



FAILURE ANALYSIS OF FUEL INJECTION PUMPS FROM GENERATOR SETS FUELED WITH JET A-1

INTERIM REPORT
BFLRF No. 268

By

P.I. Lacey
S.J. Lestz

Belvoir Fuels and Lubricants Research Facility (SwRI)
Southwest Research Institute
San Antonio, Texas

DTIC
ELECTE
APR 19 1991
S E D

Under Contract to
U.S. Army Belvoir Research, Development
and Engineering Center
Materials, Fuels and Lubricants Laboratory
Fort Belvoir, Virginia

Contract No. DAAK70-87-C-0043

Approved for public release; distribution unlimited

January 1991

DTIC FILE COPY

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Trade names cited in this report do not constitute an official endorsement or approval of the use of such commercial hardware or software.

DTIC Availability Notice

Qualified requestors may obtain copies of this report from the Defense Technical Information Center, Cameron Station, Alexandria, Virginia 22314.

Disposition Instructions

Destroy this report when no longer needed. Do not return it to the originator.

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS None		
2a. SECURITY CLASSIFICATION AUTHORITY N/A			3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited		
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE N/A			4. PERFORMING ORGANIZATION REPORT NUMBER(S) Interim Report BFLRF No. 268		
6a. NAME OF PERFORMING ORGANIZATION Belvoir Fuels and Lubricants Research Facility (SwRI)			6b. OFFICE SYMBOL (If applicable) STRBE-VF	7a. NAME OF MONITORING ORGANIZATION	
6c. ADDRESS (City, State, and ZIP Code) Southwest Research Institute 6220 Culebra Road San Antonio, Texas 78228-0510			7b. ADDRESS (City, State, and ZIP Code)		
8a. NAME OF FUNDING / SPONSORING ORGANIZATION U.S. Army Belvoir Research, Development and Engineering Center		8b. OFFICE SYMBOL (If applicable) STRBE-VF	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAK70-87-C-0043; WD 7		
8c. ADDRESS (City, State, and ZIP Code) Fort Belvoir, VA 22060-5606			10. SOURCE OF FUNDING NUMBERS	PROGRAM ELEMENT NO. 63001	PROJECT NO. IL263001 D150
				TASK NO. 07(1)	WORK UNIT ACCESSION NO.
11. TITLE (Include Security Classification) Failure Analysis of Fuel Injection Pumps From Generator Sets Fueled With Jet A-1 (U)					
12. PERSONAL AUTHOR(S) Lacey, Paul I. and Lestz, Sidney J.					
13a. TYPE OF REPORT Interim		13b. TIME COVERED FROM Nov 1990 TO Jan 1991	14. DATE OF REPORT (Year, Month, Day) 1991 January		15. PAGE COUNT 22
16. SUPPLEMENTARY NOTATION					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Failure Analysis Jet A-1 Fuel Injection Pumps Generator Set		
19. ABSTRACT (Continue on reverse if necessary and identify by block number)					
<p>The U.S. Department of Defense (DOD) has adopted the single fuel for the battlefield concept. Diesel fuel will be replaced by JP-8/Jet A-1 in compression ignition engines, thereby lowering the fuel logistics burden. These fuels have successfully undergone extensive testing in both the laboratory and in field trials. However, increased failure rates are being reported on a number of fuel-sensitive components during Operation Desert Shield in Saudi Arabia.</p> <p>Five failed Stanadyne rotary fuel injection pumps were returned to the Belvoir Fuels and Lubricants Research Facility (BFLRF) at Southwest Research Institute (SwRI) for disassembly and post-failure analysis. Particular attention was given to the possible effects of low-lubricity fuel. The results of this investigation indicate that most of the failures may be attributed to causes other than poor fuel lubricity. The reason for failure of specific components in two of the pumps could not be conclusively determined. However, it is believed that they would not have occurred as a result of short-term operation with Jet A-1.</p>					
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL Mr. T.C. Bowen			22b. TELEPHONE (Include Area Code) (703) 664-3576		22c. OFFICE SYMBOL STRBE-VF

EXECUTIVE SUMMARY

Problems and Objectives: To lower its fuel logistics burden, the Department of Defense (DOD) is advancing the use of a single fuel on the battlefield. To this end, JP-8/Jet A-1 is replacing diesel fuel (DF-2) in many applications. However, the decreased lubricity of these fuels combined with their low viscosity (compared to DF-2 diesel) is causing concern, particularly in relation to the premature failure of certain rotary fuel injection pumps.

Importance of Project: A large increase in the frequency of unplanned maintenance associated with Stanadyne rotary fuel injection pumps operating on Jet A-1 is reported from Operation Desert Shield. This component is vital to the reliable operation of many types of ground equipment. The completion of this study will determine the cause of failure in a number of pumps returned from Saudi Arabia.

Technical Approach: In this study, five failed Stanadyne pumps were examined. Little background information was available, other than that the pumps were used on diesel engine generator sets. The effect of fuel lubricity was masked by the fact that each pump has operated on both diesel and Jet A-1/JP-8 for an unspecified period of time. If the location of the failure was obvious (i.e., seizure), the pump was disassembled and the cause determined. Otherwise, the pump was placed on a test stand. The delivery was compared with the manufacturers specifications. After testing, each pump was completely disassembled. A pump specialist then subjectively rated the degree of wear present on critical components within the pump. This procedure allowed comparison among the pumps and also highlighted the more wear-sensitive areas within the pump design.

Accomplishments: The cause of pump failure was clear in each instance, and none could be directly attributed to the use of Jet A-1 in the generator sets. One pump failed due to binding of the transfer pump blades, while two of the pumps had grit or corrosion particles present within the mechanism. The most common cause of failure was fuel leakage past the metering valve while in the OFF position. The material loss due to wear appeared much less than the random variation in valve size from pump to pump. In one instance, no wear was visible on the metering valve assembly; however, the valve bore was considerably oversize, indicating a possible deviation from the correct tolerance during manufacture. The effects of poorly fitting valves is likely to be exacerbated by the use of Jet A-1/JP-8 due to the lower viscosity of these fuels.

Military Impact: The results of this study indicate that the pump failures were not directly related to the use of Jet A-1/JP 8. Some attrition is likely with all fuels, and the precise effects (if any) of Jet A-1/JP-8 could not be determined. From the present limited study, it would appear that other problems such as fuel cleanliness are of equal or greater importance than fuel lubricity.

FOREWORD/ACKNOWLEDGMENTS

This work was conducted at the Belvoir Fuels and Lubricants Research Facility (BFLRF) located at Southwest Research Institute (SwRI), San Antonio, TX, under Contract No. DAAK70-87-C-0043, during the period November 1990 through January 1991. The work was funded by U.S. Army Belvoir Research, Development and Engineering Center, Ft. Belvoir, VA, with Mr. T. C. Bowen (STRBE-VF), serving as the contracting officer's representative, and Mr. M. E. LePera, chief of Fuels and Lubricants Division (STRBE-VF), as the project technical monitor.

Technical expertise of BFLRF Technician Rodney Grinstead in disassembly, inspection, flow-bench, calibration, and diagnosis of fuel injection pumps is gratefully acknowledged. Since this effort was a fast-track response, it is also appropriate to acknowledge background assistance provided by Doug Yost and Bill Likos of the BFLRF engineering staff and Steve Westbrook of the BFLRF chemical laboratory staff. Special efforts of Esther Cantu, LuAnn Pierce, and Jim Pryor of the BFLRF documents processing group are also appreciated.

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
I. INTRODUCTION AND BACKGROUND	1
II. OBJECTIVE	3
III. EXPERIMENTAL APPROACH	3
IV. DISCUSSION OF RESULTS	7
A. Disassembly and Failure Analysis	7
1. Pump No. 1	7
2. Pump No. 2	9
3. Pump No. 3	12
4. Pump No. 4	12
5. Pump No. 5	13
B. Detailed Examination of the Metering Valves	14
C. Summary of Pump Wear Characteristics	18
V. CONCLUSIONS	20
A. General Conclusions	20
B. Specific Conclusions	20
VI. LIST OF REFERENCES	21

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By _____	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	



LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Boiling Ranges of Fuel	3
2	Exploded View of the Stanadyne Model DB Rotary Fuel Injection Pump	5
3	Rotor From Pump No. 5545723	8
4	Worn End Pieces From Transfer Pump No. 5545723	9
5	Debris on Internal Parts of Pump No. 6192152	10
6	SEM Micrograph of Surface Pitting on Cam Roller From Pump No. 6192152	11
7	View of the Worn Surfaces on the Metering Valve From Pump No. 6192152	11
8	Representative Machining Marks on Metering Valve	16
9	Worn Surfaces of the Metering Valve From Pump Serial No. 6192152	17
10	Surface of Coated Metering Valve Spindle (Pump Serial No. 5258129)	17

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Comparison of Selected Fuel Specification Requirements Related to Diesel and Turbine Engine Performance	2
2	Summary of Identification Numbers Associated With Each Pump	4
3	Results From Measurements on Metering Valves	15
4	Subjective Wear Level on Critical Pump Components	19

I. INTRODUCTION AND BACKGROUND

The U.S. Department of Defense (DOD) has adopted the single fuel for the battlefield concept.(1-2)* The U.S. Army is converting its ground tactical fleet of diesel fuel-consuming vehicles/equipment in several overseas areas from diesel fuel to MIL-T-83133 JP-8.(3) The DOD and North Atlantic Treaty Organization (NATO) "single-fuel" directives are supported by many years of engine testing (4-6) and, more recently, by an ongoing JP-8 demonstration at Fort Bliss, TX.(7) There is significant concern within the U.S. Army/DOD concerning the use of JP-8 as an alternative fuel to No. 2 diesel fuel (DF-2).

