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FUEL LUBRICITY ADDITIVE EVALUATION

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TFLRF No. 323

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13. ABSTRACT (Maximum 200 words)

The U.S. Department of Defense is using kerosene fuel in compression ignition engines. This fuel is largely replacing conventional diesel, which has been used for many years. Jet A-1 and JP-8 have a number of advantages compared to diesel fuel. In particular, logistics burden is greatly reduced through the use of a single fuel for both aviation and ground vehicles on the battlefield. However, kerosene-based fuels typically have reduced lubricity compared to diesel fuels, potentially reducing injection system durability and vehicle readiness. A range of lubricity additives have been developed for use in low sulfur diesel and are commercially available. The objective of the present study is to evaluate the effectiveness of these additives when used in kerosene-based fuels.

A number of additives were obtained and evaluated using laboratory scale tests. The most effective additive was selected based on these results and tested using a 200-hour procedure with full scale injection equipment. The equipment tests were performed with two additive concentrations in a very severely refined Jet A-1 fuel. The results indicate that the commercially available lubricity additive effectively reduces wear at a concentration of 80 mg/L. A slight additional improvement in lubricity was obtained if additive concentration was increased to 200 mg/L.

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EXECUTIVE SUMMARY

Problems and Objectives: To reduce its logistics burden, the U.S. Army is using aviation turbine fuel in compression-ignition powered vehicles. However, previous full scale pump stand tests, as well as isolated reports of field failures, indicate that Jet A-1 may increase wear in rotary-type fuel lubricated fuel injection pumps. Addition of a simple corrosion inhibitor additive, at higher treatment levels than qualified under MIL-I-25017E, may reduce wear rate. However, wear mechanisms other than oxidative corrosion, such as mild scuffing, are also involved. This report evaluates recently developed fuel-lubricity additives, which may be more effective than those qualified under MIL-I-25017E.

Importance of Project: The fuel-injection system is central to the reliable operation of compression ignition engines. Rapid failure of these components may occur with low lubricity fuel, such as kerosene. A more effective lubricity additive could significantly improve readiness of vehicles operated with Jet A-1 kerosene. However, little data exists to compare recently developed, commercially available lubricity additives.

Technical Approach: A range of lubricity additives were obtained from commercial sources. Laboratory scale tests were performed to define the effects of these additives on lubricity and water-separation characteristics of a severely refined Jet A-1 fuel. More detailed laboratory tests were performed with the better additives. However, any laboratory scale test is only an indicator of real world performance. As a result, full scale pump stand tests were performed to define the benefits provided by the most effective additive at two concentrations. To facilitate direct comparison with the existing database, the pump stand test procedure was identical to that used in previous studies.

Accomplishments: The effectiveness of the lubricity additives varied considerably when evaluated in the laboratory scale tests. The most effective additive was identified as that which produced greatly reduced wear at a low concentration with minimal effect on water-separation characteristics. The pump tests confirmed that an additive concentration of 80 mg/L presented significant benefits, with a slight further improvement up to 200 mg/L. However, it should be recognized that injection-system performance may be affected by other fuel attributes, such as viscosity and water-separation characteristics, which may not be improved by lubricity additives.

Military Impact: This study confirms that the use of highly refined Jet A-1 in a temperate climate may produce accelerated wear of rotary fuel-injection pumps. A lubricity additive was identified that significantly improves injection-system durability with Jet A-1. The additive was slightly more effective than dilineoleic acid, the additive chemistry currently qualified under MIL-I-25017.

FOREWORD/ACKNOWLEDGMENTS

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. OBJECTIVE

The objective of this study is to define the effectiveness of recently developed, commercially available fuel lubricity additives. These additives will be compared to corrosion inhibitors qualified under MIL-I-25017 (1)* and a high-sulfur no. 2 diesel fuel.

II. BACKGROUND

The U.S. Department of Defense is moving toward the use of a single fuel, JP-8, in ground equipment. (2,3) In a related area, other countries are already mandating severe restrictions on sulfur and aromatic content in their diesel-fuel specifications. This trend,directed toward reducing vehicle-exhaust emissions may benefit fuel quality, ignition ratings and stability. Laboratory studies and recent field experience in Sweden and the United States suggest a reduction in the ability of fuels to lubricate sliding components within the fuel-injection system. These factors, combined with the trend toward increasing injection pressure in modern engine design, are likely to result in reduced durability and failure of equipment which utilize rotary-type fuel lubricated fuel injection pumps to meet long-term emissions compliance.

Diesel-fuel specifications have intentionally remained broad to allow the maximum availability of the fuel and lowest possible price.(4) Historically, many developed nations have allowed a high sulfur content in the range of 0.5 mass percent (mass%), with no specification on aromatic content.(5) The industrialized nations are currently tightening diesel-fuel quality specifications, with elimination of sulfur being the primary concern. Reduction in sulfur content will minimize formation of sulfuric acid in the atmosphere and will facilitate future development of platinum-catalyzed particulate traps.(4) Data generated in a cooperative study sponsored by the Coordinating Research Council (CRC) as part of their Vehicle Emissions Program (VE 1) confirmed the primary importance of sulfur in emissions. (6, 7) However, the VE 1 study indicated that exhaust hydrocarbons, carbon monoxide, oxides of nitrogen, and particulate matter were also marginally reduced by decreasing aromatic content. Later studies have indicated that cetane number may be more directly related to emissions than aromatic concentration alone.(8)

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*Underscored numbers in parentheses refer to the list of references at the end of this report.

A selection of the relevant fuel specifications from around the world is summarized in TABLE 1. In 1991 and 1992, Sweden defined several new fuel classes that regulate a number of characteristics, including sulfur and aromatic content. Different tax classes were designed to provide economic incentives to use the clean burn Class I and II fuels rather than the higher sulfur Class III fuel. In the In October 1993, the United States Environmental Protection Agency limited the maximum fuel sulfur content to 0.05 mass% from its previous level of 0.5 mass%. Additionally, aromatics were restricted by either a 40 minimum cetane index or a 35-vol.% aromatic limit. Based on the VE 1 study, the California Air Resources Board (CARB) mandated an additional requirement of 10-vol.% aromatic in diesel fuel sold in California. Japan is scheduled to implement legislation to reduce sulfur content within the next few years.

TABLE 1. Fuel Classes

Fuel Class	Introduced	Maximum Sulfur, ppm	Maximum Aromatic, vol.%	Minimum Cetane	90% Point, °C	Mean SLC*, grams
Sweden/Class I	1991	10	5	50	285 (95%)	1,200**⊕
Sweden/Class II	1991	50	5	47	295 (95%)	1,400**⊕
Sweden/Class III	1991	3,000	--	46	340	--
Europe	1994	2,000	--	48	--	3,800⊕
Europe/CEN	1996	500	--	49	370	N/A
Japan	Pre- 1997	2,000	--	45	350	N/A
	Post-1997	500	--	45	350	N/A
USA/VV-F-800	Pre- 1993	5,000	--	40	338	3,866
USA/EPA	Post-1993	500	35***	40	338	3,086
USA/CARB	Post-1993	500	10◊	48	320	3,081

* SLC = Scuffing Load Capacity
** Later Swedish fuels that contained lubricity additives had an SLC in excess of 3,000 grams.
⊕ Represents data obtained from a small number of samples.
*** Aromatic limited to 35 vol.% or a minimum cetane index of 40.
◊ Fuel intended for use in California must have an aromatic content below 10 vol.% unless shown to produce emissions below that a CARB-specified referee fuel.

Most components within the fuel-injection system rely on fuel for effective lubrication and wear resistance. Many kerosene and low-sulfur fuels are severely refined. Hydrotreating reduces trace components, such as oxygen- and nitrogen-containing compounds and polycyclic aromatics. These naturally occurring, chemically active and polar compounds, which provide additive solubility and some lubricating qualities in formulated oils, are the only active components present in non-additized fuels to reduce wear.

To date, the Army has evaluated a number of those additives qualified under MIL-I-25017 for the improvement of diesel or kerosene fuel lubricity characteristics. While treatment with this additive has proved successful, the required treat rates are relatively high, ranging from 100 to 250 parts per million, which represents a ten-fold increase over the recommended treatment levels specified for aircraft applications. Additionally, this additive was not originally intended as a diesel-fuel lubricity additive and can produce unwelcome side effects, such as decreased water-shedding tendencies at higher treatment levels. Other commercially available diesel-fuel lubricity additives are available in the United States. The present study will evaluate the effectiveness of these additives and identify any potential side effects.

III. APPROACH

A. Summary of Technical Approach

Laboratory scale wear tests were performed to compare the effectiveness of commercially available fuel lubricity additives. The additives were also evaluated using laboratory tests for water-separation characteristics, according to ASTM procedures D 3948 and D 1094.(9, 10) These tests reflect the difficulty in coalescing water from the fuel. Surfactants and antiwear additives affect the ability of filter separators to remove free water prior to entering the engine. A number of laboratory scale wear tests for fuel lubricity are available. Directional correlation has been shown between the laboratory scale tests and full scale equipment.(5, 11) However, no laboratory scale wear test is completely accurate under all conditions. In a full scale pump, viscosity, pressure viscosity coefficient, operating temperature and fuel composition combine to create a complex lubrication process. In addition, the wear conditions in most laboratory scale tests are accelerated to produce results in a reasonable period, which may also affect accuracy. As a result, the most effective lubricity additive, as defined using the laboratory scale tests, was evaluated using a 200-hour full scale pump test. Overall degradation in performance was defined by operating each pump on a calibration stand before and after each test. Finally, each pump was completely disassembled, and qualitative and quantitative wear measurements were performed. The results were compared to baseline pump test data, obtained under identical conditions as described in Reference 19 .

B. Laboratory Scale Wear Tests

Laboratory scale wear tests were performed using both the Ball on Cylinder Lubricity Evaluator (BOCLE) and the high frequency reciprocating rig (HFRR). The principal test conditions used with both machines are summarized in TABLE 2. A more detailed description of the procedures may be obtained in References 12 and 21.

TABLE 2. Operating Conditions for Laboratory Wear Tests

Test Parameter	BOCLE (SLWT)	BOCLE (ASTM D 5001)	HFRR
Applied Load, kg	1 to 5 (variable)	0.5	0.2
Speed	525 RPM	240 RPM	50 Hz
Break-in, sec/kg	30/0.5	None	None
Duration, min	1.0	30	75
Atmosphere	Controlled Air	Controlled Air	Uncontrolled
Humidity, %Rh	50	10	Ambient
Temperature, °C	25	25	25 or 60
Pass/Fail	2.8 kg	0.65 mm	0.38/0.45 mm*

* Depending on test temperature

The HFRR consists of a reciprocating 0.25 inch ball in contact with an opposing polished flat. The test apparatus is completely computer controlled, with continuous measurement of both friction coefficient and contact resistance. The HFRR test is performed at 25°C, over a period of 75 minutes. A test procedure at 60°C is also available, but was not performed because it would have caused excessive evaporation of the relatively light Jet A-1 fuel used in the present study. Following each test, the ball specimen is removed from the reciprocating holder and the dimensions of the wear scar measured using an optical microscope. The mean diameter of the wear scar is taken as a measure of lubricity. A wear scar diameter in excess of 0.38 mm is normally considered to indicate poor fuel lubricity in tests performed at 25°C.

Two procedures exist for the Ball on Cylinder Lubricity Evaluator. The first is commonly referred to as the Scuffing Load Wear Test (SLWT) and determines the minimum applied load required for a step transition to adhesive scuffing.(12) During testing, the fluid is placed in a humidity-controlled reservoir. A nonrotating steel ball is held in a vertically mounted chuck and forced against an axially mounted polished steel ring. A sequence of one-minute tests is performed, and the applied load is systematically changed until a disproportionate change in friction and wear is observed. The test cylinder is rotated at a fixed speed while being partially immersed in the fluid reservoir. This partial immersion maintains the cylinder in a wet condition and continuously transports the test fluid to the ball/cylinder interface. The minimum applied load required to produce a transition to severe friction and wear is a measure of the fluid-lubricating properties and is inversely related to wear. A Scuffing Load Capacity (SLC) below 2800 grams is normally considered to indicate poor fuel lubricity.(11, 13) However, this value is dependent on a number of factors, including fuel viscosity, operating temperature and humidity.

A second BOCLE procedure, defined in ASTM D 5001, is widely used with aviation fuels but was excluded in the present work.(14) The ASTM D 5001 test measures the diameter of the wear scar formed on a test ball following 30 minutes of continuous, lightly loaded sliding. The principal wear mechanism is oxidative corrosion, which is significant only in the most severely refined fuels. The oxidative mechanism is eliminated by trace quantities of natural or artificial compounds that act as corrosion inhibitors. In fact, this test is primarily used to qualify the very low concentrations of corrosio inhibiting/lubricity additives specified in MIL-I-25017, as used in JP-8. Further increases in additive concentration have no effect on the very mild ASTM D 5001 BOCLE test. In reality, the load carrying ability of the fuel is improved by higher concentrations of anti-wear compounds, a fact reflected by the SLWT and HFRR tests. As a result, the ASTM D 5001 BOCLE test is only capable of predicting the poorest lubricity fuels, while the SLWT and HFRR remain viable over the complete spectrum of fuels.

C. Test Fuel and Additives

The laboratory and full-scale pump stand tests were performed with a Jet A-1 fuel of known low lubricity. This fuel has both very low viscosity and sulfur content. A complete summary of its chemical and physical properties is provided in Appendix A. A sufficient volume of fuel was obtained to allow completion of the required test matrix from a single batch. Tests were performed using this fuel, both with and without additives. Eighteen lubricity additives were obtained directly from the original manufacturers. All but two of the additives, which are experimental in nature, are commercially available. The chemical composition of the additives are proprietary. Laboratory scale tests were also performed using DCI-4A and NATO S-1750. DCI-4A is a corrosion inhibitor additive qualified under MIL-I-25017 and is primarily dilineoleic acid. NATO S-1750 is a multipurpose additive for diesel engines used by three NATO countries (i.e., BE, FR and NL),and is described by the French DCSEA 751 issue specification.

Data from full-scale pump stand tests, performed under identical test conditions with Jet A-1 fuel containing 30 mg/L of DCI-4A and also reference no. 2 diesel fuel, are also included. These tests were previously reported in Reference 19 and should be directly comparable to those in the present report. The Jet A-1 fuel is identical to that used in the present tests. The reference no. 2 diesel fuel has excellent lubricity, with a scuffing load capacity of approximately 5000 grams. The remaining chemical and physical properties of the reference no. 2 fuel are defined in Appendix A.

