time vs. Concentration for AFFF (6%) Solutions

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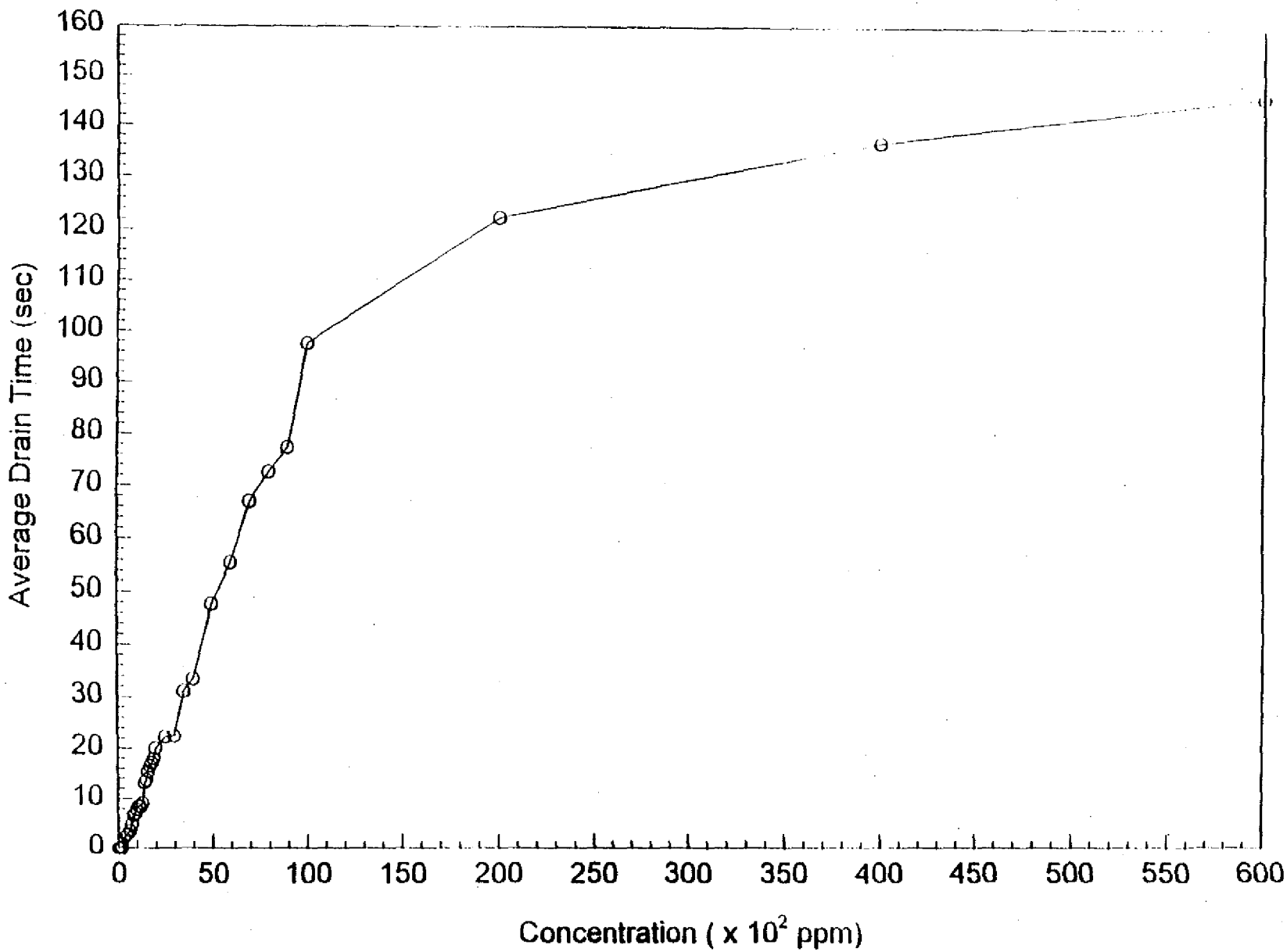

Fig. 2 - Average Drain Time vs. Concentration for AFFF (6%) Solutions

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It is typical when making comparisons between the environmental tests that it is difficult to assign particular concentrations to particular results between different wastes. To overcome this problem the BEFORE and AFTER data is compared by percent reduction. The percent reduction is defined as:

(initial concentration - final concentration) / initial concentration

The results in Table 1 that are below the detection limits are assigned the value of the detection limit. This assumption provides the maximum percent reduction that is possible. The results that are given as None Detected (ND) are given a value of 0 also reporting the maximum percent reduction possible. Table 2 lists the results of this analysis for the AFFF surfactant and the environmental tests.