Some deterioration in the performance of Stanadyne rotary fuel injection pumps (Model DB2) fitted to a General Motors (GM) 6.2-liter engine was observed in a 210-hour laboratory dynamometer test (8) and in a laboratory pump rig evaluation.(9) However, this deterioration was not evident in a subsequent 400-hour laboratory dynamometer test (10), nor in a 10,000-mile road test (11) with M1028 Commercial Utility Cargo Vehicles (CUCV) at the Mesa Arizona proving grounds. Concern regarding the use of Jet A-1 (12) fuel has recently surfaced in Operation Desert Shield. In particular, increased unplanned maintenance associated with the Stanadyne pump is claimed. The manufacturer identified and produced pump modifications much earlier to address low-viscosity fuel usage under arctic conditions.(9,11) However, the majority of pumps currently in service are of the standard type.

Five pumps reported to have failed in the field were forwarded for analysis to the Belvoir Fuels and Lubricants Research Facility at Southwest Research Institute. These pumps were removed from diesel engine driven (DED) mobile power generator sets. It should be recognized that these pumps may have operated on Jet A-1 fuel rather than JP-8. JP-8 includes a corrosion inhibitor additive, which may improve fuel lubricity. In addition, the lubricating qualities of a fuel are likely to be influenced by the amount and type of sulfur compound present. This sulfur compound varies as a function of crude source and normally ranges in levels between 0.2 and 0.4 mass%. TABLE 1 contains comparative properties associated with DF-2, JP-8, Jet A-1, DF-2, and DF-A fuels. The numbers shown in parentheses with "footnote B" in TABLE 1

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

TABLE 1. Comparison of Selected Fuel Specification Requirements Related to Diesel and Turbine Engine Performance

Properties	VV-F-800D			MIL-T-5624N			MIL-T-83133C			ASTM D 1655		
	DF-A	DF-1	DF-2	DF-2 (OCONUS)*	JP-5/NATO Code F-44	JP-8/NATO Code F-34	JP-8/NATO Code F-34	JP-8/NATO Code F-34	Jet A-1/NATO Code F-35	JP-8/NATO Code F-34	JP-8/NATO Code F-34	Jet A-1/NATO Code F-35
Flash Point, °C, min	38	38	52	56	60	38	38	38	38	NR	NR	NR
Cloud Point, °C, max	-51	**	**	13	NR†	NR	NR	NR	NR	NR	NR	NR
Pour Point, °C	Rpt	Rpt	Rpt	18	NR	NR	NR	NR	NR	NR	NR	NR
Freezing Point, °C, max	NR	NR	NR	NR	-46	-47	-47	-47	-47	-47	-47	-47
Kinematic Viscosity at 40°C, cSt	1.1 to 2.4	1.3 to 2.9	1.9 to 4.1	1.3 to 5.0(A)	NR(1.50)(B)	NR(1.25)(B)	NR(1.25)(B)	NR(1.25)(B)	NR(1.25)(B)	NR(1.25)(B)	NR(1.25)(B)	NR(1.25)(B)
Kinematic Viscosity at -20°C, cSt, max	NR	NR	NR	NR	8.5	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Distillation, °C												
10% recovered, max	NR	NR	NR	NR	205	205	205	205	205	205	205	205
20% recovered, max	NR	NR	NR	NR	Rpt	Rpt	Rpt	Rpt	Rpt	Rpt	Rpt	Rpt
50% recovered, max	Rpt	Rpt	Rpt	NR	Rpt	Rpt	Rpt	Rpt	Rpt	Rpt	Rpt	Rpt
90% recovered, max	288	288	338	357	Rpt	Rpt	Rpt	Rpt	Rpt	Rpt	Rpt	Rpt
End Point, max	300	330	370	370	290	300	300	300	300	300	300	300
Residue, vol%, max	3	3	3	3	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Carbon Residue on 10%												
Bottoms, wt%, max	0.10	0.15	0.35	0.2	NR	NR	NR	NR	NR	NR	NR	NR
Sulfur, mass%, max	0.25	0.50	0.50	0.30	0.40	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Cu Corrosivity												
3 hr at 50°C, max	3	3	3	1	NR	NR	NR	NR	NR	NR	NR	NR
2 hr at 100°C, max	NR	NR	NR	NR	1	1	1	1	1	1	1	1
Ash, wt%, max	0.01	0.01	0.01	0.02	NR	NR	NR	NR	NR	NR	NR	NR
Accelerated Stability												
mg/100 mL, max	1.5	1.5	1.5	1.5	NR	NR	NR	NR	NR	NR	NR	NR
Neutralization Number, mg KOH/g, max	0.05	NR	NR	0.1	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Particulate Contamination, mg/L, max	10	10	10	10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Cetane Number, min	40	40	40	45	NR(42.3)(B)	NR(44.9)(B)	NR(44.9)(B)	NR(44.9)(B)	NR(44.9)(B)	NR(44.9)(B)	NR(44.9)(B)	NR(44.9)(B)
Net Heat of Combustion MJ/kg, min	NR	NR	NR	NR	42.6	42.8	42.8	42.8	42.8	42.8	42.8	42.8
Btu/gal	NR	NR	NR(130,575)(B)	NR(127,776)(B)	NR(125,965)(B)	NR(123,138)(B)	NR(123,138)(B)	NR(123,138)(B)	NR(123,138)(B)	NR(123,138)(B)	NR(123,138)(B)	NR(123,138)(B)
Corrosion Inhibitor, mg/L	NR	NR	NR	NR	QPL-25017	QPL-25017	QPL-25017	QPL-25017	QPL-25017	QPL-25017	QPL-25017	QPL-25017
Antisicing Additive, vol%	NR	NR	NR	NR	0.15 to 0.20	0.10 to 0.15	0.10 to 0.15	0.10 to 0.15	0.10 to 0.15	0.10 to 0.15	0.10 to 0.15	0.10 to 0.15

* Meets all requirements of NATO Code F-34 Guide Specifications.

** Specified according to anticipated low ambient temperature at use location.

† NR = No Requirement.

(A) Kinematic Viscosity values given are equivalent to NATO requirement of 1.8 to 9.5 cSt at 20°C.

(B) Average value from Reference No. 13 shown for comparison purposes.

are average values from an earlier survey (13) that are provided for comparison purposes. Fig. 1 shows a graphical representation of the boiling range of these fuels.

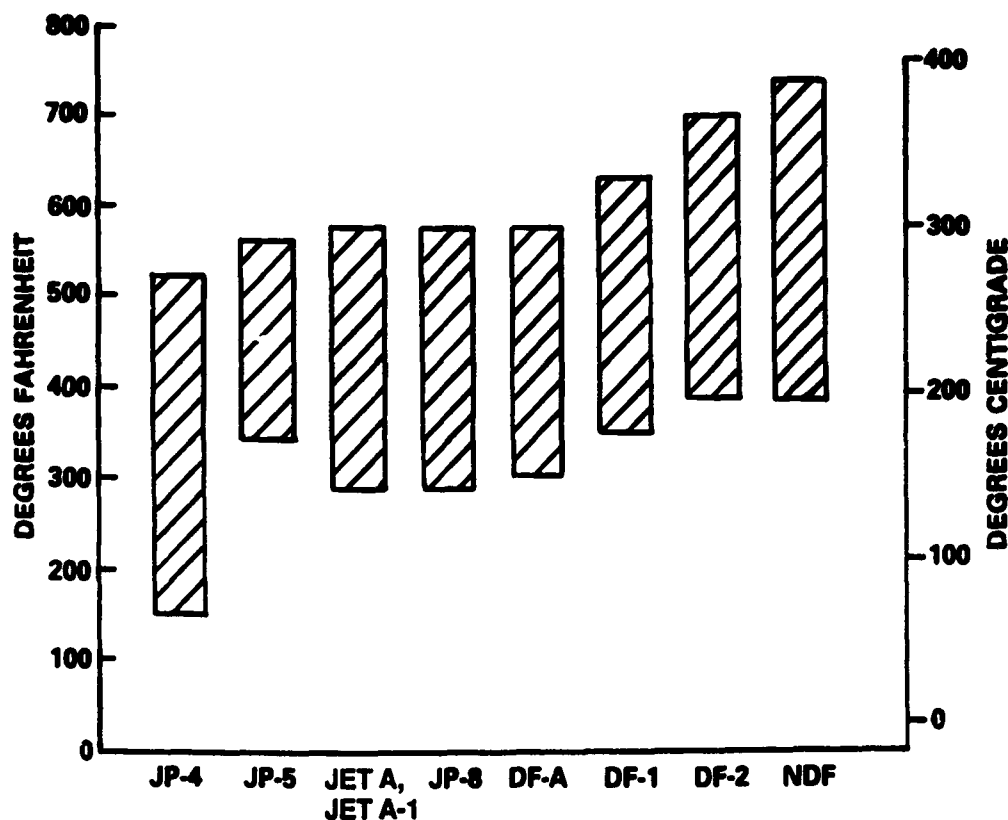


Figure 1. Boiling ranges of fuels

II. OBJECTIVE

The objective of this investigation was to determine the cause of premature failure of five Stanadyne Model DB rotary fuel injection pumps that were operated with Jet A-1 aviation fuel.