D. Pump Test Procedure

Three standard (Model No. DB2829-4524) and three arctic fuel pumps (Model No. DB2829-4523) were procured. The arctic component corresponds to that currently used on the High Mobility Multipurpose Wheeled Vehicle (HMMWV). Both pump models are identical in configuration, but the arctic pump contains an improved metallurgy in certain critical components. A more complete description of the Stanadyne pump and a schematic diagram are provided in Reference 19. For reference, each pump was assigned a code, shown in TABLE 3. Test results, performed under identical conditions and previously reported in Reference 19, are included as Pump Codes 7, 8, 9, and 10.

TABLE 3. Fuel Injection Pump Code Sheet

Code No.	Pump Type	Serial No.	Fuel	Additive Type	Additive Conc. mg/L
1	Standard	8239197	Jet A-1	None	None
2	Arctic	8164640	Jet A-1	None	
3	Standard	8239198	Jet A-1	Commercial	80
4	Arctic	8164642	Jet A-1	Commercial	80
5	Standard	8239209	Jet A-1	Commercial	200
6	Arctic	8066006	Jet A-1	Commercial	200
7	Standard*	6627505	Jet A-1**	MIL-I-25017	30
8	Arctic*	6624984	Jet A-1*	MIL-I-25017	30
9	Standard*	6627507	DF-2***	None	None
10	Arctic*	6624981	DF-2***	None	None

*Data taken from Reference 19
**Jet A-1 containing additive qualified under MIL-I-25017 is effectively JP-8
***Test fuel used in Caterpillar 1-H2 Lubricants test

The pumps were not disassembled prior to testing, and no quantitative pretest dimensional measurements were taken on individual pump components. A number of previous studies in this area have attempted to record the weight loss of parts subject to wear.(15) However, previous work at BFLRF with Stanadyne pumps has indicated that equally accurate post-test measurements are possible using surface profilometry.(16,17)

Prior to testing, each pump was placed on a calibration stand, and the fuel delivery and injection timing were precisely defined in accordance with the manufacturer's specifications.(18) Complete descriptions of the calibration procedure, results, and manufacturer's tolerances are provided in Appendix B. Because some tolerance is built into the manufacturer's specifications, the operating characteristics of each pump were precisely recorded. These results were maintained for comparison, and similar measurements were taken after completion of the pump stand tests. After these initial measurements were taken, no modifications or adjustments were made to the pumps until the test series and subsequent reevaluation on the calibrated test stand were completed.

An arctic pump and a standard pump were tested simultaneously on a Unitest stand. Pump performance was continuously monitored so that the test could be terminated prior to catastrophic failure. To ensure a realistic environment, the mounting arrangement and drive gear duplicate that of the GM 6.2L engine. A schematic diagram of the fuel delivery circuit is shown in Fig. 1. For this study, 250 gallons of test fuel were maintained in an enclosed reservoir and was continuously recirculated throughout the duration of each test. A centrifugal supply pump provided a positive head of 3 psi at the inlet to the test pumps. A primary (sock) filter (AC Part No. T935) and a cartridge filter corresponding to that used on the 6.2L engine in the HMMWV (GM Part No. 14075347) were used to remove wear debris and particulate contamination. Finally, a 5-kW explosion-resistant circulation heater produced the required fuel-inlet temperature. The heater has a relatively low-watt density of 15 W/in.^{2} to minimize fuel degradation due to flash heating. A 40-liter (11-gal.) reservoir was placed in line after the heater to ensure that the fuel supply temperature remained stable as the thermostat cycled. Each pump was fully insulated using rockwool to ensure that the temperature of the complete unit was similar to that of the incoming fuel.

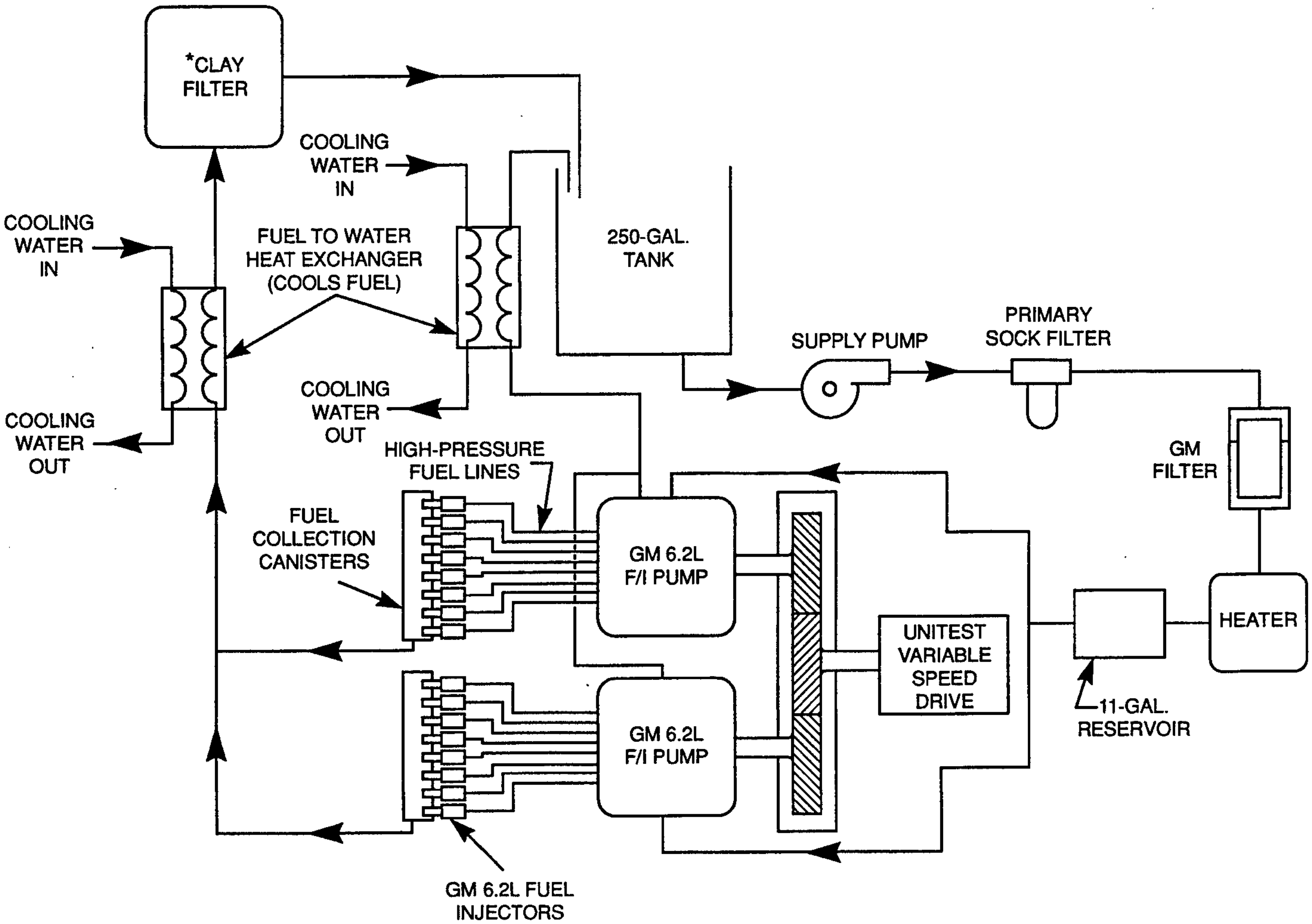

Figure 1. <u>Schematic Diagram of Fuel Delivery Circuit</u>

The high-pressure outlets from the pumps were connected to eight NA52X fuel injectors from a GM 6.2L engine and assembled in a collection canister. Fuel from both canisters was then returned to the bulk storage tank via a common return line. A separate line to the bulk storage tank was used to carry excess fuel from the governor housing. Fuel-to-water heat exchangers on both the return lines from the injector canisters and the governor housing controlled the temperature of the fuel. J-type thermocouples were placed at the inlet side of each pump and in the bulk storage tank. The temperature of the fuel reservoir was maintained below the minimum flash point of Jet A-1 (given in Appendix A) to minimize evaporation of the lighter fractions in the fuel. A pressure gauge was placed at the inlet to each pump, and a separate tool was manufactured to allow continuous measurement of the internal transfer pump pressure during normal operation.

IV. RESULTS

A. Laboratory Scale Tests

The results of initial screening tests are provided in TABLE 4. The neat Jet A-1 fuel has very poor lubricity and good water-separation characteristics. Each additive was initially tested in Jet A-1 at the concentration(s) recommended by the manufacturer. If the manufacturer recommended a range of concentrations for the additive, then it was evaluated at more than one concentration. Additive A-4 failed to dissolve completely and was eliminated from further testing. Because additives D-4 and D-5 are not commercially available, they were excluded from more detailed study.

A wide variation in additive effectiveness was observed. Only two additives, C-2 and E-2, are capable of increasing the scuffing load capacity to 2500 grams or more. A large reduction in wear rate was also observed in the HFRR tests, with a slight effect on water-separation characteristics. The results of more detailed testing with additives C-2 and E-2 are provided in TABLE 5. Baseline tests are also included for Jet A-1 containing NATO S-1750 and DCI-4A. The NATO S-1750 produced a slight increase in scuffing load capacity, but had no deleterious effects on water-separation characteristics.

DCI-4A was not particularly effective in either of the wear tests reported in TABLE 5. This additive is qualified under MIL-I-25017 for use at a concentration of approximately 22 mg/L to reduce oxidative wear in kerosene fuels. Oxidative corrosion may occur in compression ignition equipment, but will be eliminated by all the additives in the present study. This wear mechanism is best measured using the ASTM D 5001 test. The more severe wear tests designed for use with diesel fuel recorded only a slight improvement in lubricity at low concentrations of this additive. However, a significant improvement was recorded by both the SLWT and the HFRR wear test at a DCI-4A concentration of 125 mg/L and again at 250 mg/L.

Commercial additive E-2 improved lubricity, as measured by the HFRR and SLWT, at a concentration of 60 to 80 mg/L. At concentrations of 130 and 175 mg/L, additive E-2 showed a slight additional improvement. The water interface and separation results for additive E-2 were similar to those for DCI-4A, while the results from the ASTM D 3948 microseparometer test were somewhat better than those for DCI-4A. The neat fuel gave a perfect result of 100, which indicates that almost no surface active substances are present. At a concentration of 175 mg/L, additive E-2 still produced a good ASTM D 3948 result of 87.

Overall, the results of the laboratory scale tests indicate that additive E-2 is most effective. Additive C-3 required significantly higher concentrations for good lubricity. The DCI-4A additive, qualified under MIL-I-25017, performed well, but remained slightly less effective than additive E-2, with a larger affect on water-separation characteristics. As a result, additive E-2 was selected for evaluation in the full scale pump stand tests.

TABLE 4. Fuel Lubricity Additive Screening Test Results

Manuf-additive Code	Additive	Laboratory Number	Conc. mg/L	D-3948	Chg. Vol. ml	Interface	Separation	SLWT grams	HFRR mm
Neat Fuel None		20844	0	100	0	1	1	1300	0.645
A-1	Commercial	24109	25	85	0	1	1	1550	0.720
A-1	Commercial	24109	100	98	0	2	3	2000	0.550
A-2	Commercial	24110	25	98	0	1	1	1700	0.785
A-2	Commercial	24110	100	92	0	1	1	2200	0.675
A-3	Commercial	24111	25	97	0	1b	2	1700	0.710
A-3	Commercial	24111	100	42	0	2	3	2400	0.315
A-4	Commercial	24112	25*	100	0	1	1	1550	0.660
A-4	Commercial	24112	100*	96	0	1b	2	2000	0.240
B-1	Commercial	24090	50	54	0	2	2	2050	0.725
B-1	Commercial	24090	150	0	0	2	2	1850	0.385
B-2	Commercial	24091	50	0	0	2	2	1700	0.645
B-2	Commercial	24091	150	0	+8.5	2	3	2150	0.350
C-1	Commercial	24054	1450	66	0	2	3	2500	0.275
C-2	Commercial	24055	1450	83	0	2	3	2500	0.230
C-3	Commercial	24056	1450	0	+7	2	3	1950	0.375
D-1	Commercial	23980	25	94	0	1	1	1500	0.750
D-1	Commercial	23980	100	56	0	1	1	1550	0.680
D-2	Commercial	23981	25	99	0	1	1	1500	0.760
D-2	Commercial	23981	100	98	0	1	1	1600	0.610
D-3	Commercial	23982	25	100	0	1	1	1800	0.730
D-3	Commercial	23982	100	96	0	1	1	1800	0.375
D-4	Experimental	23978	25	66	0	2	2	1600	0.685
D-4	Experimental	23978	100	0	+5	2	3	1950	0.385
D-5	Experimental	23979	25	69	0	2	2	1550	0.675
D-5	Experimental	23979	100	0	+5.5	2	3	1750	0.370
E-1	Commercial	24047	700	96	0	2	2	2100	0.225
E-2	Commercial	24133	175	87	0	2	2	2550	0.215
F-1	Commercial	24050	50	97	0	1b	1	1500	0.740
F-1	Commercial	24050	100	89	0	1b	2	2050	0.390
H-1	Commercial	24032	1000	00	0	1b	2	1350	0.405

TABLE 5. Supplemental fuel Lubricity Additive Tests

Manuf-Additive Code	Additive	AL Number mg/L	Conc. ml	D-3948	Chg. Vol.	Interface	Separation	SLWT grams	HFRR
	mm								
0-0	none								
		20844	0	100	0	1	1	1300	0.645
C-2	Commercial	24055	1450	83	0	2	3	2500	0.230
C-2	Commercial	24055	700	90	0	2	1	2500	0.365
C-2	Commercial	24055	350	88	0	2	1	2050	0.475
E-2	Commercial	24133	175	87	0	2	2	2550	0.215
E-2	Commercial	24133	130	74	0	1b	1	2600	0.180
E-2	Commercial	24133	80	88	0	1b	1	2450	0.230
E-2	Commercial	24133	60	94	0	1	1	2250	0.360
E-2	Commercial	24133	40	94	0	1	1	1750	0.645
G-1	NATO S-1750	23844	1000	89	0	1	1	1800	0.230
G-1	NATO S-1750	23844	500	88	0	1	1	1750	0.265
G-1	NATO S-1750	23844	250	N/A	N/A	N/A	N/A	1700	0.610
G-1	NATO S-1750	23844	150	N/A	N/A	N/A	N/A	1550	0.620
J-1	MIL-I-25017	23926	250	58	0	1	1	2350	0.225
J-1	MIL-I-25017	23926	125	57	0	1	1	2150	0.300
J-1	MIL-I-25017	23926	50	71	0	1	1	1950	0.705
J-1	MIL-I-25017	23926	30	90	0	1	1	1700	0.680

B. Full-Scale Pump Stand Test Data

As detailed in TABLE 3, full-scale pump stand tests were performed using neat Jet A-1, as well as Jet A-1 containing both 80 and 200 mg/L of additive E-2. The pumps were inspected at regular intervals throughout each 200 hour test. Measurements taken for each of the six pumps are provided in Appendix C. The data includes ambient temperature and humidity, along with fuel temperature at the inlet to the pump, at the outlet from the pump and in the fuel-storage drum. Fuel pressure was measured at the inlet to the pump, within the pump housing, and in the low-pressure fuel return line following the collection canister.