Table 1 - Results of Environmental Tests

TEST	MILSPEC TEST BEFORE	MILSPEC TEST AFTER	WASTEWATER BEFORE	WASTEWATER AFTER
DRAIN TIME in PPM	1350	240	1800	500
BIOCHEMICAL OXYGEN DEMAND in mg/l (PPM)	<1000	220	1,100	870
CHEMICAL OXYGEN DEMAND in mg/l (PPM)	13000	2400	4,700	3,100
METHYLENE BLUE ACTIVE SUBSTANCES in mg/l (PPM)	13	3.7	98	29
TOTAL PETROLEUM HYDROCARBON in mg/l (PPM)	Not Taken	Not Taken	140	94
VOLATILE PETROLEUM HYDROCARBONS in µg/l (PPB)	2,000,000	100,000	300,000	65,000
BTEX				
BENZENE in µg/l (PPB)	20,000	200	700	200
TOLUENE in µg/l (PPB)	32,000	<100	2000	ND
ETHYLBENZENE in µg/l (PPB)	3200	ND	500	ND
XYLENES in µg/l (PPB)	17,000	ND	2400	<300
pH	8.1	8.5	5.6	5.6

The MILSPEC TEST samples contained volatile organic compounds that are effectively removed by the aeration process in the separator. The BTEX and VPH are reduced by over 95%. The MBAS, BOD_5 and COD are reduced by 78 - 82%, providing excellent agreement. This would seem to imply that the COD and BOD_5 tests are adequately taking into account the AFFF surfactants.

The results of the WASTEWATER samples are not as straight forward. While the percent reduction of the more volatile organics as evidenced by the BTEX and VPH results is still quite large, they do not correlate well with the change in COD. There may be several reasons for this. The starting concentration for VPH and BTEX are considerably lower for the WASTEWATER samples than for the MILSPEC TEST samples. As such they do not contribute as much to the COD results. The concentrations for BTEX and VPH for both AFTER samples are in the same concentration range. Using the values for VPH from Table 1 for AFTER samples of MILSPEC TEST and WASTEWATER, the results are 300,000 ppb and 65,000 ppb respectively. There may be a lower limit to the reduction of VPH using the AFFF separator so that the percent reduction analysis is misleading. Lastly, the presence of heavy hydrocarbons that are not as effectively removed by the aeration process may be more responsible for the COD than the volatile hydrocarbons for the WASTEWATER samples. The percent reductions between the TPH, COD and BOD_5 are in better agreement than any other tests of the WASTEWATER samples. This would seem to imply that the AFFF surfactants are not affecting the changes in the BOD_5 or COD very much, if at all. This discrepancy between the MILSPEC and WASTEWATER samples is not explainable at the current time with the limited test data available.

Table 2 - Percent Reductions between BEFORE and AFTER Samples

	MILSPEC TEST	WASTEWATER
TEST	% REDUCTIONS	% REDUCTIONS
DRAIN TIME	82%	72%
BOD_5	78%	21%
COD	82%	34%
MBAS	72%	70%
TPH	NA	33%
VPH	95%	78%
BTEX		
BENZENE	99%	71%
TOLUENE	100%	100%
ETHYLBENZENE	100%	100%
XYLENES	100%	88%

4.3 MBAS and Drain Time Correlation

To determine if the MBAS test could be correlated to the drain time results, four standard samples of Angus 3% MILSPEC AFFF were prepared: 1000 ppm, 500 ppm, 100 ppm, and 10 ppm. These samples were prepared using the same concentration assumptions used in the previous work [3]. The drain time for the standards were measured and the concentrations determined using the drain time versus concentration plots provided in Figures 1 and 2. The results are provided in Table 3. The drain time concentration values for the two samples below drain time detection limits are estimated using the average values from the drain time data and are shown in italics.