III. EXPERIMENTAL APPROACH

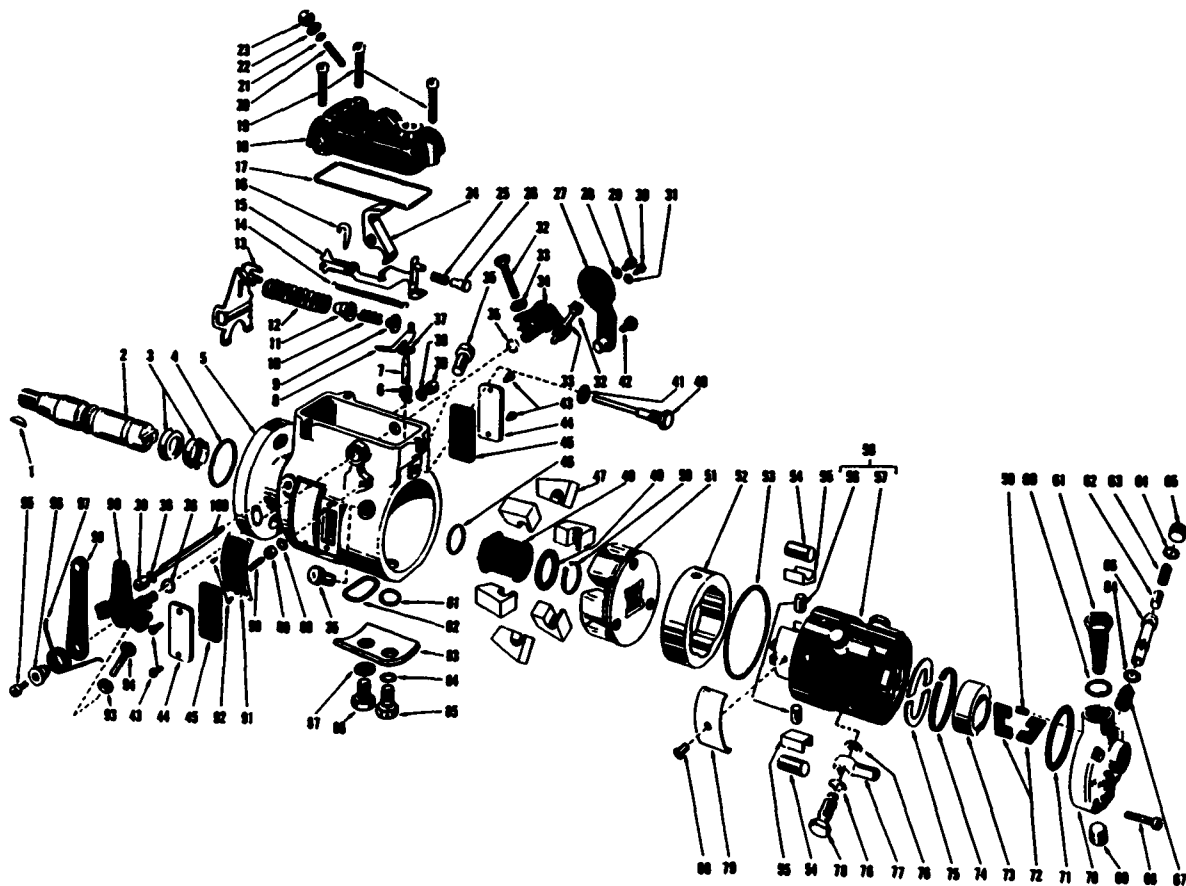
The five pumps received by BFLRF were identified only by the manufacturer, model number and serial number stamped on each unit. Little background information was available other than the Stanadyne Model DB rotary fuel injection pumps had been used on Army diesel engine driven mobile power generator sets in Operation Desert Shield. The identification numbers associated with each pump are summarized in TABLE 2.

TABLE 2. Summary of Identification Numbers Associated With Each Pump

<u>Pump No.</u>	<u>Serial No.</u>	<u>Model No.</u>	<u>AL No.</u>
1	5545723	DBMFC 629-2LQ	AL-19573-X
2	6192152	DBMFC 2605	AL-19574-X
3	5258129	DBMFC 6331LK	AL-19577-X
4	6192153	DBMFC 2605	AL-19575-X
5	6192664	DBMFC 633-2604	AL-19576-X

An exploded view of the Stanadyne DB pump may be seen in Fig. 2. The manufacturer describes this pump as a single-cylinder, opposed plunger, inlet metering, distributor type. Power is transmitted to the pump by a removable drive shaft connected to the pump rotor through a drive tang. A weak point is provided in the drive shaft to protect the engine in case of pump seizure. Fuel is drawn into the unit by a positive displacement, vane-type transfer pump. During normal operation, a precisely metered volume of fuel passes from the transfer pump to the hydraulic head at relatively low pressure of less than 130 psi. The volume of fuel transferred is defined by a metering valve, the position of which is determined by the throttle setting and a centrifugal governor. Fuel is forced from the hydraulic head at high pressure by two plungers and is sent to the appropriate injector connection through a distributor rotor. The final component in the pump mechanism is a delivery valve that ensures a sharp fuel cut off at the end of the delivery cycle.

The drive shafts were missing from most of the pumps. Each pump was tested for seizure using the drive shaft from Pump No. 5258129 (AL-19577-X). Pump No. 5545723 (AL-19573-X) had a different drive shaft geometry from the others. As a result, it could not be tested for seizure in this way. One of the pumps appeared to be seized, and several others were excessively stiff. Subsequent examination indicated that the governor weights fall from their retainer when the drive shaft is removed (this may be prevented if the throttle is held in the wide open position). The weights then bind with the mechanism, making the pump appear seized.



- | | | |
|--|--|---------------------------------------|
| 1. KEY, drive shaft | 35. SCREW, head locking | 69. PLUG, end plate pipe |
| 2. SHAFT, drive | 36. SEAL, shaft | 70. PLATE, end |
| 3. SEAL, drive shaft | 37. SHIM, metering valve | 71. SEAL, transfer pump |
| 4. SEAL, pilot tube | 38. SEAL, pivot shaft | 72. BLADE, transfer pump |
| 5. HOUSING ASSEMBLY, pump | 39. NUT, pivot shaft retainer | 73. LINER, transfer pump |
| 6. SPRING, metering valve | 40. STUD, guide | 74. RING, rotor retainer |
| 7. VALVE, metering | 41. WASHER, guide stud | 75. RETAINER, rotor |
| 8. ARM ASSEMBLY, metering valve | 42. SCREW, stop lever fitting | 76. WASHER, fuel line connector screw |
| 9. GUIDE, idling spring | 43. SCREW, timing line cover | 77. CONNECTOR, fuel line |
| 10. SPRING, idling | 44. COVER, timing line | 78. SCREW, fuel line connector |
| 11. RETAINER, spring | 45. GASKET, timing line cover | 79. SPRING, leaf |
| 12. SPRING, governor control | 46. RING, drive shaft retaining | 80. SCREW, leaf spring adjusting |
| 13. ARM, governor | 47. WEIGHT, governor | 81. SEAL, head locating screw |
| 14. SPRING, governor linkage | 48. SLLEEVE, governor thrust | 82. SEAL, cam hole |
| 15. HOOK ASSEMBLY, governor linkage | 49. WASHER, governor sleeve thrust | 83. PLATE, cam locating |
| 16. CAM, shut-off | 50. RING, governor cage retaining | 84. SEAL, head locating screw |
| 17. GASKET, control cover | 51. RETAINER ASSEMBLY, governor weight | 85. SCREW, head locating |
| 18. COVER, governor control | 52. CAM RING | 86. SCREW, cam locating |
| 19. SCREW, cover hold-down | 53. SEAL, hydraulic head | 87. WASHER, cam locating screw |
| 20. SCREW, low idle adjusting | 54. ROLLER, cam | 88. SEAL, torque screw |
| 21. SEAL, low idle adj. screw | 55. SHOE, cam roller | 89. NUT, torque screw |
| 22. WASHER, low idle adj. screw | 56. PLUNGER, rotor | 90. SCREW, torque |
| 23. NUT, low idle adj. screw | 57. HEAD AND ROTOR, hydraulic | 91. PLATE, name |
| 24. LEVER, throttle shaft | 58. HYDRAULIC HEAD AND ROTOR ASSEMBLY | 92. SCREW, name plate |
| 25. SPRING, damper | 59. ROLLPIN, end plate locating | 93. NUT, high idle adjusting screw |
| 26. SLEEVE, damper | 60. SEAL, filter cap | 94. SCREW, high idle adjusting |
| 27. LEVER ASSEMBLY, adj. shut-off | 61. CAP & FILTER ELEMENT ASSEMBLY | 95. SCREW, throttle lever retaining |
| 28. LOCKWASHER, adj. shut-off lever ret. screw | 62. PISTON, regulating | 96. RETAINER, throttle lever spring |
| 29. SCREW, adj. shut-off lever retaining | 63. SPRING, regulating | 97. SPRING, throttle lever |
| 30. SCREW, adj. shut-off lever positioning | 64. SEAL, end plate sleeve | 98. LEVER ASSEMBLY, throttle shaft |
| 31. LOCKWASHER, adj. shut-off lever pos. screw | 65. PLUG, end plate | 99. SHAFT ASSEMBLY, throttle |
| 32. SCREW, shut-off lever adjusting | 66. SLEEVE, end plate | 100. SHAFT, governor arm pivot |
| 33. NUT, adjusting screw | 67. SPRING, plunger retaining | |
| 34. SHAFT ASSEMBLY, shut-off | 68. SCREW, end plate | |

Figure 2. Exploded view of the Stanadyne model DB rotary fuel injection pump
 (Note: This figure was taken from the Stanadyne operation and instruction manual.)