Each of the pumps successfully completed the 200-hour test with no obvious failures. The fuel delivery is plotted in Figs. 2 and 3 for the standard and arctic pumps respectively. The plotted data represents the fuel flow through the high-pressure injectors and does not contain the low-pressure excess fuel return from the pumps. In general, little or no variation in pump delivery was observed during the 200-hour tests. However, a significant increase in delivery was observed with neat Jet A-1 following 175 hours of testing. This increase was probably due to wear of the rotor-retainer spring. Wear tests were performed with each test fuel following completion of the 200-hour test. Little or no variation in fuel lubricity was observed in tests performed with the HFRR and the SLWT. This indicates that the composition of the test fuel was not significantly affected by degradation or contamination during the extended pump test.

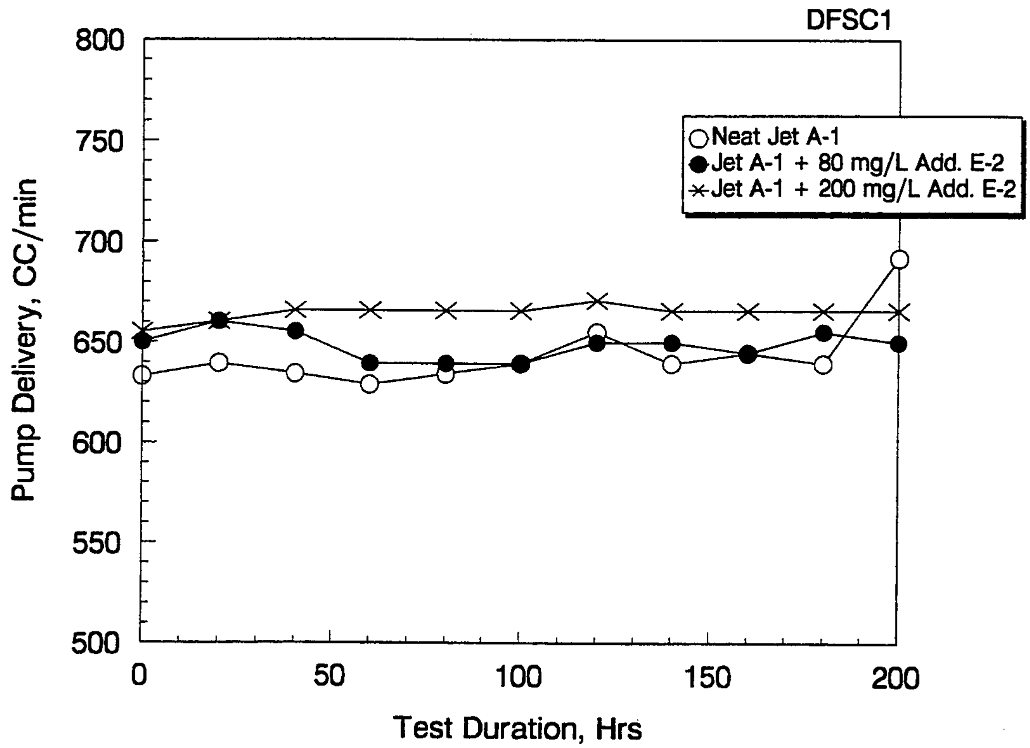

Figure 2. <u>Fuel Delivery with Standard Pumps</u>

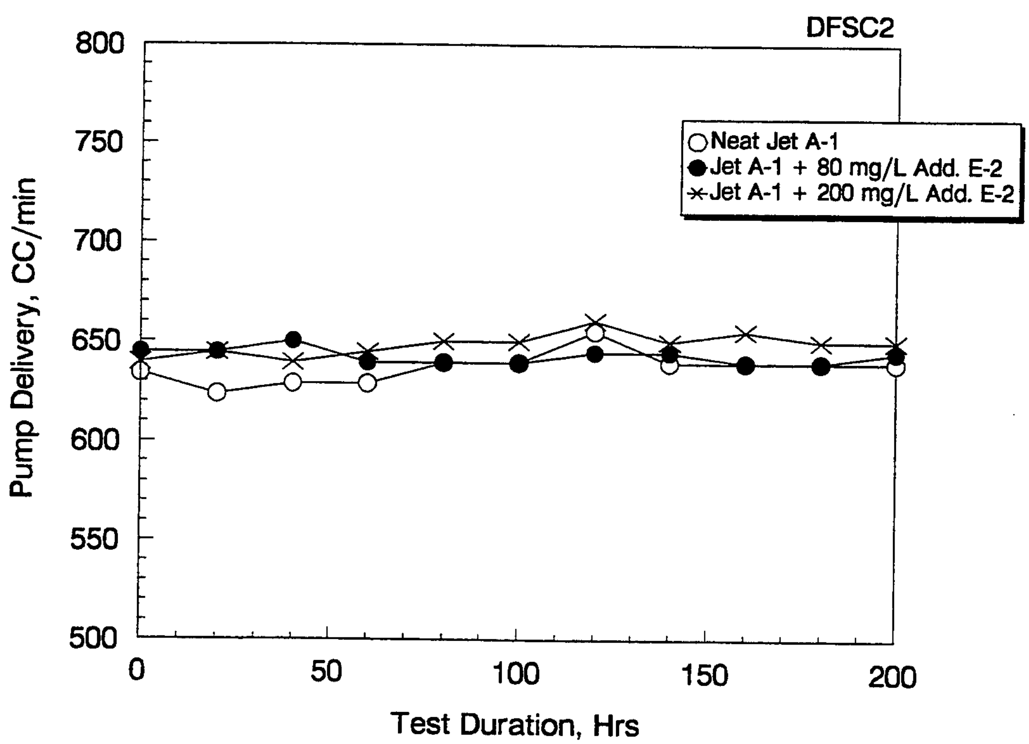

Figure 3. <u>Fuel Delivery with Arctic Pumps</u>

C. Pump Calibration Stand

After completion of the 200-hour tests, each pump was reevaluated on a calibrated test stand. The pump characteristics were measured using the conditions specified by the manufacturer (18), repeating those made prior to testing. Both the pretest and post-test measurements are provided in Appendix B. As expected, the pretest pump measurements were all within the range specified by the manufacturer. Following the 200-hour test, with pumps 1 and 2 operated with neat Jet A-1, the transfer pump pressures were slightly below the range specified by the manufacturer. By comparison, little or no variation was observed for the remaining pumps, which operated on additized Jet A-1. Overall, a significant degradation in pump operating performance was not produced during any of the 200-hour tests.

D. Full-Scale Pump Disassembly and Wear Measurement

The post-test pump operating characteristics described in the previous sections are a complex function of the degradation and wear processes distributed throughout the pump. Some components, such as the drive tang and slot, will have no effect on the performance as measured on the calibrated test stand. Wear of other components, such as the transfer pump vanes, may not be evident until a critical level is reached. An accurate measure of additive effectiveness requires quantitative measurement of wear throughout the pump.

Particular attention was given to areas of the pump previously demonstrated to be susceptible to wear when used with low-lubricity fuels.(16, 17, 19, 20) Furthermore, the metallurgy in many of these components was upgraded in the arctic kit, facilitating quantitative comparison between the standard and arctic pumps. The following components were selected and include a wide range of contact conditions:

a. Transfer pump blades
b. Drive tang
c. Drive slot
d. Governor sleeve thrust washer
e. Governor weights
f. Cam roller shoe
g. Rotor retainers

The wear volume ($mm^3 \times 10^{-3}$) measured in each of the pumps described in TABLE 3 is summarized in TABLE 6. The dimensions of each wear scar were normally defined from surface profiles taken using a Talysurf profilometer, although optical microscopy was also used in some instances. A more complete description of the wear measurement procedure is available in Reference 19.

TABLE 6. Wear Volume on Selected Pump Components ($mm^3 \times 10^{-3}$)
(**NOTE:** Bold text denotes arctic components with improved metallurgy.)

	Pump Blades	Drive Tang	Drive Slot	Thrust Washer	Governor Weight	Roller Shoe	Rotor Retainers
Pump No. 1	149	11025	4725	599	84	183	2640
Pump No. 2	**10**	4752*	**1440**	**141**	137	327	2442
Pump No. 3	2	640	176	80	60	17	1884
Pump No. 4	**2**	**50**	**60**	**150**	123	57	1635
Pump No. 5	2	91	41	239	89	7	990
Pump No. 6	**3**	**14**	**14**	**183**	95	3	-
Pump No. 7**	5	147	112	145	132	19	1188
Pump No. 8**	**3**	**28**	**60**	**192**	96	30	1188
Pump No. 9**	7	101	31	-	36	38	99
Pump No. 10**	**2**	**5**	**36**	**135**	36	24	132

*Data taken from Reference 19
**This pump was provided to SwRI as an arctic pump but did not contain the modified drive tang

Clearly, a wide variation in the severity of the wear process exists among the components selected for quantitative wear measurement. Many contacts are lightly loaded and produce a corrosive wear mechanism with neat Jet A-1,resulting in a polished-surface topography. The inside of the aluminum housing on both the arctic and standard pumps that operated on neat Jet A-1 contained a brown rust deposit, while the pumps that operated on additized Jet A-1 were relatively clean. No evidence of oxidative corrosion was present with any additized fuel. A similar effect was previously discussed in Reference 19.

In general, severe wear is present throughout the complete standard pump (pump no. 1) that operated on neat Jet A-1. Severe wear, due to an adhesive mechanism, was present on highly loaded areas, such as the drive tang and roller shoe, when compared with tests performed with additized fuel. Photographs of the wear scars on selected components are provided in Appendix D. The DCI-4A and the E-2 additives successfully reduced wear throughout the pump, sometimes by over an order of magnitude. Increasing concentrations of the E-2 additive from 80 to 175 mg/l showed only slightly improvement. Surprisingly, additive E-2 was no more effective than DCI-4A in reducing wear on the components discussed in TABLE 6. In fact, the simple dilineoleic acid type additive was used at only 30 mg/L, compared to the 80 and 200 mg/L for the E-2 additive. Overall, the baseline tests with conventional high-sulfur diesel fuel produced least wear (pumps 9 and 10), probably due to a combination of good lubricity and relatively high viscosity.

The wear observed on arctic components is denoted using bold text in TABLE 6. The improved metallurgy of the arctic components significantly reduced the amount of wear present on pump vanes lubricated with neat Jet A-1. However, pump no. 2 came from the manufacturer with a standard drive tang in place of the correct arctic component. As a result, no conclusion can be drawn for either the drive tang or drive slot on this pump. The arctic components produced a slight further reduction in the measured wear rate with the better lubricity fuels when compared with the standard components. Clearly, the arctic kit improves pump durability, particularly with low-lubricity fuels. It should be noted, however, that only a limited number of components have the improved metallurgy. The governor thrust washer was the only revised component that was not improved by the new metallurgy. However, in the present case, the degree of wear of this component was not found to be critical, but was reduced by the use of lubricity additives. A similar effect has been observed in previous reports. (19)

Only seven components were selected for quantitative wear measurement. Detailed wear measurement on the complex geometries of every component in each of the pumps is prohibitively difficult. Instead, the procedure developed in previous reports (16, 17) was used; wear-prone components throughout each pump were subjectively graded from 0 to 10 according to the degree of wear present. The results of this process are given in TABLE 7.

TABLE 7. Subjective Wear Level* on Critical Pump Components

	Component	1	2	3	4	5	6	7	8	9	10
Hydraulic Head & Rotor											
	Distributor Rotor	6	4	2	2	2	0	2	2	0	0
	Delivery Valve	8	6	4	4	4	4	4	4	2	2
	Plungers	8	6	8	6	4	2	4	6	2	2
	Cam Rollers & Shoes	8	6	4	4	4	4	6	6	2	2
	Leaf Spring & Screw	4	4	2	2	2	2	2	2	2	2
	Drive Shaft Tang	10	8	6	6	4	2	6	2	2	2
	Cam	4	4	2	2	2	2	2	2	2	2
Governor	Governor Weights	6	4	4	4	4	4	4	2	2	2
	Governor Thrust Washer	4	2	2	2	2	2	4	4	2	2
	Governor Thrust Sleeve	6	2	2	4	2	2	4	4	2	2
	Metering Valve	6	4	4	4	4	4	4	2	2	2
Transfer Pump	Pressure Regulator	6	4	2	2	2	6	4	4	2	4
	Regulating Piston	4	4	4	2	4	4	4	4	4	4
	Blades	10	2	4	4	4	2	4	2	2	2
	Liner	10	4	6	4	6	4	4	6	2	4
	Rotor Retainers	6	6	6	6	6	6	6	6	2	2
Advance	Piston	6	6	6	6	4	4	6	6	2	4

Column heads 1–10: Pump.

* 0 = No Wear; 10= Failure.

The average results derived from all the components in each complete pump are summarized in Fig. 4. This subjective measure of pump durability qualitatively agrees with the measurements taken from selected components. The improved metallurgy in the arctic components normally reduced wear, with a particularly large decrease for neat Jet A-1. Each of the lubricity additives significantly reduced wear, although least wear was recorded for high-sulfur diesel fuel. Wear rate for Jet A-1 with 80 mg/L of additive E-2 was only slightly lower than that observed for 30 mg/L of DCI-4A. However, a further reduction in wear rate was observed when the concentration of additive E-2 was increased to 200 mg/L.