Table 3 - Drain Time and Concentration of AFFF Standard Solutions

CONCENTRATION BY DILUTION, PPM	DRAIN TIME SECONDS	CONCENTRATION BY DRAIN TIME, PPM
10	ND	*7*
100	ND	*68*
500	2.29	360
1000	4.34	670

The concentrations based on drain time are approximately 30% lower than predicted from dilution. This is not unexpected. Firstly, there were considerable assumptions made in the previous work in determining the concentration of the AFFF surfactants. Secondly, the AFFF used for this study is different than the one used for the previous study, Angus 3% MILSPEC AFFF versus 3M 6% MILSPEC AFFF (FC-206 CF), respectively. It is reasonable to expect that there are different concentrations of surfactants between the two proprietary formulations.

These four standard solutions and a control blank with the same water used to dilute the standards were sent for MBAS analysis. The results are provided in Table 4 with the results for the MILSPEC and WASTEWATER samples.

Table 4 - Drain Time Concentration versus MBAS Results

SAMPLE	CONCENTRATION BY DRAIN TIME, PPM	MBAS PPM
S-2 (CONTROL BLANK)	0	0
S-1	*7*	0.05
S-4	*70*	0.44
S-5	360	4.4
S-3	670	7.4
MILSPEC BEFORE	1350	13
MILSPEC AFTER	240	3.7
WASTEWATER BEFORE	1800	98
WASTEWATER AFTER	500	29

The intent was to determine if the MBAS results could be used to determine the concentration of AFFF surfactants. A Correlation Factor was developed by dividing the drain time concentration by MBAS. The results are provided in Table 5. The results for the standards and the MILSPEC TEST samples all appear to be in the same range. However, the WASTEWATER results are an order of magnitude higher for similar drain time concentrations. Possible explanations for this discrepancy are provided later in the report. The average Correlation Factor of 106 for the four standards and the MILSPEC tests is used to calculate concentrations based on the MBAS. The results are also provided in Table 5 with the percent difference between the two concentrations.

Table 5 - Drain Time-based Concentration versus MBAS-based Concentration in ppm

	DRAIN TIME	MBAS	CORRELATION	MBAS	
SAMPLE	CONCENTRATION		FACTOR	CONCENTRATION	DIFFERENCE
S-2	0	0	NA	0	NA
S-1	7	0.05	139	5	23%
S-4	70	0.44	158	47	33%
S-5	360	4.4	82	468	-30%
S-3	670	7.4	91	787	-17%
MILSPEC BEFORE	1350	13	104	1382	-2%
MILSPEC AFTER	240	3.7	65	393	-64%
WASTEWATER BEFORE	1800	98	18	10421	-479%
WASTEWATER AFTER	500	29	17	3084	-517%

The results for the standard samples are the best with absolute value percent differences ranging 17 to 33 % but the values for the others are not as good (i.e., 2 - 64% for MILSPEC TEST samples and 479 to 517% for WASTEWATER samples) and would not provide an adequate estimation of the AFFF surfactants.

There are several possibilities why this may be occurring. The MBAS test that is specified by the wastewater treatment plants is for anionic surfactants only. However, AFFF is a complex mixture of surfactants that may include anionic, non-ionic and cationic surfactants, and therefore only an unknown portion of the surfactants may be accounted for in this test. Secondly, the test was developed for typical surfactants used as detergents and is reported as LAS [5]. In calculating the results in a certain molecular weight is assumed that is almost certainly different from the molecular weight(s) of the AFFF surfactants. The results, therefore, would not be linear. Lastly, there may be chlorides in the WASTEWATER samples that are interfering with the results [5]. Chlorides may be present in the wastewater because the QPL test

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requires testing AFFF formulations with simulated salt water. The MBAS test alone does not appear to be adequate to determine the concentration of AFFF surfactants.