An evaluation of Stanadyne Model DB2 rotary fuel injection pumps, which are used in the Commercial Utility Cargo Vehicle (CUCV) and the High Mobility Multipurpose Wheeled Vehicle (HMMWV), was conducted running on JP-8 fuel.⁽¹⁰⁾ In this evaluation, it was found that drive tang wear in the fuel pump contributed to a loss in performance. Only one complete drive assembly was provided with the present batch of pumps, making it impossible to reevaluate this wear mechanism.

In most instances, the cause of failure may be determined by careful examination of the used pump and may typically be attributed to one of the following causes:

- a. Dirty fuel
- b. Excessive hydraulic loading on the transfer pump
- c. Misalignment between the drive and the pump
- d. Plugging of discharge lines or injectors
- e. Corrosion (moisture).

In the present study, the additional effects of low fuel lubricity must also be considered. A range of contact and materials conditions coexist within the pump. The rotor is hydrodynamically suspended on a thin film of liquid, the properties of which are affected by fuel viscosity. By comparison, the plunger/cam assembly in the hydraulic head is highly loaded and is likely to depend on boundary/elastohydrodynamic (EHD) lubrication between the opposing surfaces.

Because of the possible range of lubrication and failure mechanisms in each pump, careful disassembly was required. In particular, all internal surfaces within the pump were rinsed with iso-octane during disassembly and the solvent collected for examination. If the cause of failure was not obvious on disassembly (i.e., the pump was not seized), the pump was placed on a test stand, and its delivery characteristics were compared with the manufacturer's specifications.

IV. DISCUSSION OF RESULTS

A. Disassembly and Failure Analysis

1. Pump No. 1

Number: AL-19573-X

Model No: DCMFC 629-2LQ

Serial No: 5545723

Outlet Ports: 6

Remarks:

- a. All the fuel ports were exposed
- b. The drive shaft was sheared.
- c. The pump was tagged with:
60 kW
Model No. MEP006A
Serial No. F20090
Registration No. N/A
WO No. A044492
Hours: 414

This pump was received with the drive shaft and drive gear in place. The pump rotor was seized within the hydraulic head, and the shaft was sheared. To allow complete disassembly, the pump lining was pressed from the hydraulic head and sectioned parallel to the axis of the seized rotor. Seizure between the rotor and the hydraulic head occurred at a point close to the transfer pump, as shown in Fig. 3.

In running the engine with diesel fuel, seizure at this position normally indicates that excessive side thrust is occurring at the transfer pump, due either to mechanical or hydraulic loading. Such loading is normally caused by one of the following:

- a. Excessive transfer pump pressure (maladjustment, over-speed, misalignment)
- b. Tight transfer pump blades
- c. Broken transfer pump blades
- d. Over tightened end plate screws on the transfer pump.

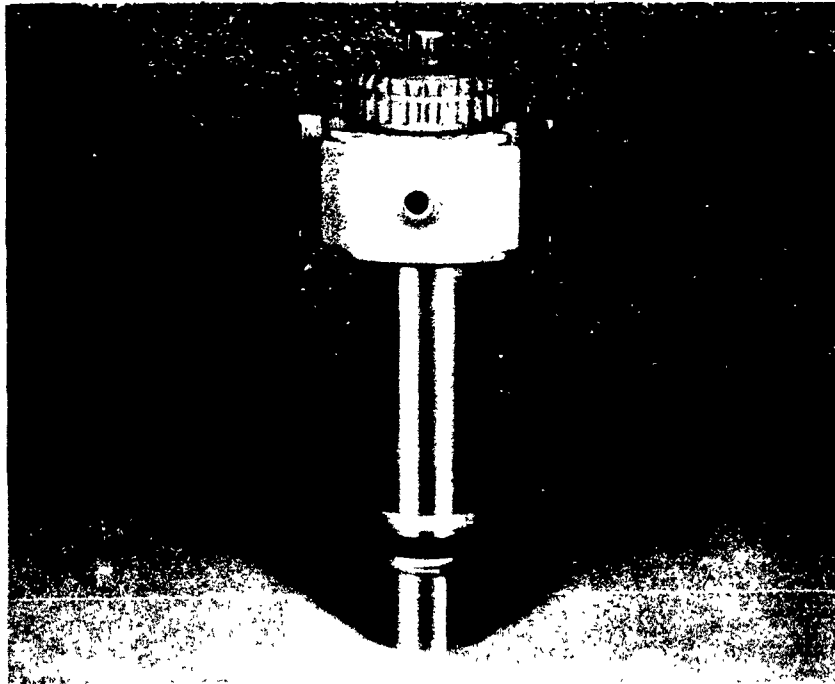
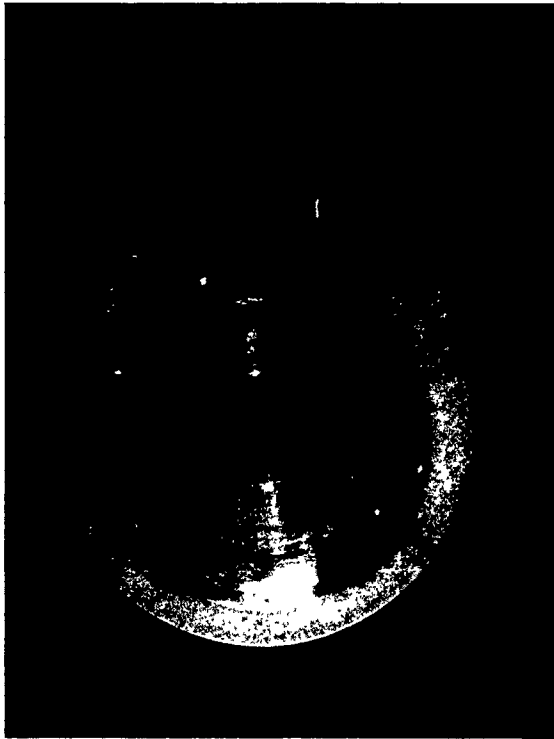


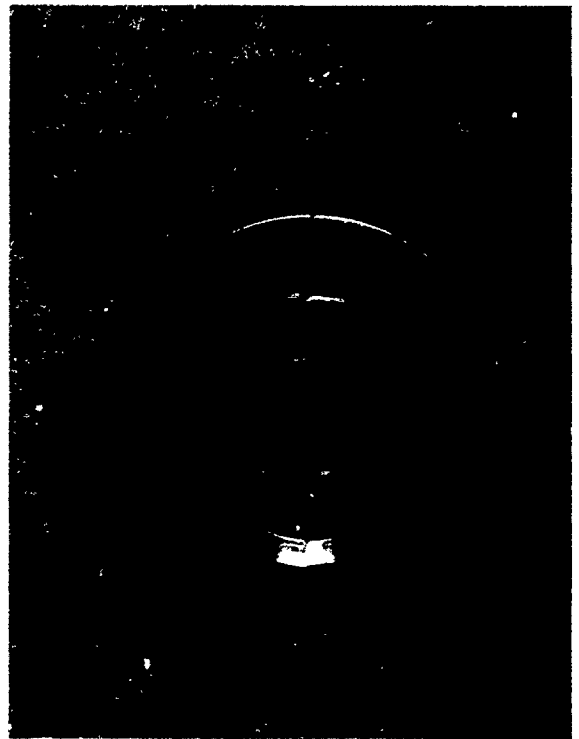
Figure 3. Rotor from Pump No. 5545723
[Note: Abraded ring caused by seizure (close to transfer pump at the bottom of the picture).]

Subsequent examination revealed high wear at both ends of the transfer pump on the outlet side, as shown in Fig. 4a and 4b. The crescent-shaped wear scar was relatively deep and confined to a small area towards the outside of the circle swept by the blades. The shape of the scar indicates that it was probably due to some form of misalignment within the pump assembly. In addition, the spring between two of the four transfer pump blades was broken, indicating a serious problem in this area of the pump.