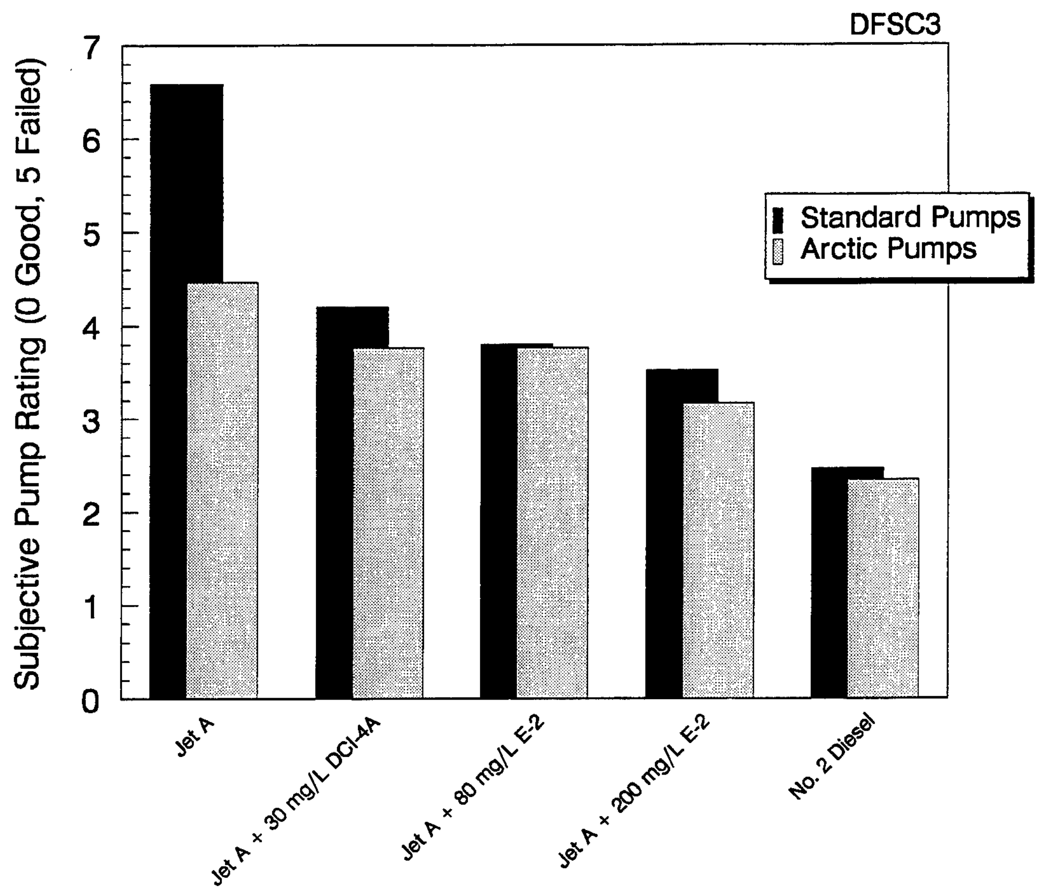

Figure 4. Subjective Wear Level on Pump Components-Averaged for Each Pump

V. DISCUSSION

The effectiveness of fuel lubricity additives was evaluated using laboratory scale tests as well as full scale pump stand tests. The laboratory scale screening tests were performed using a range of commercially available lubricity additives in a severely refined Jet A-1 fuel. Significant differences were observed in the effectiveness of the additives tested. The most effective additive was evaluated in full scale pump tests at two different concentrations. The 200-hour test duration was not sufficient to produce a significant deterioration in pump performance, with or without additive. Nonetheless, relatively severe internal pump wear was observed with the Jet A-1 fuel, while the lubricity additives reduced wear to a level approaching that observed with the reference no. 2 diesel fuel in previous studies.(19)

A large data base of laboratory and full scale pump data now exists at SwRI. The results obtained using the SLWT are compared to wear produced in previous full-scale pump tests in Fig. 5 using hollow symbols.(11) The results obtained with the test fuels used in the present study are taken from TABLE 7 and depicted using solid symbols. Good correlation was observed between the laboratory tests and full scale pump wear, with an overall correlation coefficient 0.81 for the complete data base. Much of the pump test data was produced by the original manufacturers, and significantly higher correlations were observed among individual equipment types.

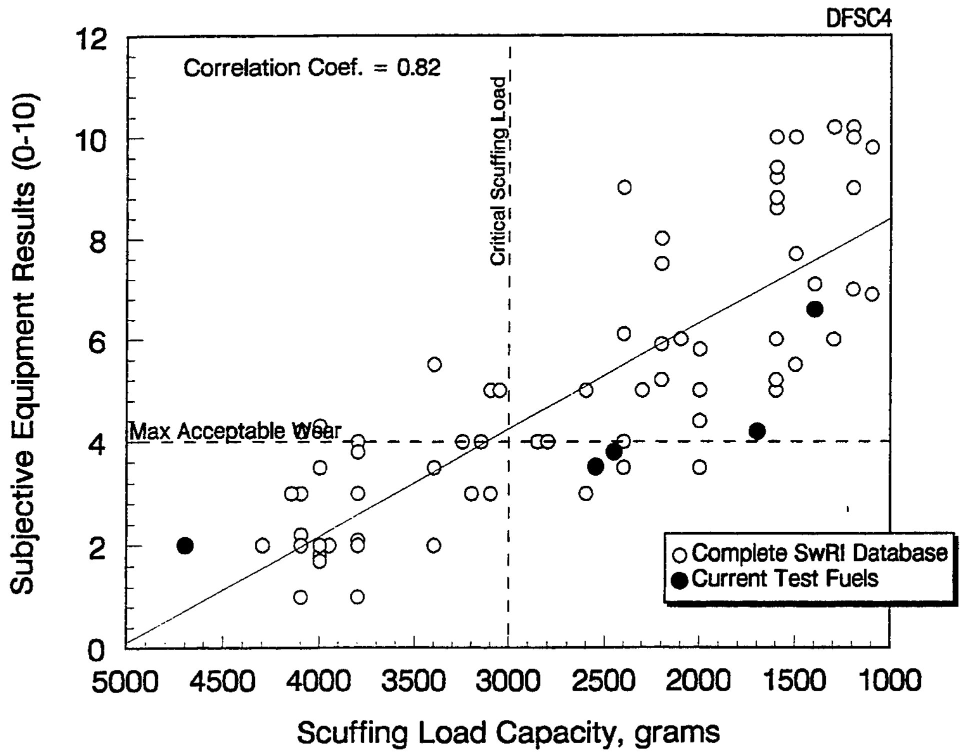

Figure 5. **Correlation Between Scuffing Load Wear Test and Full Scale Pump Data**

The present data is in general agreement with the trends of earlier tests, with the good-lubricity, high-sulfur reference number 2 diesel fuel and the poor-lubricity Jet A-1 fuel both falling close to the best-fit correlation line. The lubricity additives had a marginally greater effect on pump wear with Jet A-1 fuel than predicted by the SLWT. In particular, Jet A-1 with 30 mg/L of DCI-4A produced a result of only 1700 grams but still demonstrated relatively mild pump wear. As a result, each of the lubricity additives produced similar wear rates in the full scale pump, even though the SLWT and HFRR wear tests indicated that the E-2 additive should be measurably better than DCI-4A. The reason for this result is unclear but may be due to the presence of an oxidative corrosion wear mechanism in addition to the more severe adhesive mechanism produced by the SLWT and HFRR tests. In addition, larger differences in pump performance may have been apparent following a longer operating period than the 200 hours used in the present work.

VI. CONCLUSIONS

a) Unacceptably severe fuel-injection system wear may be produced by use of neat Jet A-1 fuel.

b) Pump wear rate may be significantly reduced through use of fuel-lubricity additives at concentrations below 100 mg/L.

c) Fuel lubricity additive E-2 was the most effective chemistry evaluated in laboratory tests, with minimal effects on water-separation characteristics.

d) Additive E-2 reduced pump wear at a concentration of 80 mg/L. A slight additional reduction in wear rate was produced at 200 mg/L, at the expense of poor water-separation characteristics.

e) DCI-4A corrosion inhibitor additive, qualified under MIL-I-25017E but used at ten times the recommended allowable concentration, reduced pump wear to a level approaching that observed with additive E-2.

f) Directional correlation was observed between the pump durability tests and the HFRR and SLWT laboratory scale wear tests.

g) Lubricity additives were more effective in reducing full scale pump wear than would have been predicted by the laboratory scale wear tests.

h) Pump durability was improved through use of arctic components that contain improved metallurgy.

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APPENDIX A

Characteristics of Jet A-1 Test Fuel

TABLE A-1. U.S. Jet A-1 Turbine Fuel

Test	Specifications Minimum	Specifications Maximum	Result
Gravity, °API	37.0	51.0	49.5
Density, kg/m	0.775	0.840	0.782
Color	Report		+25
Distillation, °C			
Initial Boiling Point			160
5%			165
10%		204	167
20%			169
30%			170
40%			172
50%			175
60%			178
70%			182
80%			187
90%			195
95%			207
End Point		300	218
Recovery, vol%			99.1
Residue, vol%		1.5	0.9
Loss, vol%		1.5	0.0
Sulfur, wt%		0.300	0.002
Doctor Test		Negative	Negative
Freeze Point, °C		-47.0	-59.5
Flash Point, °C	38		44
Viscosity, cSt, at -34°C		8.0	4.2
Viscosity, cSt, at 40°C			1.07
Copper Corrosion		1B	1B
Existent Gum, mg/100 mL		7.0	3.4
Particulates, mg/L		1.0	0.8
Smoke Point, mm	20.0		29.0
WSIM	Report		99
Hydrocarbon Composition, vol%			
Aromatics		20.0	8.1
Olefins		5.0	0.0
Saturates	Report		91.9
Acidity, total (mg KOH/g)		0.015	0.004
Net Heat of Combustion, MJ/kj	42.80		43.54
JFTOT, mm Hg		25.0	0.0
JFTOT, TDR		12	1
Water Reaction		1B	1A
Separation Rating, max.		2.0	0.0
Interfacing Rating, max.		1B	1A

TABLE A-2. Reference No. 2 (Cat 1-H) Diesel Fuel

Test	Specifications Minimum	Specifications Maximum	Result
Gravity, °API	33.0	35.0	34.1
Distillation, °F (°C)			
Initial Boiling Point			400 (204)
5%			449 (232)
10%			462 (239)
20%			476 (247)
30%			489 (254)
40%			501 (261)
50%	500	530	515 (268)
60%			531 (277)
70%			550 (288)
80%			573 (301)
90%	590	620	611 (322)
95%			642 (339)
End Point	650	690	669 (354)
Recovery, vol%			99.0
Residue, vol%			1.0
Loss, vol%			0.0
Cetane Number	47.0	53.0	50.0
Flash Point, °F (°C)	140 (60)		
188 (87)			
Cloud Point, °F (°C)			
24 (-4)			
Pour Point, °F (°C)		20 (-7)	
15 (-9)			
Water and Sediment, vol%		0.05	<0.05
Sulfur, wt%	0.38	0.42	0.39
Ash, wt%		0.010	0.001
Viscosity, cSt, at 40°C	2.00	4.00	3.00
Copper Corrosion		2	1A
Neutralization No., mg KOH/g		0.15	0.07
Ramsbottom, 10% residium, wt%		0.20	0.10
Net Heat of Combustion, MJ/kj			42.41

APPENDIX B

Pump Calibration Stand Results

Pump Calibration Stand Measurements

Both the pretest and post-test pump calibration series were performed at a local San Antonio Stanadyne-appointed dealer. Initially, the pumps were set to within the limits specified in "Stanadyne Injection Pump Specification for Customer Part No. 23500414." In addition, the exact values were recorded in each instance for comparison with the post-test measurements. The results of these measurements are provided in Tables B-1 to B-8. The test stand conformed to ISO 4008 with SAE 0968/ISO 7440 calibrating injectors. The calibration fluid was Viscor conforming to SAE 0967/ISO 4113. The fluid supply temperature to the pump was maintained between 110° to 115°F (43° to 46°C) at a pressure of 5 $\pm$ 0.5 psi (34.5 $\pm$ 3 kPa). The pump was operated for 10 minutes prior to calibration to allow the system to stabilize. The computerized stand provided a digital readout of pump delivery per stroke at the required test speeds, eliminating errors. Injection advance is measured by a mechanical attachment that follows the movement of the cam ring (commonly known as a bat wing gauge).

TABLE B-1. Pretest Pump Delivery

Pump#:	Delivery, mm³St at rpm				
	75	200	1000	1800	1950
Spec.	>29	>47	51 to 55	>46	>44
1	37.5	48.5	54	54.5	52.5
2	38	48	54	54	51.5
3	37	50	53	54.5	52
4	41.5	51.5	54.5	56	53
5	41	49	-	55	53
6	37	47.5	54	55	52
Note: Readings at wide open throttle (St = Stroke).					

TABLE B-2. Pretest Transfer Pump Pressure

Pump#:	Pressure, psi at rpm			
	75	1000	1800	2100
Spec.	>12	70 to 76	No Spec	<135
1	30	75	108	130
2	18	76	112	140
3	20	76	104	120
4	20	74	110	135
5	22	74	106	128
6	20	72	106	135
Note: Readings at wide open throttle.				

TABLE B-3. Pretest Injection Advance Measurement

Pump#:	Advance, Degrees on Pump	
Speed:	325	1000
Throttle:	LI	WOT
Spec.	>1.5	0.5 to 2.5
1	4	1.5
2	2.5	1.5
3	4	1.5
4	3	1.5
5	4.5	1.5
6	4	1.5
Note: LI = Low Idle; WOT = Wide Open Throttle.		

TABLE B-4. Pretest Sundry Measurements

Pump#:	RF	SO	BA
Units:	cc/min	mm³/St	mm³St
Spec.	225 to 375	<4	<8
1	300	0	0
2	325	0	0
3	375	0	0
4	375	0	0
5	375	0	0
6	375	0	0
Note: RF = Return Fuel from Housing to Tank. SO = Shut Off Fuel Flow. BA = Fuel Flow at Break-Away Speed (2100 pump rpm). St = Stroke			

TABLE B-5. Post-Test Pump Delivery

Pump#:	Delivery, mm³St at rpm				
	75	200	1000	1800	1950
Spec.	>29	>47	51 to 55	>46	>44
1	42	55	61	61	61.5
2	35	47	52.5	54.5	53.5
3	37	50	54	55	54
4	40	49	54	55	54
5	40	48	53.5	55	54
6	36	48	53	54.5	54
Note: Readings at wide open throttle (St = Stroke).					

TABLE B-6. Post-test Transfer Pump Pressure

Pump#:	Pressure, psi at rpm			
	75	1000	1800	2100
Spec.	>12	70 to 76	No Spec	<135
1	16	66	90	110
2	12	68	99	120
3	17	73	100	130
4	16	72	105	130
5	18	70	96	118
6	16	70	102	126
Note: Readings at wide open throttle.				

TABLE B-7. Post-test Injection Advance Measurement

Pump#:	Advance, Degrees on Pump	
Speed:	325	1000
Throttle:	LI	WOT
Spec.	>1.5	0.5 to 2.5
1	2.5	.5
2	1.75	.5
3	4.5	1.5
4	3	1.5
5	3.5	1.5
6	3	1.5
Note: LI = Low Idle; WOT = Wide Open Throttle.		