There is another environmental test that may be used to measure non-ionic surfactants, Cobalt Thiocyanate Active Substances (CTAS) . It is recommended that future work include both the MBAS and CTAS tests to determine if the combined results correlate to the drain time concentrations. There does not appear to be an EPA test method for cationic surfactants. The rationale is that the cationic surfactants represent only a small fraction of the total quantity of surfactant manufactured in the U.S. Unfortunately, the percent of cationic surfactants within AFFF formulations may be considerably higher than the U.S. average.

4.4 Summary

The AFFF separator is reducing the AFFF surfactants for these typical firefighting waste waters as well as it performed with 'pure' AFFF- water solutions. The presence of contaminants that would typically be found in firefighting wastes, such as petroleum hydrocarbons and aromatic compounds, do not appear to adversely affect the mechanism or the efficiency of the process. In addition, the separator is reducing the other pollutants in the waste as measured by BOD_5, COD, VPH, BTEX and TPH. The concomitant reduction can be significant, e.g., 95 to 100%, particularly for the more volatile species. The overall results are extremely encouraging and continued development of the AFFF separator is recommended, as discussed below.

5.0 CONCLUSION

1. The AFFF separator is able to reduce the AFFF surfactant concentrations of the firefighting wastewaters tested. Typical contaminants such as petroleum fuels and volatile aromatic compounds do not have an adverse effect on the final surfactant reduction process or final concentration.

2. The AFFF separator is also reducing the volatile petroleum hydrocarbons and aromatic compounds through the aeration process. The results from all of the environmental tests indicate that the effluent from the AFFF separator is less polluting than the original wastewater as based on COD and BOD_5.

3. The BOD_5 test is not adequate to characterize the typical firefighting wastewaters tested. A longer residence time is apparently needed for the bacteria to consume the organics. It is recommended that the BOD_{20} test be specified for all future testing.

4. The tests did not lend any insight into whether or not the AFFF surfactants are breaking down in the BOD or COD tests. The limited data does not provide any insight to this question.

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5. The MBAS test alone does not adequately correlate to the AFFF concentrations as measured by drain time. The environmental test for CTAS should also be included in any further testing.

6. It is not possible to determine whether these wastewaters would be acceptable to the wastewater treatment plants at CBD or Hampton Roads as direct influent. The degree of dilution with other influent wastewaters will impact this decision. However, the separator is improving the wastewater and should assist in making these effluents acceptable.

7. The results are extremely encouraging and continued development of the separator suitable for field testing is recommended.

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REPORT OF ANALYSIS

Report No. 96-03-124 Report Date: March 20, 1996

Report To: Hughes Associates Page: 1 of 15

Sample I.D. Submitted Water: CBD/K-09, WWI, dated 03/06/96 (0815)

	Results	Detection Limits
Benzene	700	100
Toluene	2,000	100
Ethylbenzene	500	100
Total Xylenes	2,400	300
Volatile Petroleum Hydrocarbons (reported as gasoline, C4 to C12)	300,000	10,000

Surrogate Recovery (%)

Trifluorotoluene	99

Dilution Factor: 100

Notes

(1) Results expressed as ug/l (ppb).
(2) Analysis performed according to method EPA 8020/8015-M.
(3) Analyst(s): CPB; Date Test Completed: 03/12/96.

William L. Lock
Laboratory Director

APPENDIX A

Gascoyne Laboratories, Inc.

Baltimore, MD 21224-6697

(410) 633-1800
(800) GAS-COYN
FAX NO.
(410) 633-5443

REPORT OF ANALYSIS

Report No. 96-03-124 Report Date: March 20, 1996

Report To: Hughes Associates Page: 2 of 15

Sample I.D. Submitted Water: CBD/K-09, WWII, dated 03/06/96 (0830)

	Results	Detection Limits
Benzene	200	100
Toluene	ND	100
Ethylbenzene	ND	100
Total Xylenes	<300	300
Volatile Petroleum Hydrocarbons (reported as gasoline, C4 to C12)	65,000	10,000

Surrogate Recovery (%)

Trifluorotoluene	117

Dilution Factor: 100

Notes

(1) Results expressed as ug/l (ppb).
(2) Analysis performed according to method EPA 8020/8015-M.
(3) Analyst(s): CPB; Date Test Completed: 03/12/96.