Some shiny debris was found inside the pump. X-ray analysis (EDAX) indicates that this debris is mainly iron and calcium. The iron was probably produced by the formation of wear particles during seizure, while the source of the calcium deposit is less clear. Analysis of sand from Saudi Arabia indicates that it is formed largely from calcium. However, sand normally contains an appreciable amount of silicon, which was not found in the present analysis. Contamination of the parts by water either before or after failure may also have introduced calcium deposits.



a. Retainer



b. Regulator

Figure 4. Worn end pieces from transfer Pump No. 5545723

2. Pump No. 2

Number: AL-19574-X
Model No: DBMFC 2605
Serial No: 6192152
Cutlet Ports: 4

Remarks: a. Drive shaft and top cover removed
b. All fuel ports exposed
c. Rotor is not seized
d. Pump tagged with: "Continues to feed fuel after shutdown"

On disassembly, particles and fine debris were found throughout the pump, as shown in Fig. 5, which depicts the cam screw plug and end plate. X-ray analysis (EDAX) of representative particles collected from around the advance piston mechanism confirms that the particles are predominantly ferrous in nature.



a. Cam Screw Plug



b. End Plate

Figure 5. Debris on internal parts of Pump No. 6192152

(Note: The particles are toward the center of the end plate, which is adjacent to the transfer pump.)

Pitting was visible on both the cam ring and rollers, while abrasive scratches were visible in the roller shoes. Surface pitting is a common characteristic in corroded injector pumps, probably due to corrosion-induced fatigue. A scanning electron micrograph of surface damage on one of the rollers is shown in Fig. 6.

Although the rotor was not seized, the pump was not placed on a test stand as the debris within the pump may have caused further damage during operation. The pump was tagged with "continues to feed fuel after shutdown," indicating some problem with the fuel metering system. The metering valve spindle, which controls the fuel supply from the pump, was removed and found to be slightly worn, as shown in Fig. 7. This worn spindle may allow fuel to flow, even in the OFF position. A new oversize metering valve was obtained and was found to fit most of the way into the existing metering valve bore, confirming that the bore is oversize.



Figure 6. SEM micrograph of surface pitting on cam roller from Pump No. 6192152

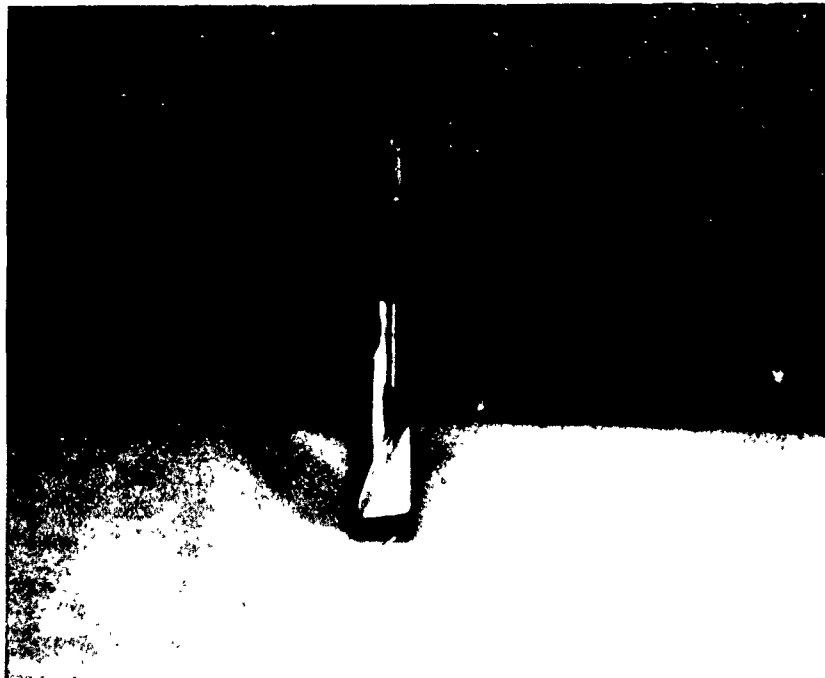


Figure 7. View of the worn surfaces on the metering valve from Pump No. 6192152

3. Pump No. 3

Number: AL-19577-X
Model No: DBMFC 633-1LK
Serial No: 5258129
Outlet Ports: 6
Remarks: a. Fuel inlet port exposed
b. Fuel outlet ports covered
c. Drive shaft installed
d. Rotor does not appear to be seized
e. Pressure regulator sleeve assembly missing

The rotor on this pump was not seized and could turn freely in the pump housing. The pump was visually inspected inside the governor housing and transfer pump, and no obvious damage or debris was present. As catastrophic failure had not taken place, the pump was placed on a test stand before disassembly to determine the cause of failure.

The pump was operational and met the manufacturer's specifications for both flow rate and timing during normal running. However, the fuel flow rate with the throttle at the off position exceeded the maximum value specified (7 cm³/1000 strokes vs. 3 cm³/1000 strokes). This flow resulted in enough fuel to open the injectors on the test stand and may cause run-on in a practical application. The metering valve was removed and found to be free of visible wear. An oversize metering valve would fit freely into the existing bore, indicating that the standard metering valve was too loose. The pump was retested on the stand and perfect operation was restored by the oversize valve.

4. Pump No. 4

Number: AL-19575-X
Model No: DBMFC 2605
Serial No: 6192153
Outlet Ports: 4
Remarks: a. Drive shaft and top cover removed
b. All fuel ports exposed
c. Rotor binds at a certain position once during each revolution

Although the inlet filter screen was missing, the remainder of the pump appeared new or to have been thoroughly overhauled. Grease used during assembly was still present around a number of O-rings and seals.

The pump rotor was stiff and could be turned only with difficulty. However, seizure had not occurred, so components in contact with the rotor were carefully disassembled to determine the cause of binding. Weights from the governor assembly were found to have slipped from the proper position and were interfering with the rotor. This slippage probably occurred when the drive shaft was withdrawn after the pump was removed from the engine and was not the cause of failure.

Little or no wear was present in the transfer pump on either the eccentric liner or the four blades. As the cause of failure was not evident, the pump was reassembled and placed on a test stand. During testing, the pump was found to pass fuel with the throttle in the off position (6 cm³/1000 strokes vs. 3 cm³/1000 strokes). The metering valve spindle was removed and found to be slightly worn. An oversize metering valve fitted approximately half way into the valve bore, indicating that the hole was slightly large.

5. Pump No. 5

Number: AL-19576-X
Model No: DBMFC 633-2604
Serial No: 6192664
Outlet Ports: 6
Remarks: a. Drive shaft and top cover removed
b. Side cover opened
c. All fuel ports exposed
d. Rotor appears seized

The rotor on this pump was stiff and could be turned only with difficulty. Some wear was visible in the transfer pump on both the blades and the eccentric liner. However, the level of transfer pump wear was not excessive, and the rotor remained stiff after removal of the transfer pump assembly. The rotor became free after removal of the high-pressure head and rotor

assembly from the pump housing. Little or no wear was visible in the metering valve or the plunger/cam ring assembly.

As the cause of failure was not evident, the pump was reassembled and mounted on a test stand. However, the pump failed to pass any fluid and was stopped immediately to prevent further damage due to build up of hydraulic head. The delivery valve was removed and found to contain grit. This valve is on the outlet from the pump and had not been removed during the previous inspection. The valve itself was found to be in acceptable condition and was replaced in the pump after cleaning. The pump was retested and found to meet the manufacturer's specifications.

During the initial disassembly and inspection of the pump, it was noticed that the filter element assembly was missing from the inlet to this pump. This assembly may have been unscrewed by accident during removal of the pump from the engine. However, the presence of coarse grit in the delivery valve would indicate otherwise.

B. Detailed Examination of the Metering Valves

Failure of the metering valve to stop fuel flow in the off position occurred in three of the five pumps. For this reason, the metering valves were selected for a more detailed examination. The metering valve consists of a spindle with a helix machined into one side, as shown in Fig. 7. The position of the helix relative to an orifice in the bore determines the fuel supply rate. If the valve spindle is rotated so that the helix is away from the bore, the fuel supply from the transfer pump to the hydraulic head is stopped. Some fuel will normally leak around the valve spindle in the off position ($3 \text{ cm}^3/1000$ strokes maximum). However, if the clearance between the valve and the bore is excessive, enough fuel may pass to cause the injectors to open, allowing the engine to run-on.

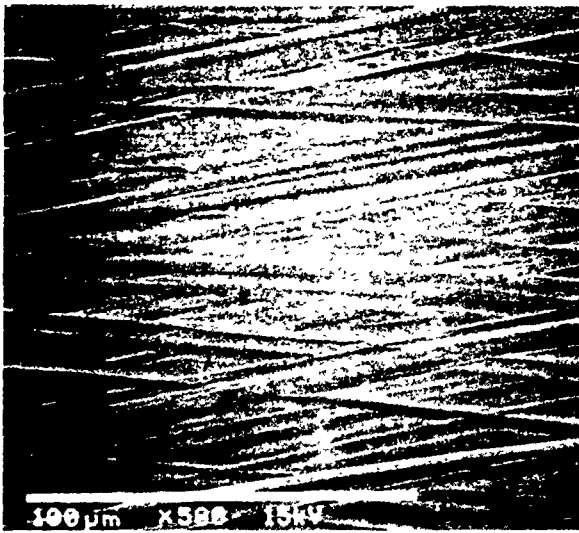
Critical dimensions measured from each of the metering valve components are given in TABLE 3.