TABLE B-8. Post-test Sundry Measurements

Pump#:	RF	SO	BA
Units:	cc/min	mm³/St	mm³St
Spec.	225 to 375	<4	<8
1	340	0	0
2	340	0	0
3	425	0	0
4	350	0	0
5	425	0	0
6	400	0	0
Note: RF = Return Fuel from Housing to Tank. SO = Shut Off Fuel Flow. BA = Fuel Flow at Break-Away Speed (2100 pump rpm). St = Stroke			

APPENDIX C

In Test Pump Measurements

TEST#: 1 AND 2 **FUEL TYPE: NEAT JET A-1**

Date:(1)	12/18/96	12/18/96	12/28/96	12/19/96	12/19/96	12/19/96	12/19/96	12/21/96	12/22/96	12/28/96	12/28/96	12/28/96	12/29/96
Time:	12:40PM	2:40PM	4:10PM	10:40AM	2:40PM	6:40PM	9:40PM	6:05PM	12:35PM	3:30PM	7:30PM	11:30PM	3:30AM
Duration, Hours	1	3	4.5	8.5	12.5	16.5	19.5	24.5	30	35	39	43	47
Speed, rpm	1800	1798	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Std. Pump Flow, cc/min	628.59	633.845	633.845	633.845	633.845	639.1	639.1	639.1	639.1	633.845	633.845	633.845	225.5315
Arctic Pump Flow, cc/min	633.845	633.845	623.335	623.335	623.335	623.335	623.335	639.1	633.845	633.845	628.59	628.59	633.845
Temperature, ^{0}F													
Inlet:	155	163	167	165	170	170	170	158	160	169	169	170	170
Reservoir:	73	85	91	92	100	98	99	84	89	97	100	100	100
Ambient:	68.4	70.1	70.5	68.5	69.9	69.1	68.7	64	65	67.6	69.4	72	71
Humidity%:	59	52	50	40	40	40	40	41	43	35	34	35	33
Pressures, psi													
Fuel Outlet:	3.5	3.7	3.8	3.7	3.8	3.7	3.7	3.6	3.7	3.8	3.8	3.8	3.8
Fuel Inlet:	3.0	3.2	3.0	3.0	2.7	2.9	3.0	3.5	3.0	3.0	3.1	3.0	3.0
Std. Pump Housing:	4.2	4.4	4.5	4.5	4.6	4.6	4.6	4.4	4.6	5.2	5.2	5.2	5.3
Arctic Pump Housing:	4.0	4.3	4.4	4.2	4.4	4.2	4.2	4.1	4.2	4.7	4.7	4.8	4.8
Std. Transfer Pump:	113.2	111.4	111.0	109.2	107.6	107.5	107.4	105.1	104.2	103.3	103.1	102.2	101.6
Arctic Transfer Pump:	118.4	115.8	115.1	112.1	110.5	109.4	110.1	108.8	108	107	106.7	106.0	105

TEST#: 1 AND 2 **FUEL TYPE: NEAT JET A-1**

Date:	12/29/96	12/29/96	12/29/96	01-02-97	01-02-97	01-02-97	01-02-97	01-03-97	01-03-97	01-03-97	01-03-97	01-04-97	01-04-97
Time:	7:30AM	11:30AM	2:30PM	10:40AM	2:40PM	6:40PM	8:40PM	10:30AM	2:30PM	6:30PM	8:30PM	10:15AM	2:15PM
Duration, Hours	51	55	58	62	66	70	72	76	80	84	86	90	94
Speed, rpm:	1800	1800	1800	1800	1800	1800	1800	1801	1800	1800	1800	1800	1800
Std. Pump Flow, cc/min	633.845	628.59	628.59	649.61	633.845	639.1	639.1	633.845	633.845	639.1	639.1	639.1	639.1
Arctic Pump Flow, cc/min	628.59	628.59	628.59	639.1	639.1	639.1	639.1	639.1	639.1	639.1	639.1	639.1	639.1
Temperature, ^{0}F													
Inlet:	169	169	170	158	168	168	167	167	167	166	167	169	165
Reservoir:	100	98	100	82	97	98	97	96	98	97	98	101	99
Ambient:	69.3	68	69	63	65	65	67	66	67.5	68	68	68	72.3
Humidity%:	35	39	42	34	30	31	30	29	30	26	26	35	34
Pressures, psi													
Fuel Outlet:	3.8	3.8	3.8	3.7	3.8	3.8	3.8	3.8	3.9	4.0	4.0	4.1	4.1
Fuel Inlet:	2.9	2.9	2.8	3.0	3.0	2.9	2.8	3.0	3.0	3.0	3.0	3.0	3.0
Std. Pump Housing:	5.2	5.1	5.1	4.8	5.1	5.2	5.2	5.3	5.3	5.3	5.4	5.5	5.5
Arctic Pump Housing:	4.7	4.7	4.7	4.5	4.8	4.8	4.8	4.8	4.9	5.0	5.0	5.2	5.2
Std. Transfer Pump:	101.0	100.5	100.1	100.7	99.7	99.6	99.7	98.4	98.1	98	97.9	97.7	97.3
Arctic Transfer Pump:	105.1	104.4	103.3	105.0	103.4	103.6	102.5	103.7	103.4	103	101.8	102.4	102.4

TEST#: 1 AND 2 **FUEL TYPE: NEAT JET A-1**

Date:(2)	01-04-97	01-04-97	01-05-97	01-05-97	01-05-97	01-05-97	01-06-97	01-06-97	01-08-97	01-08-97	01-08-97	01-09-97	01-09-97
Time:	6:15PM	9:15PM	10:20AM	2:20PM	6:20PM	9:20PM	2:40PM	6:40PM	9:00AM	1:00PM	4:00PM	10:00AM	2:00PM
Duration, Hours	98	101	105	109	113	116	120	124	128	132	135	139	143
Speed, rpm:	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Std. Pump Flow, cc/min	639.1	639.1	639.1	639.1	639.1	639.1	654.865	639.1	649.61	639.1	633.845	639.1	639.1
Arctic Pump Flow, cc/min	639.1	639.1	639.1	639.1	639.1	639.1	654.865	639.1	644.355	639.1	639.1	639.1	639.1
Temperature, ^0F													
Inlet:	166	167	164	164	164	165	152	158	157	163	163	161	164
Reservoir:	100	99	98	98	98	99	79	90	87	98	97	95	100
Ambient:	72	72	68	72	68.6	66	60	60	59	65.5	67.1	69.8	72.4
Humidity%:	36	37	43	43	40	39	33	32	26	22	17	32	32
Pressures, psi													
Fuel Outlet:	4.2	4.2	4.1	4.2	4.2	4.2	4.0	4.2	4.1	4.3	4.3	4.3	4.4
Fuel Inlet:	3.0	3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9	3.0	3.0
Std. Pump Housing:	5.5	5.6	5.6	5.7	5.7	5.8	5.5	5.7	5.8	6.0	6.0	6.0	6.0
Arctic Pump Housing:	5.2	5.3	5.2	5.3	5.4	5.4	5.1	5.3	5.2	5.4	5.5	5.5	5.6
Std. Transfer Pump:	97	97.2	97	96.8	96.7	97.3	96.3	96.3	96.4	96.3	96.1	95.8	95.7
Arctic Transfer Pump:	101.1	101.4	101.9	101.8	100.8	100.5	101.5	100	100.2	99.7	99.7	99.5	99.5

TEST#: 1 AND 2 **FUEL TYPE: NEAT JET A-1**

Date:	01-09-97	01-09-97	01-10-97	01-10-97	01-11-97	01-11-97	01-11-97	01-11-97	01-12-97	01-12-97	01-12-97	01-12-97	01-13-97
Time:	6:00PM	9:00PM	2:55PM	9:55PM	10:15AM	2:15PM	6:15PM	9:15PM	10:20AM	3:50PM	6:20PM	9:25PM	1:00PM
Duration, Hours	147	150	154	156	160	164	168	171	175	180.5	183	186	190
Speed, rpm:	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Std. Pump Flow, cc/min	639.1	639.1	639.1	633.845	644.355	639.1	639.1	639.1	639.1	639.1	639.1	639.1	639.1
Arctic Pump Flow, cc/min	639.1	639.1	639.1	639.1	639.1	639.1	639.1	639.1	639.1	639.1	639.1	639.1	639.1
Temperature, ^0F													
Inlet:	164	166	162	167	160	163	165	166	164	164	163	164	165
Reservoir:	101	100	96	102	94	98	101	102	101	101	100	100	102
Ambient:	71	70	72.2	72.6	68.2	70.2	71.2	70.8	66.7	73	73.8	73.1	74
Humidity%:	34	34	45	45	34	24	25	26	29	20	26	30	29
Pressures, psi													
Fuel Outlet:	4.4	4.4	4.4	4.5	4.4	4.4	4.5	4.5	4.5	4.6	4.6	4.5	4.6
Fuel Inlet:	3.0	3.0	3.0	3.0	3.0	2.8	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Std. Pump Housing:	6.0	6.0	5.9	6.1	6.0	6.1	6.2	6.2	6.2	6.3	6.2	6.2	6.2
Arctic Pump Housing:	5.6	5.6	5.6	5.7	5.6	5.6	5.7	5.7	5.7	5.8	5.7	5.8	5.8
Std. Transfer Pump:	95.4	95.2	94.4	93.7	93.2	92.9	92.8	92.4	91.8	91.3	91	90.9	90.8
Arctic Transfer Pump:	99.2	99.8	99.7	99.2	100.3	100.1	99.7	99	99.9	99.6	98.6	98.7	100

TEST#: 1 AND 2 **FUEL TYPE: NEAT JET A-1**

Date:(3)	01-13-97	01-16-97	01-16-97										
Time:	5:00PM	10:10AM	12:10PM										
Duration, Hours	194	198	200										
Speed, rpm:	1800	1800	1800										
Std. Pump Flow, cc/min	639.1	660.12	691.65										
Arctic Pump Flow, cc/min	639.1	639.1	639.1										
Temperature, ^{0}F													
Inlet:	165	166	161										
Reservoir:	101	103	100										
Ambient:	74.5	72.4	73.7										
Humidity%:	24	59	53										
Pressures, psi													
Fuel Outlet:	4.6	4.7	4.7										
Fuel Inlet:	3.0	3.0	3.0										
Std. Pump Housing:	6.2	6.4	6.4										
Arctic Pump Housing:	5.8	6.3	6.1										
Std. Transfer Pump:	90.3	89	87.8										
Arctic Transfer Pump:	99.2	98.9	99.2										

TEST#: 3 AND 4 **FUEL TYPE: JET A-1 + 80 mg/L ADDITIVE E-2**

Date:(4)	03-06-96	03-06-96	03-06-96	03-06-96	03-06-96	03-07-96	03-07-96	03-07-96	03-07-96	03-08-96	03-08-96	03-08-96	03-08-96
Time:	12:10PM	12:40PM	3:40PM	7:40PM	8:40PM	10:50AM	2:50PM	6:50PM	8:50PM	10:35AM	2:35PM	6:35PM	8:35PM
Duration, Hours	0.5	1	4	8	9	13	17	21	23	27	31	35	37
Speed, rpm:	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Std. Pump Flow, cc/min	660.12	649.61	639.1	639.1	639.1	649.61	649.61	660.12	660.12	654.865	644.355	654.865	639.1
Arctic Pump Flow, cc/min	660.12	644.355	633.845	639.1	639.1	649.61	644.355	644.355	644.355	644.355	644.355	644.355	639.1
Temperature, ^{0}F													
Inlet:	146	153	170	166	166	156	162	161	161	166	162	163	163
Reservoir:	73	86	105	98	98	88	98	92	94	99	95	96	97
Ambient:	75.1	76.7	81.5	75	73	60.6	65.7	66.7	67.1	63.6	67.5	65.6	65.7
Humidity%:	75	72	60	39	36	22	4	2	2	2	2	2	2
Pressures, psi													
Fuel Outlet:	3.3	3.4	3.6	3.6	3.6	3.5	3.5	3.6	3.6	3.7	3.6	3.6	3.6
Fuel Inlet:	3.0	3.0	3.0	3.2	3.1	3.0	3.0	3.0	3.0	3.0	3.2	3.0	3.0
Std. Pump Housing:	4.6	4.7	5.1	5.0	5.1	5.0	5.1	5.2	5.2	5.4	5.3	5.3	5.4
Arctic Pump Housing:	4.5	4.6	5.0	4.8	4.9	4.6	4.7	4.8	4.8	4.8	4.8	4.8	4.8
Std. Transfer Pump:	115.7	116.0	114.0	110.4	111	110.7	109.4	108.3	109.3	109.0	109.4	108.2	108
Arctic Transfer Pump:	118.0	117.2	112.8	113.2	112.8	110.7	110.5	110.4	108.6	110.7	109.2	109.7	110

TEST#: 3 AND 4 **FUEL TYPE: JET A-1 + 80 mg/L ADDITIVE E-2**

Date:	03-11-96	03-11-96	03-11-96	03-12-96	03-12-96	03-12-96	03-12-96	03-13-96	03-13-96	03-13-96	03-13-96	03-14-96	03-14-96
Time:	10:40AM	2:40PM	4:10PM	10:30AM	2:30PM	6:30PM	9:00PM	10:10AM	2:10PM	6:10PM	9:10PM	10:50AM	2:50PM
Duration, Hours	41	45	46.5	50.5	54.5	58.5	61	65	69	73	77	81	85
Speed, rpm:	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Std. Pump Flow, cc/min	654.865	639.1	644.355	649.61	639.1	639.1	639.1	639.1	639.1	639.1	639.1	639.1	639.1
Arctic Pump Flow, cc/min	649.61	639.1	639.1	644.355	639.1	639.1	639.1	639.1	639.1	639.1	639.1	639.1	639.1
Temperature, ^{0}F													
Inlet:	153	168	163	161	165	167	166	161	169	170	169	168	170
Reservoir:	84	104	101	95	102	101	101	97	109	113	112	103	114
Ambient:	62.6	70.3	70.5	66.4	72.3	76.2	72.2	70.3	78.1	80	74.5	75.2	81
Humidity%:	46	36	36	56	52	46	58	66	51	52	64	64	46
Pressures, psi													
Fuel Outlet:	3.5	3.8	3.7	3.6	3.7	3.8	3.7	3.6	3.8	3.8	3.7	3.7	3.8
Fuel Inlet:	3.0	3.0	3.1	3.0	3.0	3.0	3.1	3.0	2.4	3.0	3.0	3.0	3.0
Std. Pump Housing:	5.1	5.4	5.4	5.1	5.3	5.3	5.3	5.2	5.3	5.3	5.3	5.4	5.4
Arctic Pump Housing:	4.6	5.0	5.0	4.9	5.0	5.0	5.0	5.0	5.0	5.1	5.1	5.2	5.2
Std. Transfer Pump:	110.1	108.3	107.9	107.0	107.4	107.7	108.6	107.4	105.6	107.6	108	108	107.5
Arctic Transfer Pump:	109.0	108.3	107.9	107.5	108.6	107.1	107.2	107.6	106.7	106.4	107.1	106.2	106.3