William L. Lock
Laboratory Director

US00007074

Gascoyne Laboratories, Inc.

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REPORT OF ANALYSIS

Report No. 96-03-124 Report Date: March 20, 1996

Report To: Hughes Associates Page: 3 of 15

Sample I.D. Submitted Water: CBD/K-09, MSI, dated 03/06/96 (0840)

	Results	Detection Limits
Benzene	20,000	1,000
Toluene	32,000	1,000
Ethylbenzene	3,200	1,000
Total Xylenes	17,000	3,000
Volatile Petroleum Hydrocarbons (reported as gasoline, C4 to C12)	2,000,000	100,000

Surrogate Recovery (%)

Trifluorotoluene	98

Dilution Factor: 1000

Notes

(1) Results expressed as ug/l (ppb).
(2) Analysis performed according to method EPA 8020/8015-M.
(3) Analyst(s): CPB; Date Test Completed: 03/12/96.

William L. Lock
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REPORT OF ANALYSIS

Report No. 96-03-124 Report Date: March 20, 1996

Report To: Hughes Associates Page: 4 of 15

Sample I.D. Submitted Water: CBD/K-09, MSII, dated 03/06/96 (0850)

	Results	Detection Limits
Benzene	200	100
Toluene	<100	100
Ethylbenzene	ND	100
Total Xylenes	ND	300
Volatile Petroleum Hydrocarbons (reported as gasoline, C4 to C12)	100,000	10,000

Surrogate Recovery (%)

Trifluorotoluene	95

Dilution Factor: 100

Notes

(1) Results expressed as ug/l (ppb).
(2) Analysis performed according to method EPA 8020/8015-M.
(3) Analyst(s): CPB; Date Test Completed: 03/12/96.

William L. Lock
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US00007076

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REPORT OF ANALYSIS

Report No. 96-03-124 Report Date: March 20, 1996

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Sample I.D. Submitted Water: CBD/K-09, WWI, dated 03/06/96 (0815)

	Test Results	Detection Limits	Method	Analyst	Date Test Completed
Biochemical Oxygen Demand	1,100	300	EPA 405.1	RAH	03/12/96
Chemical Oxygen Demand	4,700	1,000	EPA 410.4	PBK	03/13/96
Detergents (MBAS)	98	4	EPA 425.1	PBK	03/07/96
pH	5.6	NA	EPA 150.1	GB	03/06/96

Notes

(1) Results expressed as mg/l (ppm).

William L. Lock
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REPORT OF ANALYSIS

Report No. 96-03-124 Report Date: March 20, 1996

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Sample I.D. Submitted Water: CBD/K-09, WWI, dated 03/06/96 (0815)

	Test Results	Detection Limits	Method	Analyst	Date Test Completed
Total Pet. Hydrocarbons	140	1	EPA 418.1	PRM	03/15/96

Notes

(1) Results expressed as mg/l (ppm).

William L. Lock
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US00007078

Gascoyne Laboratories, Inc.

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REPORT OF ANALYSIS

Report No. 96-03-124 Report Date: March 20, 1996

Report To: Hughes Associates Page: 7 of 15

Sample I.D. Submitted Water: CBD/K-09, WWII, dated 03/06/96 (0830)

	Test Results	Detection Limits	Method	Analyst	Date Test Completed
Biochemical Oxygen Demand	870	300	EPA 405.1	RAH	03/12/96
Chemical Oxygen Demand	3,100	1,000	EPA 410.4	PBK	03/13/96
Detergents (MBAS)	29	2	EPA 425.1	PBK	03/07/96
pH	5.6	NA	EPA 150.1	GB	03/06/96

Notes

(1) Results expressed as mg/l (ppm).

William L. Lock
Laboratory Director

Gascoyne Laboratories, Inc.

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REPORT OF ANALYSIS

Report No. 96-03-124 Report Date: March 20, 1996

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Sample I.D. Submitted Water: CBD/K-09, WWII, dated 03/06/96 (0830)

	Test Results	Detection Limits	Method	Analyst	Date Test Completed
Total Pet. Hydrocarbons	94	1	EPA 418.1	PRM	03/15/96

Notes

(1) Results expressed as mg/l (ppm).