TABLE 3. Results From Measurements on Metering Valves

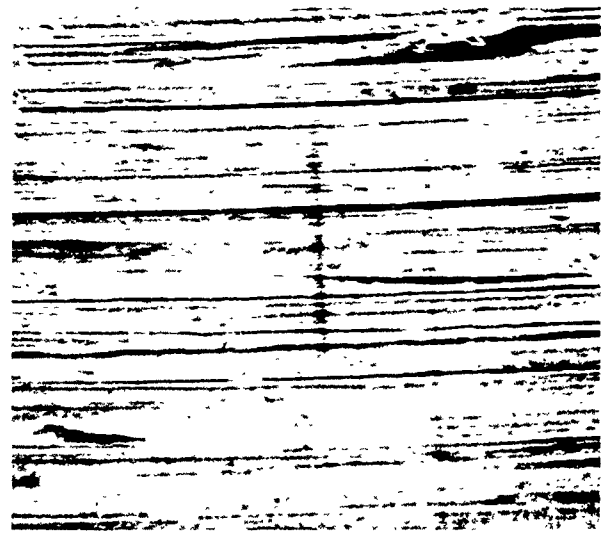
Serial Nos.	Diameter			Roughness	
	Valve, inches	Bore, inches	Bore Roundness, in.	Spindle, μ inches	Bore, μ inches
5545723	0.2485	0.2498	± 0.0001	6.9	10.8
6192152	0.2484	0.2501	± 0.0000	12.3	9.1
5258129	0.2485	0.2506	± 0.0000	12.3	8.9
6192153	0.2486	0.2502	± 0.0001	10.0	8.5
6192664	0.2485	0.2498	± 0.0000	6.8	12.0
Oversize Valve	0.2500	-	-	6.6	-

The surface roughness was measured using a Talysurf 10 at a filter cut off length of 0.03 inch (0.076 cm). The tabulated value is the average of two readings taken parallel to the axis of the valve. The surface roughness of the valve spindle on Pump Nos. 2, 3 and 4 (all of which failed to seal) is greater than either Pump Nos. 1 or 5. The reason for the greater roughness of these parts is unclear, but is unlikely to be related to the use of Jet A-1 fuel, as no deformation was visible when the surface was examined in the Scanning Electron Microscope (SEM). In general, the surface roughness of the worn areas was much less than the remainder of the part. The diameters of both the valve and the bore were also measured for each pump. No variation in diameter was found along the bore, although two of the bores were found to be very slightly out of round. The diameter of each valve spindle was measured at a number of points. Particular attention was given to comparing the diameter at worn and unworn areas. However, no measurable deviation in the diameter of any of the five valve spindles was found.

After completion of the pump tests, the bores from Pump Nos. 2, 3, and 4 were cut from the hydraulic heads and sectioned parallel to the axis of the valve using an electric discharge machine (EDM). Almost no material was lost during the cutting process, and the complete surface of the valve bore was then available for examination. Machining marks were visible on the surface of each bore and valve spindle, as shown in Fig. 8.



a. Bore

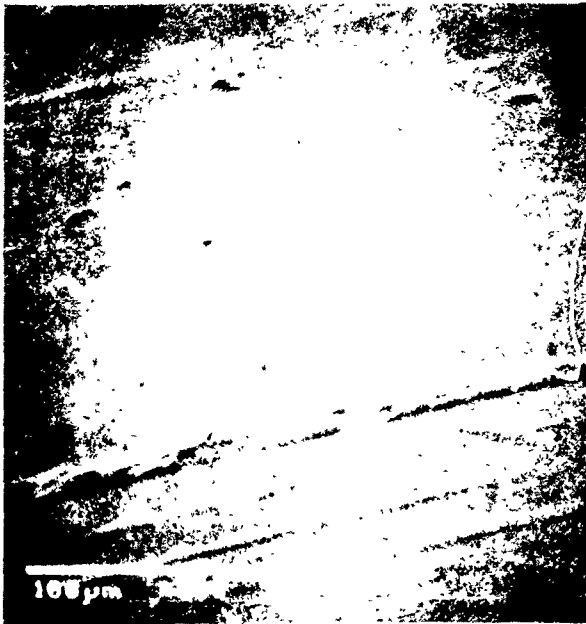


b. Valve spindle

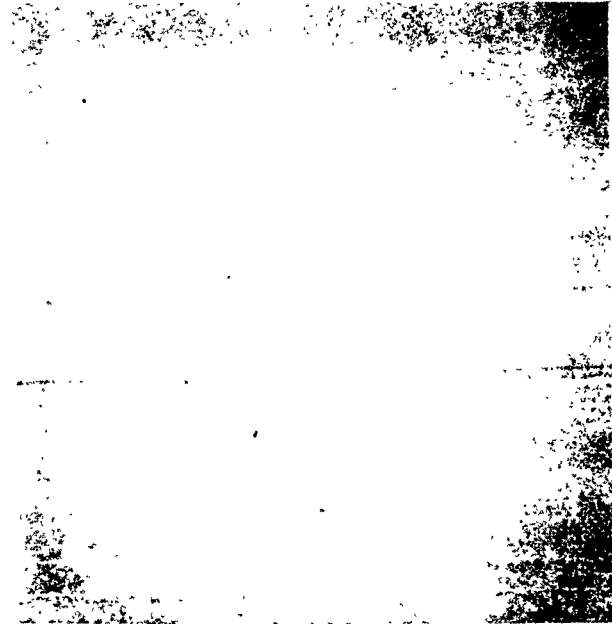
Figure 8. Representative machining marks on metering valve

Visual examination of the metering valve spindle from Pump No. 2 (Serial No. 6192152) shows areas of wear on the surface close to the helix. The corresponding area on the valve bore is also worn, and the shape of the helix is clearly visible. Although wear of the metering valve is not common, it is occasionally seen in this area close to the helix after extended use (with diesel fuel). Examination of the parts using a scanning electron microscope indicates that the worn areas on both surfaces are highly polished, as shown in Fig. 9a and 9b for the bore and the valve spindle, respectively. The deeper scratches from the machining process are still visible on the bore. No abrasive scratches are visible, and the corrosion that occurred within the remainder of this pump does not appear to have affected the metering valve.

Both the metering valve spindle and the bore from Pump No. 3 (Serial No. 5258129) are free of wear. The spindle has an unidentified thin coating. This coating has the uniform texture shown in Fig. 10 over the complete surface. The normal machining marks are also visible around the entire valve bore. Although it is free of wear, the diameter of the bore is much greater than normal and, as previously stated, will accept an oversize metering valve spindle. The cause of this deviation is unclear. However, it does not appear to be wear related and is unlikely to have been caused by the use of Jet A-1 or JP-8 fuels.



a. Bore



b. Valve spindle

Figure 9. Worn surfaces of the metering valve from Pump Serial No. 6192152

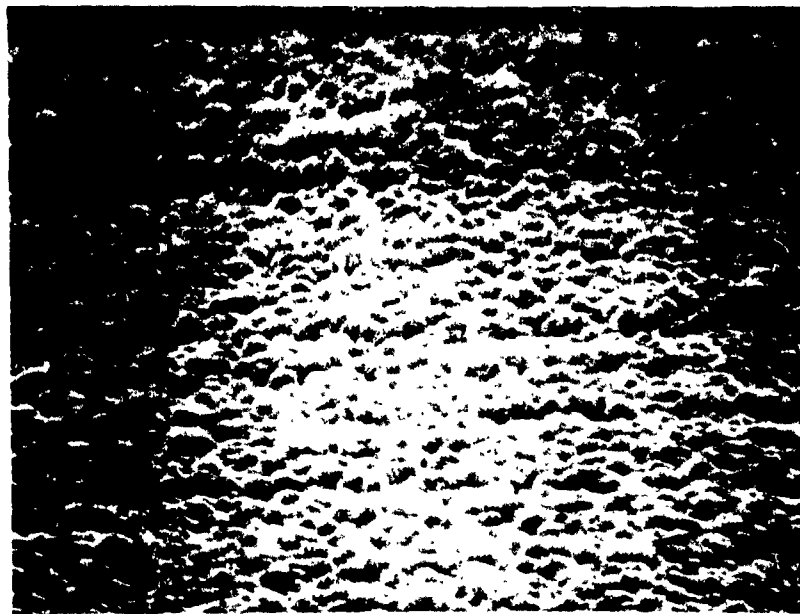


Figure 10. Surface of coated metering valve spindle (Pump Serial No. 5258129)

The bore from Pump No. 4 (Serial No. 6192153) also appears unworn, but is slightly bigger than normal (it will almost accept an oversize spindle). The metering valve spindle shows slight wear in two very narrow vertical strips, both of which are away from the helix. Examination of these areas in the scanning electron microscope confirms that the surface is polished and was formed

by a mild nonabrasive wear mechanism. The topography of the wear scars is very similar to that seen on the metering valve in Pump No. 2.