TEST#: 3 AND 4 **FUEL TYPE: JET A-1 + 80 mg/L ADDITIVE E-2**

Date:(5)	03-14-96	03-14-96	03-14-96	03-15-96	03-15-96	03-15-96	03-18-96	03-18-96	03-20-96	03-20-96	03-20-96	03-21-96	03-21-96
Time:	3:50PM	7:50PM	9:50PM	11:00AM	3:00PM	7:00PM	10:50AM	3:50PM	10:45AM	2:45PM	4:15PM	10:50AM	2:50PM
Duration, Hours	86	90	92	96	100	104	112	117	121	125	126.5	130.5	134.5
Speed, rpm:	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Std. Pump Flow, cc/min	639.1	639.1	639.1	639.1	639.1	639.1	649.61	639.1	649.61	649.61	644.355	649.61	649.61
Arctic Pump Flow, cc/min	639.1	639.1	639.1	639.1	639.1	639.1	649.61	639.1	644.355	644.355	633.845	644.355	639.1
Temperature, ^{0}F													
Inlet:	169	170	166	165	167	167	155	164	163	165	164	162	164
Reservoir:	116	115	115	101	103	104	86	99	100	103	103	102	103
Ambient:	82	83	80	75	80	83	79.1	85	68.2	71.8	72.9	67.5	73.2
Humidity%:	40	38	53	62	44	41	30	18	21	16	12	31	33
Pressures, psi													
Fuel Outlet:	3.8	3.9	3.9	3.8	3.9	3.9	3.8	4.0	3.9	4.0	4.0	4.0	4.1
Fuel Inlet:	2.9	2.9	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.8	3.0	3.0
Std. Pump Housing:	5.4	5.4	5.4	5.4	5.4	5.4	5.3	5.5	5.7	5.8	5.7	5.7	5.7
Arctic Pump Housing:	5.2	5.1	5.1	5.2	5.2	5.2	4.9	5.2	5.2	5.4	5.3	5.3	5.4
Std. Transfer Pump:	106.3	106.6	106.3	107.6	106.5	106	107	106.3	107.6	108.1	107.5	106.4	106.4
Arctic Transfer Pump:	107.3	106	107.7	107.0	106.0	107	107.7	107.0	107.8	107.7	104.7	106.1	106.2

TEST#: 3 AND 4 **FUEL TYPE: JET A-1 + 80 mg/L ADDITIVE E-2**

Date:	03-21-96	03-22-96	03-22-96	03-22-96	03-25-96	03-25-96	03-25-96	03-25-96	03-26-99	03-26-96	03-27-96	03-27-96	03-27-96
Time:	4:20PM	10:20AM	2:20PM	4:20PM	10:05AM	3:40PM	7:40PM	10:40PM	10:35AM	2:35PM	11:45AM	3:45PM	7:45PM
Duration, Hours	136	140	144	146	150	155	159	162	166	170	176	180	184
Speed, rpm:	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Std. Pump Flow, cc/min	639.1	649.61	644.355	639.1	649.61	644.355	644.355	644.355	649.61	654.865	649.61	654.865	654.865
Arctic Pump Flow, cc/min	639.1	644.355	639.1	639.1	644.355	639.1	639.1	639.1	644.355	644.355	639.1	639.1	649.61
Temperature, ^{0}F													
Inlet:	164	161	162	162	161	163	166	162	163	163	164	161	161
Reservoir:	102	100	102	102	100	100	103	100	101	101	103	99	99
Ambient:	75.2	70.2	77.7	78.9	66.7	70	69.4	67.8	66	67.5	67.5	67.6	67
Humidity%:	33	68	45	44	28	24	27	31	34	35	46	48	48
Pressures, psi													
Fuel Outlet:	3.9	3.9	4.0	4.1	4.0	4.1	4.2	4.0	4.2	4.2	4.1	4.1	4.0
Fuel Inlet:	3.0	3.0	3.0	3.0	3.0	3.0	2.8	2.9	3.0	3.0	3.0	3.0	3.0
Std. Pump Housing:	5.6	5.6	5.7	5.7	5.7	5.9	5.9	5.8	5.9	5.9	5.9	5.8	5.8
Arctic Pump Housing:	5.2	5.3	5.4	5.5	5.4	5.5	5.4	5.3	5.4	5.6	5.6	5.6	5.5
Std. Transfer Pump:	105.5	107.4	106.9	106.6	106.4	106.4	104	104.6	104.6	105.5	104.6	104.5	104
Arctic Transfer Pump:	106.1	107.0	104.5	104.7	105.0	104.6	106	105.8	106.4	107	106.5	105	105

TEST#: 3 AND 4 FUEL TYPE: JET A-1 + 80 mg/L ADDITIVE E-2

Date:(6)	03-27-96	03-28-96	03-28-96	03-28-96	03-28-96								
Time:	8:45PM	10:50AM	2:50PM	6:50PM	9:30PM								
Duration, Hours	185	189	193	197	200								
Speed, rpm:	1800	1800	1800	1800	1800								
Std. Pump Flow, cc/min	649.61	649.61	649.61	654.865	649.61								
Arctic Pump Flow, cc/min	649.61	644.355	644.355	639.1	644.355								
Temperature, ^{0}F													
Inlet:	164	161	163	161	164								
Reservoir:	102	100	102	100	103								
Ambient:	67	68	72.6	73.8	74.4								
Humidity%:	47	46	43	43	44								
Pressures, psi													
Fuel Outlet:	4.1	4.0	4.2	4.1	4.2								
Fuel Inlet:	3.0	3.0	3.0	3.0	3.0								
Std. Pump Housing:	5.9	5.8	5.9	5.8	5.9								
Arctic Pump Housing:	5.6	5.5	5.6	5.7	5.7								
Std. Transfer Pump:	104.5	104.2	104.3	104.9	104.6								
Arctic Transfer Pump:	104.3	106.6	106.4	105.7	106.7								

TEST#: 5 AND 6 **FUEL TYPE: JET A-1 + 200 mg/L ADDITIVE E-2**

Date:(7)	07-16-96	07-16-96	07-16-96	07-16-96	07-16-96	07-17-96	07-17-96	07-17-96	07-17-96	07-18-96	07-18-96	07-18-96	07-19-96
Time:	8:20AM	12:15PM	4:15PM	8:15PM	9:15PM	12:25PM	4:25PM	8:25PM	9:25PM	12:10PM	4:10PM	9:40PM	12:15PM
Duration, Hours	0:05	4	8	12	13	17	21	25	26	30	34	39.5	43.5
Speed, rpm:	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Std. Pump Flow, cc/min	675.885	654.865	654.865	660.12	654.865	660.12	660.12	665.375	660.12	665.375	665.375	665.375	665.375
Arctic Pump Flow, cc/min	665.375	639.1	639.1	639.1	644.355	644.355	644.355	639.1	644.355	644.355	639.1	639.1	639.1
Temperature, ^{0}F													
Inlet:	152	168	170	169	169	169	163	167	169	169	163	167	169
Reservoir:	93	112	113	112	111	107	110	111	111	107	111	111	109
Ambient:	75.8	88.3	92.3	88.3	87.2	88.8	91.7	88	87.6	88.6	92.2	87.5	88.7
Humidity%:	76	55	45	48	52	52	44	52	55	52	46	56	55
Pressures, psi													
Fuel Outlet:	4.1	4.5	4.5	4.4	4.4	4.5	4.5	4.6	4.6	5.5	4.6	4.6	4.7
Fuel Inlet:	2.9	3.0	3.0	3.1	3.1	3.0	3.0	3.0	3.0	1.9	3.0	3.0	3.0
Std. Pump Housing:	5.6	6.1	6.1	6.0	6.0	6.1	6.1	6.2	6.2	6.0	6.3	6.4	6.4
Arctic Pump Housing:	5.6	6.1	6.1	6.0	6.0	6.1	6.1	6.1	6.1	6.0	6.2	6.2	6.2
Std. Transfer Pump:	106.3	106.6	105	102	103	101.4	101.7	99	100	98.7	100.9	101	98
Arctic Transfer Pump:	111.1	105.2	105.3	104	104	104.0	102.0	103	103	100.9	100.7	102	100

TEST#: 5 AND 6 **FUEL TYPE: JET A-1 + 200 mg/L ADDITIVE E-2**

Date:	07-19-96	07-19-96	07-19-96	07-20-96	07-20-96	07-22-96	07-22-96	07-22-96	07-23-96	07-23-96	07-23-96	07-24-96	07-24-96
Time:	4:15PM	8:15PM	10:15PM	2:25PM	5:55PM	10:05AM	2:05PM	4:05PM	12:05PM	4:05PM	10:05PM	12:10PM	4:10PM
Duration, Hours	47.5	51.5	53.5	57.5	65	69	73	75	79	83	89	93	97
Speed, rpm:	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Std. Pump Flow, cc/min	665.375	665.375	665.375	665.375	660.12	665.375	660.12	660.12	665.375	665.375	665.375	665.375	670.63
Arctic Pump Flow, cc/min	639.1	639.1	644.355	644.355	649.61	649.61	649.61	649.61	649.61	649.61	649.61	649.61	649.61
Temperature, ^{0}F													
Inlet:	167	167	167	166	168	161	161	164	161	163	165	160	163
Reservoir:	110	111	110	111	113	106	107	106	106	109	109	106	110
Ambient:	91	87.4	87	83.6	86.3	81.2	82.8	84.6	79.5	83.4	86.3	80	84.2
Humidity%:	46	53	54	59	48	70	61	55	63	51	63	66	63
Pressures, psi													
Fuel Outlet:	4.7	4.7	4.7	4.7	4.8	4.7	4.8	4.7	4.7	4.8	4.8	4.8	4.8
Fuel Inlet:	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9	3.0	3.0	3.0	3.0	3.0
Std. Pump Housing:	6.4	6.4	6.4	6.4	6.5	6.4	6.4	6.4	6.4	6.4	6.5	6.5	6.6
Arctic Pump Housing:	6.3	6.3	6.3	6.3	6.4	6.3	6.3	6.3	6.4	6.4	6.4	6.4	6.5
Std. Transfer Pump:	101	101	100	98	100	98.4	98.0	98.0	99.7	100.3	100	99.7	97.8
Arctic Transfer Pump:	101.6	102	103	103	101	102.3	102.4	102.4	102.6	101.8	101	102.6	102.6

TEST#: 5 AND 6 **FUEL TYPE: JET A-1 + 200 mg/L ADDITIVE E-2**

Date:(8)	07-24-96	07-24-96	07-25-96	07-25-96	07-25-96	07-25-96	07-26-96	07-26-96	07-26-96	07-26-96	07-27-96	07-29-96	07-29-96
Time:	8:10PM	12:10AM	12:05PM	4:05PM	8:05PM	12:05AM	11:40AM	3:40PM	7:40PM	11:40PM	6:30PM	12:10PM	4:10PM
Duration, Hours	101	105	109	113	117	121	125	129	133	137	141	145	149
Speed, rpm:	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Std. Pump Flow, cc/min	665.375	670.63	665.375	665.375	670.63	670.63	665.375	665.375	670.63	670.63	665.375	665.375	665.375
Arctic Pump Flow, cc/min	649.61	649.61	649.61	649.61	654.865	660.12	649.61	649.61	654.865	660.12	649.61	649.61	654.865
Temperature, ^0F													
Inlet:	166	163	161	163	163	161	160	164	167	164	167	158	162
Reservoir:	110	109	107	110	109	105	105	110	112	109	111	105	110
Ambient:	86.3	83.4	80.4	82	80.1	77.4	86.3	92	90.1	88.6	94	83	85.4
Humidity%:	62	66	67	60	63	66	65	47	59	61	40	62	51
Pressures, psi													
Fuel Outlet:	4.9	4.8	4.8	4.9	4.9	4.9	4.9	4.9	4.9	4.9	5.0	4.9	5.0
Fuel Inlet:	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Std. Pump Housing:	6.6	6.6	6.6	6.6	6.7	6.7	6.8	6.9	6.9	9.6	7.0	6.9	7.0
Arctic Pump Housing:	6.6	6.5	6.5	6.6	6.6	6.6	6.7	6.7	6.7	6.7	6.7	6.7	6.7
Std. Transfer Pump:	96.6	97.7	100.0	98.2	99.5	98.6	99.6	99.1	99.3	98.6	99	100	99.4
Arctic Transfer Pump:	102.4	103.2	101.9	102.5	102.1	102.4	101.8	101.4	101.1	101.9	100	102	101.7

TEST#: 5 AND 6 **FUEL TYPE: JET A-1 + 200 mg/L ADDITIVE E-2**

Date:	07-29-96	07-29-96	07-30-96	07-30-96	07-30-96	07-30-96	07-31-96	07-31-96	07-31-96	08-01-96	08-01-96	08-01-96	08-05-96
Time:	8:10PM	11:40PM	11:55AM	3:55PM	5:55PM	11:25PM	12:10PM	4:00PM	9:10PM	12:10PM	4:10PM	7:10PM	12:10PM
Duration, Hours	153	156.5	160.5	164.5	168.5	172.5	176	180	185	189	193	196	200
Speed, rpm:	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Std. Pump Flow, cc/min	665.375	665.375	665.375	665.375	665.375	665.375	665.375	665.375	665.375	665.375	665.375	665.375	665.375
Arctic Pump Flow, cc/min	649.61	654.865	654.865	654.865	654.865	660.12	654.865	649.61	649.61	649.61	649.61	649.61	649.61
Temperature, ^0F													
Inlet:	165	163	159	163	165	163	159	162	163	162	165	165	161
Reservoir:	112	110	106	117	112	110	106	110	109	110	113	111	107
Ambient:	86.9	84.3	81.1	86.2	87.2	84.4	80.3	72.6	84.3	80.4	83	82	85.3
Humidity%:	52	61	66	50	54	60	65	51	50	65	53	52	67
Pressures, psi													
Fuel Outlet:	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.1	5.1	5.1	5.2	5.2	5.1
Fuel Inlet:	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9	3.0
Std. Pump Housing:	7.1	7.1	6.9	7.0	7.0	7.1	7.0	7.0	7.1	7.1	7.1	7.1	7.2
Arctic Pump Housing:	6.9	6.9	6.8	6.9	6.9	6.9	6.9	6.9	7.0	7.0	7.1	7.1	7.1
Std. Transfer Pump:	99.8	98.5	99.5	100	99.7	100.4	97.9	99.3	97	98	97.5	100	100.3
Arctic Transfer Pump:	100.8	102.5	102.1	101	100.2	106.1	102.6	101.1	102	102	101.2	100	101.2