William L. Lock
Laboratory Director

US00007080

Gascoyne Laboratories, Inc.

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REPORT OF ANALYSIS

Report No. 96-03-124 Report Date: March 20, 1996

Report To: Hughes Associates Page: 9 of 15

Sample I.D. Submitted Water: CBD/K-09, MSI, dated 03/06/96 (0840)

	Test Results	Detection Limits	Method	Analyst	Date Test Completed
Biochemical Oxygen Demand	ND	1,000	EPA 405.1	RAH	03/12/96
Chemical Oxygen Demand	13,000	1,000	EPA 410.4	PBK	03/13/96
Detergents (MBAS)	13	1	EPA 425.1	PBK	03/07/96
pH	8.1	NA	EPA 150.1	GB	03/06/96

Notes

(1) Results expressed as mg/l (ppm).

William L. Lock
Laboratory Director

Gascoyne Laboratories, Inc.

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REPORT OF ANALYSIS

Report No. 96-03-124 Report Date: March 20, 1996

Report To: Hughes Associates

Sample I.D. Submitted Water: CBD/K-09, MSII, dated 03/06/96 (0850)

	Test Results	Detection Limits	Method	Analyst	Date Test Completed
Biochemical Oxygen Demand	220	50	EPA 405.1	RAH	03/12/96
Chemical Oxygen Demand	2,400	500	EPA 410.4	PBK	03/13/96
Detergents (MBAS)	3.7	0.5	EPA 425.1	PBK	03/07/96
pH	8.5	NA	EPA 150.1	GB	03/06/96

Notes

(1) Results expressed as mg/l (ppm).

William L. Lock
Laboratory Director

US00007082

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REPORT OF ANALYSIS

Report No. 96-03-124 Report Date: March 20, 1996

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Sample I.D. Submitted Water: CBD/K-09, S2, dated 03/06/96 (0900)

	Test Results	Detection Limits	Method	Analyst	Date Test Completed
Detergents (MBAS)	ND	0.02	EPA 425.1	PBK	03/07/96

Notes

(1) Results expressed as mg/l (ppm).

William L. Lock
Laboratory Director

US00007083

Gascoyne Laboratories, Inc.

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REPORT OF ANALYSIS

Report No. 96-03-124 Report Date: March 20, 1996

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Sample I.D. Submitted Water: CBD/K-09, S1, dated 03/06/96 (0900)

	Test Results	Detection Limits	Method	Analyst	Date Test Completed
Detergents (MBAS)	0.05	0.02	EPA 425.1	PBK	03/07/96

Notes

(1) Results expressed as mg/l (ppm).

William L. Lock
Laboratory Director

US00007084

Gascoyne Laboratories, Inc.

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REPORT OF ANALYSIS

Report No. 96-03-124 Report Date: March 20, 1996

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Sample I.D. Submitted Water: CBD/K-09, S3, dated 03/06/96 (0900)

	Test Results	Detection Limits	Method	Analyst	Date Test Completed
Detergents (MBAS)	7.4	0.5	EPA 425.1	PBK	03/07/96

Notes

(1) Results expressed as mg/l (ppm).

William L. Lock
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US00007085

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REPORT OF ANALYSIS

Report No. 96-03-124 Report Date: March 20, 1996

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Sample I.D. Submitted Water: CBD/K-09, S4, dated 03/06/96 (0900)

	Test Results	Detection Limits	Method	Analyst	Date Test Completed
Detergents (MBAS)	0.44	0.04	EPA 425.1	PBK	03/07/96

Notes

(1) Results expressed as mg/l (ppm).

William L. Lock
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REPORT OF ANALYSIS

Report No. 96-03-124 Report Date: March 20, 1996

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Sample I.D. Submitted Water: CBD/K-09, S5, dated 03/06/96 (0900)

	Test Results	Detection Limits	Method	Analyst	Date Test Completed
Detergents (MBAS)	4.4	0.2	EPA 425.1	PBK	03/07/96

Notes

(1) Results expressed as mg/l (ppm).

William L. Lock
Laboratory Director

US00007087