The causes of wear on Pump Nos. 2 and 4 are unclear. However, it should be noted that machining marks are still visible on the valve bore, so the wear depth is likely to be less than the surface roughness (<10 micro inch). The amount of material removed from the diameter of the valve spindle could not be measured, but is less than 0.0001 inch. Both of these figures are less than the variation in the bore diameter from pump to pump (± 0.0004 inch), indicating a possible problem during the machining process. This theory is supported by the fact that the metering valve bore in Pump No. 3 is considerably oversized but appears to be completely free of wear. In addition, leakage past a poorly fitting valve is likely to be increased by the use of a low viscosity fuel such as JP-8/Jet A-1.

C. Summary of Pump Wear Characteristics

After completion of the pump stand tests and the complete disassembly of each pump, the wear-prone components were examined, irrespective of the failure mechanism. The majority of these parts did not contribute to the pump failure and would have remained serviceable for some time. In order to define the level of wear, a subjective scale from 0 to 5 was used, with 0 corresponding to no wear and 5 corresponding to component failure or seizure.

The results from this examination are given in TABLE 4. Pump Nos. 1 and 2 were the most severely worn, while Pump No. 3 is almost new. The results for Pump No. 2 are largely influenced by pitting and abrasive wear, probably due to corrosion within the pump and, as such, may not be considered normal wear. Little or no wear was observed around the hydraulic head and rotor assembly on any of the pumps (except for Pump No. 1, which seized due to problems outside this area). In general, significantly more wear was visible in the transfer pump and governor assemblies.

TABLE 4. Subjective Wear Level* on Critical Pump Components

Component		Pump No.				
		1	2	3	4	5
Hydraulic Head and Rotor	Hydraulic Head	5	1	0	1	1
	Discharge Fittings	0	0	0	0	0
	Distributor Rotor	5	1	0	1	1
	Delivery Valve	3	3	0	1	3
	Plungers	1	0	0	0	1
	Cam Rollers & Shoes	1	2	1	1	1
	Leaf Spring and Screws	1	1	0	0	0
	Cam	0	4	0	0	0
	Governor Weight Ret.	1	3	0	0	3
	Governor Weights	0	0	0	0	0
	Governor Thrust Washer	2	2	0	1	1
	Governor Thrust Sleeve	1	1	0	0	0
	Transfer Pump	End Cap	0	2	0	0
Inlet Screen		1	4	NA	NA	NA
End Plate Adj. Plug		0	4	NA	0	0
Regulating Piston		3	4	NA	1	1
Regulator		4	3	2	2	1
Blades		2	3	1	1	1
Liner		3	3	3	4	2
Governor	Rotor Retainers	3	3	1	2	2
	Pivot Shaft	2	3	1	2	2
	Arm	1	1	0	0	0
	Metering Valve	3	4	0	1	1
Advance	Metering Valve Arm	1	1	0	0	1
	Piston	2	4	0	1	1
	Cam Advance Screw	2	2	0	0	0
	Plugs	0	2	0	0	0

* 0 = no wear; 5 = failure.

NA = Parts were not available when pump was received at BFLRF.

Note: Pump No. 1 = Serial No. 5545723
 Pump No. 2 = Serial No. 6192152
 Pump No. 3 = Serial No. 5258129

Pump No. 4 = Serial No. 6192153
 Pump No. 5 = Serial No. 6192664

V. CONCLUSIONS

A. General Conclusions

The failures of Pump Nos. 1, 3, and 4 could be attributed to quality problems during production/rebuild. The metering valve and bore diameters indicate that they were incorrectly matched during assembly or rebuild. The corrosion found in Pump No. 2 is assumed to have begun prior to its arrival in Saudi Arabia. The failure of Pump No. 5 is assumed to be caused by the use of dirty fuel.

B. Specific Conclusions

Of the five pumps examined, none of the failures could be directly attributed to the use of low lubricity fuel. Indeed, two pumps contained foreign material, and solid particles were proven to be the prime cause of failure in one case.

Most critical components in the pumps suffered relatively mild wear (except for the apparently corroded pump).

It is significant that in Pump No. 3, no wear was visible on the surface of the failed metering valve. In addition, the wear depth on the metering valve spindles/bores appears to be less than the random variation of the bore diameter from pump to pump. This variation may indicate a problem during the manufacturing/reconditioning process.

Wear of the metering valve assembly is occasionally seen after extended operation with diesel fuel. The lower viscosity of Jet A-1 compared to No. 2 diesel fuel (DF-2) is likely to increase leakage past the poorly fitting metering valves, thereby compounding an existing problem.

VI. LIST OF REFERENCES

1. Department of Defense Directive 4140.43, Subject: "Fuel Standardization," March 1988.
2. NATO Standardization Agreement, STANAG 4362, "Fuel Requirements in Future Ground Equipment," draft, developed in October 1987, now under final coordination.
3. U.S. Military Specification MIL-T-83133C, Turbine Fuels, Aviation, Kerosene Types, NATO F-34 (JP-8) and NATO F-35, 22 March 1990.
4. "Development of Military Fuel/Lubricant/Engine Compatibility Test," Coordinating Research Council, Inc., New York, NY, Final Report, January 1967.
5. Engine Compatibility Test, 240-Hour Tracked Vehicle Cycle Using 6V-53T Engine, prepared by U.S. Army Fuels and Lubricant Research Laboratory, Southwest Research Institute, San Antonio, TX, 6V-53T Test No. 39, March 14, 1984; discussed in Annotated Bibliography of Interim Report AFLRF No. 192, "JP-8 and JP-5 as Compression Ignition Engine Fuel" (AD A150796), pp. 27-28, January 1985.
6. "Accelerated Fuel-Engines Qualification Procedures Methodology Engine Test 210-Hour Wheeled Vehicle Cycle Using the Cummins NHC-250 Diesel Engine Operating on JP-8 Fuel," prepared by U.S. Army Fuels and Lubricants Research Laboratory, Southwest Research Institute, San Antonio, TX, October 1985, printed in Interim Report BFLRF No. 232, "Laboratory Evaluation of MIL-T-83133 JP-8 Fuel in Army Diesel Engines" (AD A205281), pp. 159-178, January 1988.
7. Butler, W.E., Jr., et al., "Field Demonstration of Aviation Turbine Fuel MIL-T-83133C, Grade JP-8 (NATO Code F-34) at Fort Bliss, TX," Interim Report BFLRF No. 264, prepared by Belvoir Fuels and Lubricants Research Facility (SwRI), Southwest Research Institute, San Antonio, TX, December 1990.
8. "Accelerated Fuel-Engines Qualification Procedures Methodology Engine Test 210-Hour Wheeled Vehicle Cycle Using the GM 6.2L Diesel Engine Operating on JP-8 Fuel," prepared by U.S. Army Fuels and Lubricants Research Laboratory, Southwest Research Institute, San Antonio, TX, October 1985, printed in Interim Report BFLRF No. 232, "Laboratory Evaluation of MIL-T-83133 JP-8 Fuel in Army Diesel Engines" (AD A205281), pp. 119-132, January 1988.
9. Montemayor, A. F. and Owens, E. C., "Comparison of 6.2L Arctic and Standard Fuel Injection Pumps Using JP-8 Fuel," Interim Report BFLRF No. 218 (AD A175597), prepared by Belvoir Fuels and Lubricants Research Facility (SwRI), Southwest Research Institute, San Antonio, TX, October 1986.

10. "Accelerated Fuel-Engines Qualification Procedures Methodology Engine Test 400-Hour NATO Qualification Cycle Using the GM 6.2L Diesel Engine Operating on JP-8 Fuel," prepared by U.S. Army Fuels and Lubricants Research Laboratory, Southwest Research Institute, San Antonio, TX, January 1986, printed in Interim Report BFLRF No. 232, "Laboratory Evaluation of MIL-T-83133 JP-8 Fuel in Army Diesel Engines" (AD A205281), pp. 133-146, January 1988.
11. "10,000 Mile JP-8 Fuel Test of 6.2L Diesel Engines in M1028 CUCV Vehicles," Project Request 87-027, Contract No. DAAE07-86-C-R108 (CUCV STS Contract), prepared by General Motors Corporation Military Vehicles Operations, Warren, MI, July 1987.
12. American Society for Testing and Materials Standard D 1655, "Aviation Turbine Fuel, Grades Jet A-1/Jet A," 1989.
13. Bowden, J.N. and Westbrook, S.R., "A Survey of JP-8 and JP-5 Properties," Interim Report BFLRF No. 253 (AD A207721), prepared by Belvoir Fuels and Lubricants Research Facility (SwRI), Southwest Research Institute, San Antonio, TX, September 1988.