APPENDIX D

Photographs of Wear Scars on Selected Components

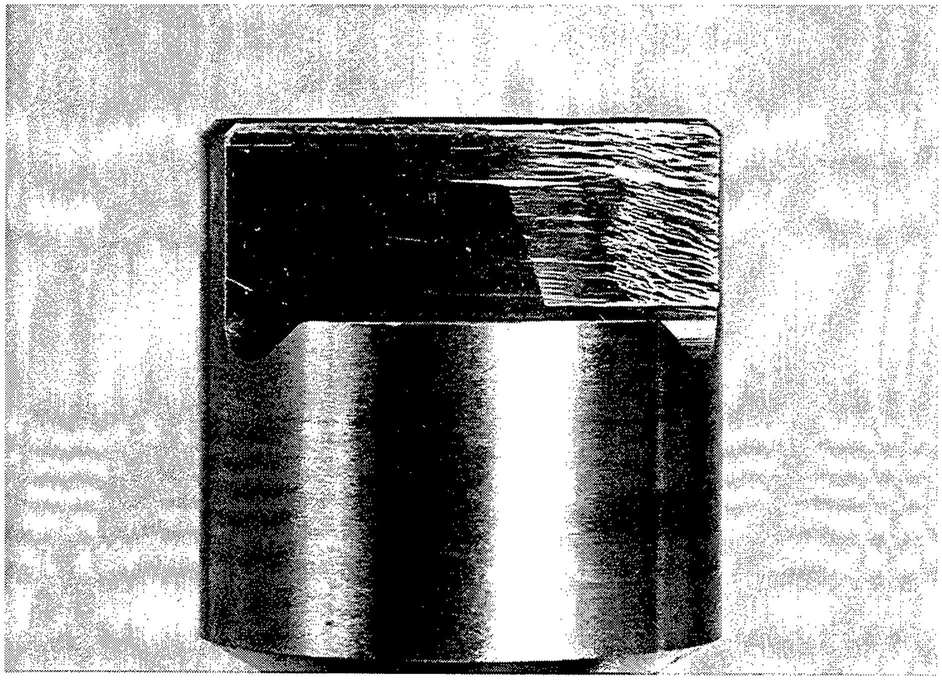

Fig. D-1. Drive Tang from Standard Pump Operated on Neat Jet A-1

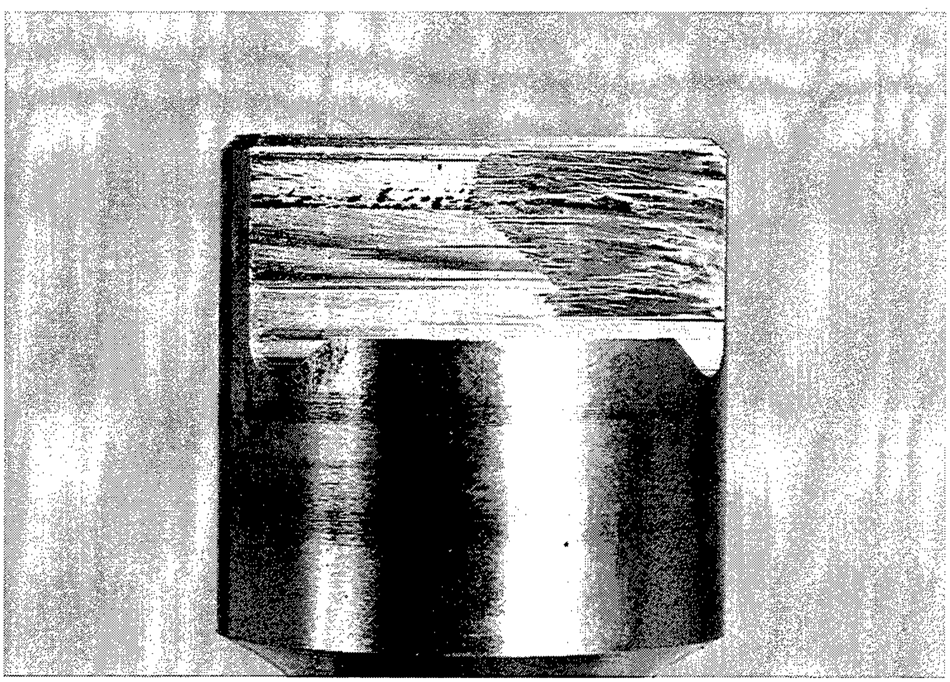

Fig D-2. Drive Tang from Arctic Pump Operated on Neat Jet A-1

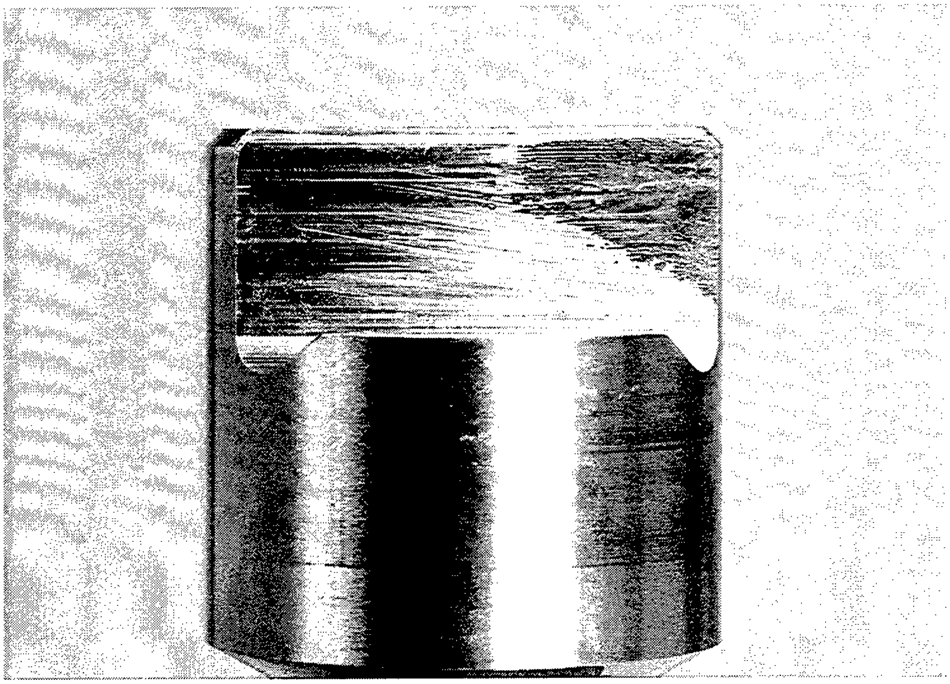

Fig. D-3. **Drive Tang from Standard Pump Operated on Jet A-1 + 80 mg/L Additive E-2**

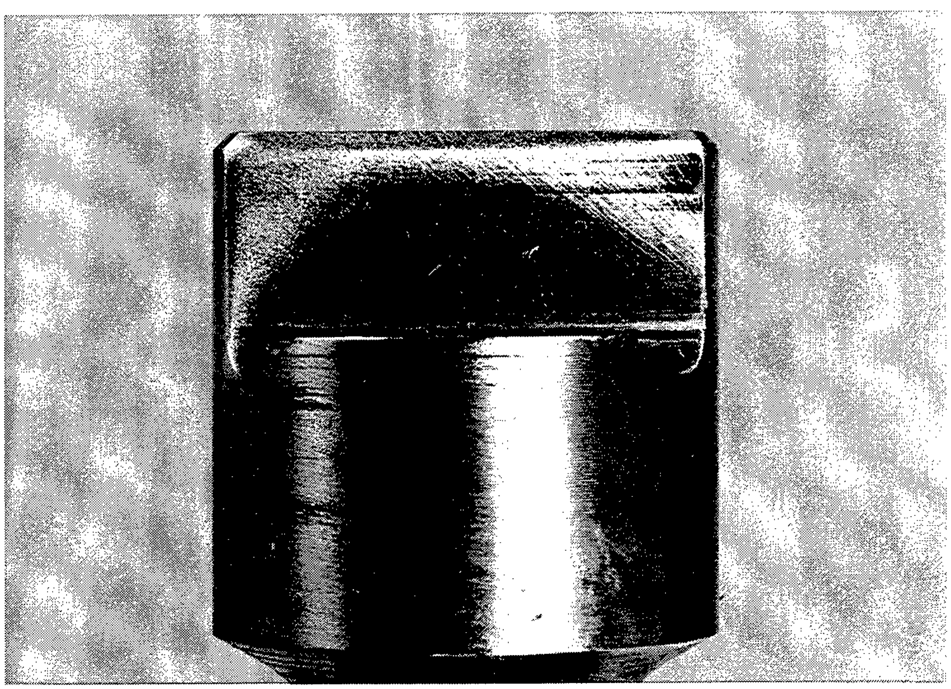

Fig D-4. **Drive Tang from Arctic Pump Operated on Jet A-1 + 80 mg/L Additive E-2**

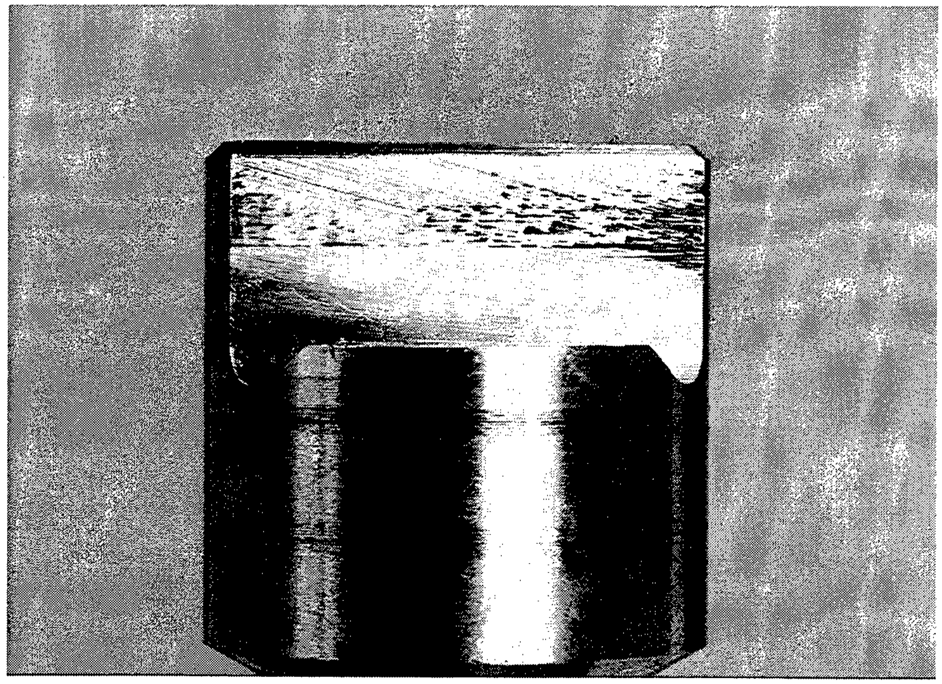

Fig. D-5. Drive Tang from Standard Pump Operated on Jet A-1 + 200 mg/L Additive E-2