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

DEFENSE TECHNICAL INFORMATION CTR
CAMERON STATION 12
ALEXANDRIA VA 22314

DEPT OF DEFENSE
OASD/P&L
ATTN: L/EP (MR DYCKMAN)
WASHINGTON DC 20301-8000

CDR
DEFENSE FUEL SUPPLY CTR
ATTN: DFSC-Q (MR MARTIN)
CAMERON STATION 1
ALEXANDRIA VA 22304-6160

DOD
ATTN: DUSDRE (RAT) (DR DIX)
ROOM 3-D-1089, PENTAGON
WASHINGTON DC 20301

DEPARTMENT OF THE ARMY

CDR
US ARMY BELVOIR RESEARCH,
DEVELOPMENT & ENGINEERING CTR
ATTN: STRBE-VF 10
STRBE-BT 2
STRBE-F 1
STRBE-TQ 1
STRBE-FG 2
FORT BELVOIR VA 22060-5606

HQ, DEPT OF ARMY
ATTN: DALO-TSE 1
DALO-TSZ-B (MR KOWALCZYK) 1
SARD-TR (MS VANNUCCI) 1
WASHINGTON DC 20310-0561

CDR
US ARMY MATERIEL COMMAND
ATTN: AMCDE-SS 1
AMCSM-SP 1
AMCDE-WH 1
5001 EISENHOWER AVE
ALEXANDRIA VA 22333-0001

CDR
US ARMY LABORATORY COMMAND
ATTN: AMSLC-TP-PB (MR GAUL) 1
ADELPHI MD 20783-1145

DIRECTOR
US ARMY MATERIEL SYSTEMS
ANALYSIS ACTIVITY
ATTN: AMXSY-CM 1
ABERDEEN PROVING GROUND MD
21005-5006

CDR
US ARMY TANK-AUTOMOTIVE COMMAND
ATTN: AMSTA-RG 1
AMSTA-RG (MR CHECKLICH) 1
AMSTA-TSL (MR BURG) 1
AMSTA-MTC (MR GAGLIO) 1
AMSTA-MC 1
AMSTA-MV 1
WARREN MI 48397-5000

PROJ MGR, MOBILE ELECTRIC POWER
US ARMY TROOP SUPPORT COMMAND
ATTN: AMCPM-MEP-TM 3
(COL BRAMLETTE)
7500 BACKLICK ROAD
SPRINGFIELD VA 22150

CDR
THEATER ARMY MATERIAL MGMT
CENTER (200TH)-DPGM
DIRECTORATE FOR PETROL MGMT
ATTN: AEAGD-MMC-PT-Q 1
APO NY 09052

CDR
US ARMY GENERAL MATERIAL &
PETROLEUM ACTIVITY
ATTN: STRGP-F 1
STRGP-FE, BLDG 85-3 1
(MR GARY SMITH)
STRGP-FT 1
NEW CUMBERLAND PA 17070-5008

CDR
US ARMY RES, DEVEL & STDZN GROUP
(UK)
ATTN: AMXSN-UK-RA 1
(DR REICHENBACH)
BOX 65
FPO NEW YORK 09510-1500

CDR
US ARMY LEA
ATTN: LOEA-PL 1
NEW CUMBERLAND ARMY DEPOT
NEW CUMBERLAND PA 17070

CDR US ARMY FORCES COMMAND ATTN: FCSJ-SA FORT MCPHERSON GA 30330-6000	1	PROJ MGR, LIGHT ARMORED VEHICLES ATTN: AMCPM-LA-E WARREN MI 48397	1
CDR US ARMY RESEARCH OFFICE ATTN: SLCRO-EG (DR MANN) SLCRO-CB P O BOX 12211 RSCH TRIANGLE PARK NC 27709-2211	1 1	HQ, EUROPEAN COMMAND ATTN: J4/7-LJPO VAIHINGEN, GE APO NY 09128	1
CDR US ARMY TANK-AUTOMOTIVE CMD PROGR EXEC OFF CLOSE COMBAT PM ABRAMS, ATTN: AMCPM-ABMS PM BFVS, ATTN: AMCPM-BFVS PM 113 FOV, ATTN: AMCPM-M113 PM M60 FOV, ATTN: AMCPM-M60 APEO SYSTEMS, ATTN: AMCPEO-CCV-S PM LAV, ATTN: AMCPM-LA-E WARREN MI 48397-5000	1 1 1 1 1 1	CDR US ARMY ENGINEER SCHOOL ATTN: ATSE-CD FORT LEONARD WOOD MO 65473-5000	1
CDR US ARMY YUMA PROVING GROUND ATTN: STEYP-MT-TL-MP YUMA AZ 85365-9103	1	HQ, US ARMY T&E COMMAND ATTN: AMSTE-TE-T ABERDEEN PROVING GROUND MD 21005-5006	1
CDR US ARMY TANK-AUTOMOTIVE CMD PROGR EXEC OFF COMBAT SUPPORT PM LIGHT TACTICAL VEHICLES ATTN: AMCPM-TVL PM MEDIUM TACTICAL VEHICLES ATTN: AMCPM-TVM PM HEAVY TACTICAL VEHICLES ATTN: AMCPM-TVH WARREN MI 48397-5000	1 1 1 1	CDR US ARMY ORDNANCE CENTER & SCHOOL ATTN: ATSL-CD-CS ABERDEEN PROVING GROUND MD 21005-5006	1
CDR, US ARMY TROOP SUPPORT COMMAND ATTN: AMSTR-ME AMSTR-S AMSTR-WL 4300 GOODFELLOW BLVD ST LOUIS MO 63120-1798	1 1 1	HQ US ARMY TRAINING & DOCTRINE CMD ATTN: ATCD-SL FORT MONROE VA 23651-5000	1
CDR US ARMY GENERAL MATERIAL & PETROLEUM ACTIVITY ATTN: STRGP-PW BLDG 247, DEFENSE DEPOT TRACY TRACY CA 95376-5051	1	CDR US ARMY TRANSPORTATION SCHOOL ATTN: ATSP-CD-MS FORT EUSTIS VA 23604-5000	1
		CDR US ARMY QUARTERMASTER SCHOOL ATTN: ATSM-CDM ATSM-PWD FORT LEE VA 23801	1 1
		PROJECT MANAGER PETROLEUM & WATER LOGISTICS ATTN: AMCPM-PWL 4300 GOODFELLOW BLVD ST LOUIS MO 63120-1798	3
		CDR COMBINED ARMS COMBAT DEVELOPMENT ACTIVITY ATTN: ATZL-CAT-E FORT LEAVENWORTH KS 66027-5300	1

CDR
US ARMY NATICK RES, DEV & ENGR CTR
ATTN: STRNC-U
NATICK MA 01760-5020

1

HQ, US ARMY ARMOR CENTER
ATTN: ATSB-CD-ML
ATSB-TSM-T
FORT KNOX KY 40121

1

1

CDR
US ARMY COMBINED ARMS &
SUPPORT COMMAND
ATTN: ATCL-CD
FORT LEE VA 23801-6000

1

CDR
US ARMY FIELD ARTILLERY SCHOOL
ATTN: ATSF-CD
FORT SILL OK 73503-5600

1

CDR
US ARMY INFANTRY SCHOOL
ATTN: ATSH-CD-MS-M
ATSH-TSM-FVS
FORT BENNING GA 31905-5400

1

1

CDR
US ARMY AVIATION CTR & FT RUCKER
ATTN: ATZQ-DI
FORT RUCKER AL 36362

1

CDR
US ARMY SAFETY CENTER
ATTN: PESC-SSD
FORT RUCKER AL 36362

1

CDR
DAVID TAYLOR RESEARCH CTR
ATTN: CODE 2759 (MR STRUCKO)
ANNAPOLIS MD 21402-5067

1

DEPARTMENT OF THE NAVY
HQ, US MARINE CORPS
ATTN: LPP/2
WASHINGTON DC 20380

3

CDR
NAVAL AIR SYSTEMS COMMAND
ATTN: CODE 53632F (MR MEARNES)
WASHINGTON DC 20361-5360

1

CDR
NAVAL RESEARCH LABORATORY
ATTN: CODE 6180
WASHINGTON DC 20375-5000

1

CDR
NAVY PETROLEUM OFFICE
ATTN: CODE 43 (MR LONG)
CAMERON STATION
ALEXANDRIA VA 22304-6180

1

OFFICE OF THE CHIEF OF NAVAL
RESEARCH
ATTN: OCNR-126 (DR ROBERTS)
ARLINGTON VA 22217-5000

1

CG
USMC RDA COMMAND
ATTN: CODE CBAT
QUANTICO VA 22134-5080

1

DEPARTMENT OF THE NAVY

DEPARTMENT OF THE AIR FORCE

CDR
NAVAL AIR PROPULSION CENTER
ATTN: PE-33 (MR D'ORAZIO)
P O BOX 7176
TRENTON NJ 06828-0176

1

PROJ MGR, M60 TANK DEVELOPMENT
ATTN: USMC-LNO
US ARMY TANK-AUTOMOTIVE
COMMAND (TACOM)
WARREN MI 48397-5000

1

CDR
US AIR FORCE WRIGHT AERO LAB
ATTN: AFWAL/POSF (MR DELANEY)
WRIGHT-PATTERSON AFB OH
45433-6563

1

CDR
SAN ANTONIO AIR LOGISTICS CTR
ATTN: SA-ALC/SFT (MR MAKRIS)
SA-ALC/MMPRR
KELLY AIR FORCE BASE TX 78241

1

1

CDR
WARNER ROBINS AIR LOGISTIC CTR
ATTN: WRALC/MMVR-1
(MR PERAZZOLA)
ROBINS AFB GA 31098

HQ, USAF
ATTN: LEYSF
WASHINGTON DC 20330

1

1