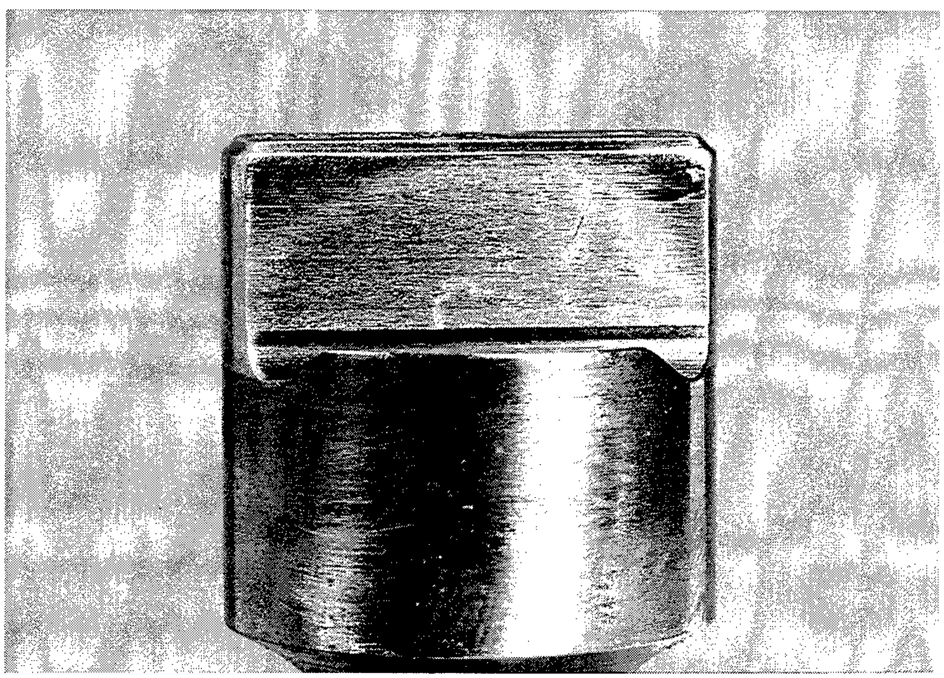

Fig D-6. Drive Tang from Arctic Pump Operated on Jet A-1 + 200 mg/L Additive E-2

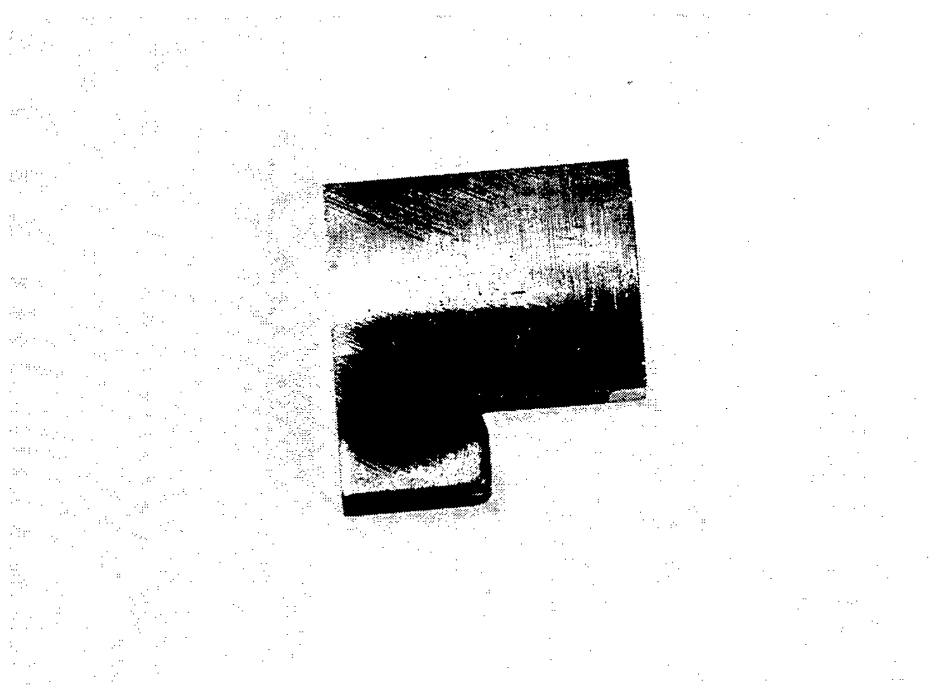

Fig. D-7. Transfer Pump Blade from Standard Pump Operated on Neat Jet A-1

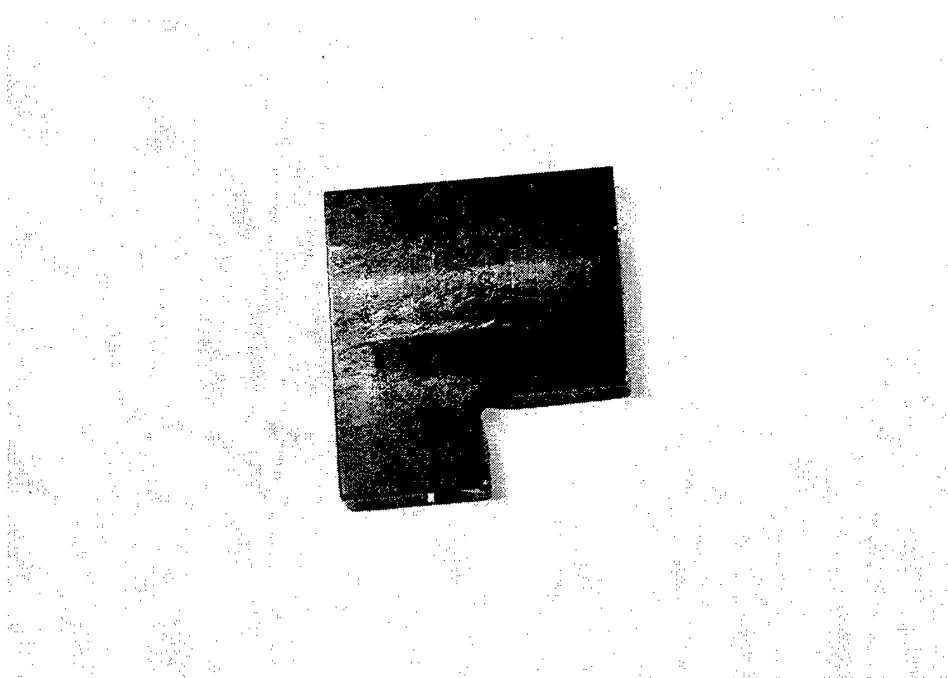

Fig D-8. Transfer Pump Blade from Arctic Pump Operated on Neat Jet A-1

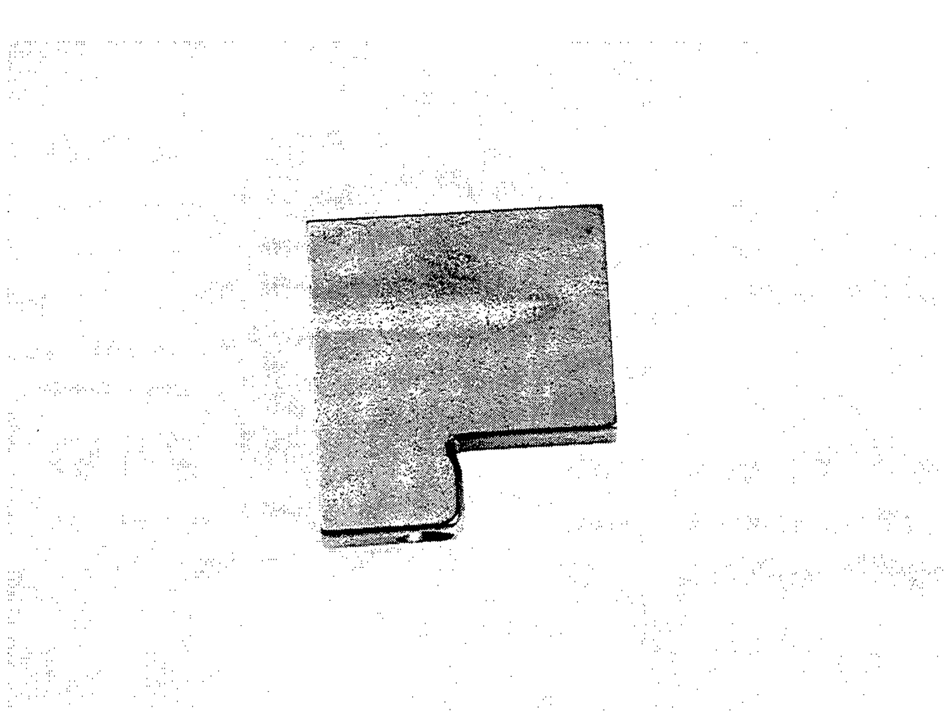

Fig. D-9. **<u>Transfer Pump Blade from Standard Pump Operated on Jet A-1 + 80 mg/L Additive E-2</u>**

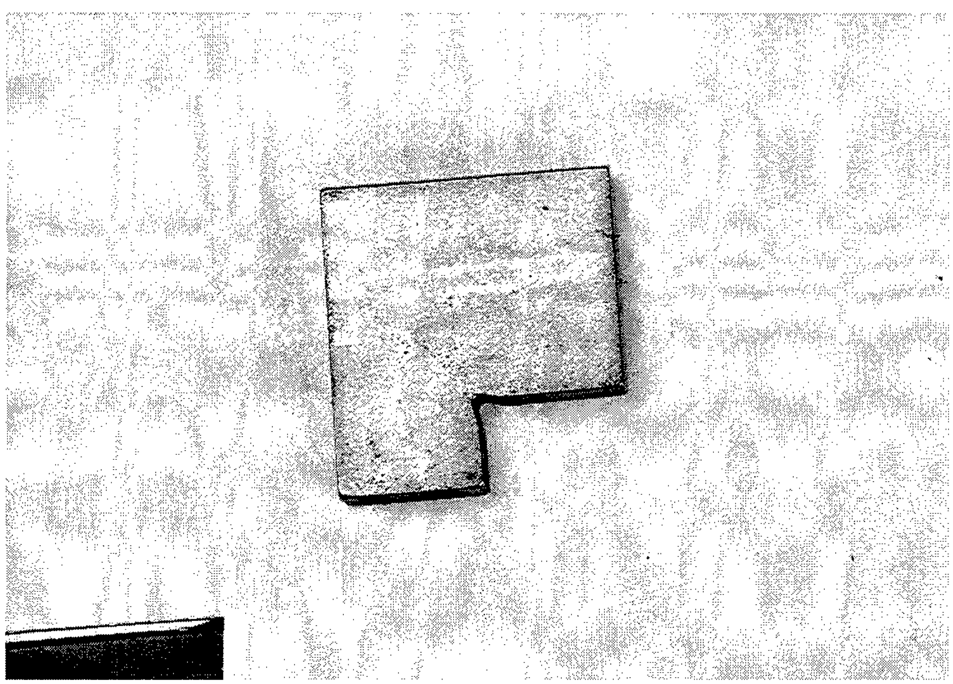

Fig D-10. **<u>Transfer Pump Blade from Arctic Pump Operated on Jet A-1 + 80 mg/L Additive E-2</u>**

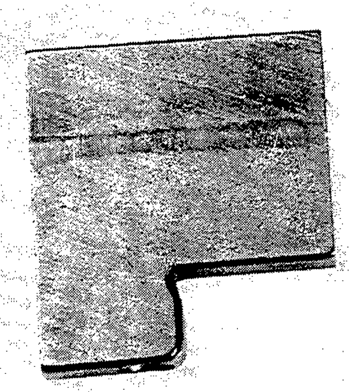

Fig. D-11. <u>Transfer Pump Blade from Standard Pump Operated on Jet A-1 + 200 mg/L Additive E-2</u>

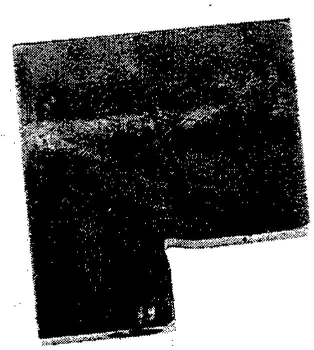

Fig D-12. <u>Transfer Pump Blade from Arctic Pump Operated on Jet A-1 + 200 mg/L Additive E-2</u>

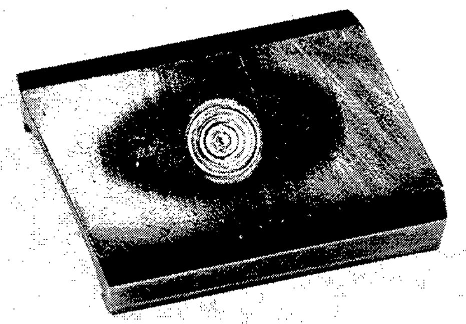

Fig. D-13. Roller Shoe from Standard Pump Operated on Neat Jet A-1

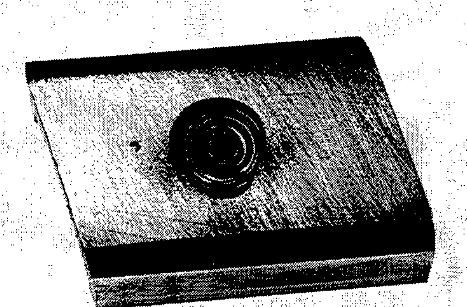

Fig D-14. Roller Shoe from Arctic Pump Operated on Neat Jet A-1

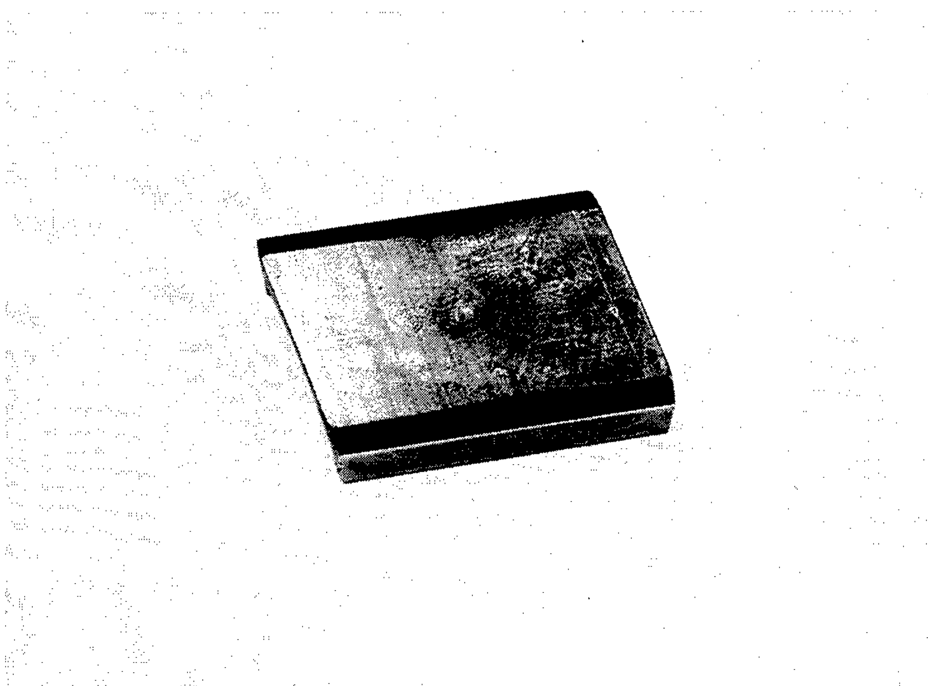

Fig. D-15. Roller Shoe from Standard Pump Operated on Jet A-1 + 80 mg/L Additive E-2

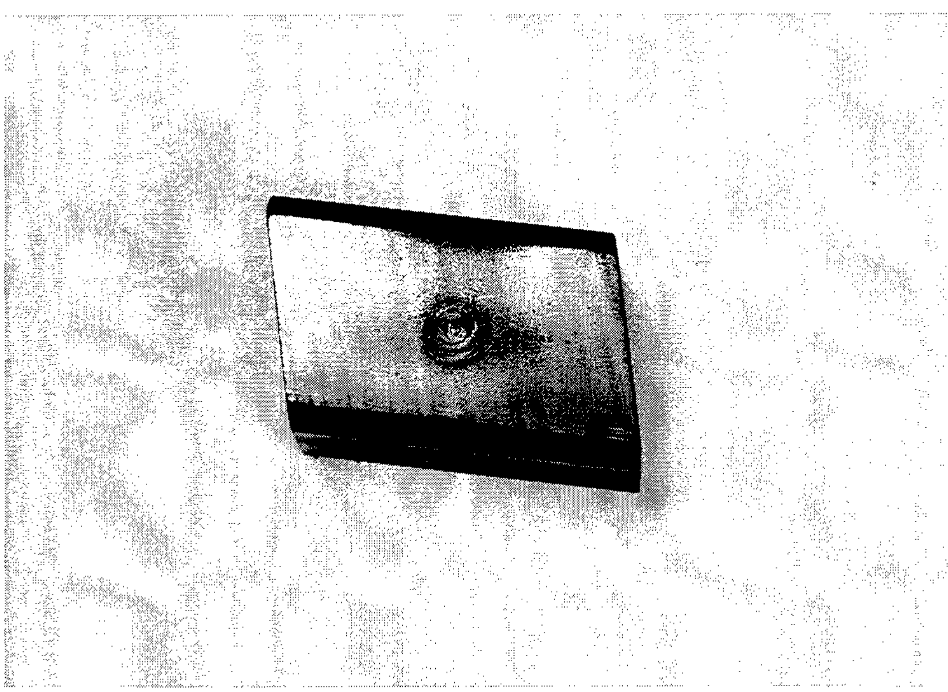

Fig D-16. Roller Shoe from Arctic Pump Operated on Jet A-1 + 80 mg/L Additive E-2

Fig. D-17. Roller Shoe from Standard Pump Operated on Jet A-1 + 200 mg/L Additive E-2

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