ADA

EVALUATION OF SYNTHETIC FUEL IN MILITARY TACTICAL GENERATOR SETS

INTERIM REPORT
TFLRF No. 392

by

Ruben Alvarez
Edwin A. Frame

U.S. Army TARDEC Fuels and Lubricants Research Facility
Southwest Research Institute® (SwRI®)
San Antonio, TX

for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Contract No. DAAE-07-99-C-L053 (Task VIII, WD23)

June 2008

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June 2008

Approved by:

Steven D. Marty, P.E., Director
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14. ABSTRACT
A program was developed to compare data on performance, fuel economy and exhaust emissions during side–by-side evaluations of military tactical generator sets while using various fuels, including Fischer-Tropsch (FT) synthetic aviation kerosene fuel. The generators identified as Tactical Quiet Generators, 10kW 60 Hz, MEP-803A were provided by the Mobile Electric Power Group at Ft. Belvoir, VA. All three generators were operated on a 25-hour break-in run using Ultra-Low Sulfur Diesel (ULSD). Then, generators No.1 and No. 3 operated on ULSD for a total of 100 hours and then were switched between JP-8 and a 50:50 volumetric blend of JP-8 and FT synthetic kerosene every 450 hours of operation. Generator No. 2 was operated on FT synthetic aviation kerosene fuel for the entire 1,000-hour test. The generators operated at 50% capacity throughout the evaluation and three 10kW electrical load banks provided continuous, controlled load to the generators. Monitored data included engine speed, electrical output, exhaust temperature, inlet fuel temperature, fuel consumption, and exhaust emissions. Variances of automated data, i.e., engine rpm, electrical output, fuel temperature and exhaust temperature were insignificant during the test period. Measured emissions gasses were NOx, ppm, CO, ppm, CO2, %, and O2 %. There were insignificant variances in CO2 and O2 emissions. However, data show reductions in NOx and CO when using FT synthetic aviation kerosene or a blend of JP-8 and FT synthetic aviation kerosene fuel instead of ULSD or JP-8.

15. SUBJECT TERMS

Running Time	Emissions	Materials	S-8 Fuel	S-8/JP-8 Blend	JP-8	ULSD
Generators	Load Banks	Injection	Testing	Matrix	Low Sulfur Diesel	Fischer-Tropsch Fuel

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EXECUTIVE SUMMARY

Problems and Objectives

Fischer-Tropsch (FT) synthetic fuel can be produced from various resources such as natural gas, coal, biomass, or other carbon-containing streams. In each case, the starting resource must first be converted to synthesis gas consisting of mainly carbon monoxide and hydrogen. From there, this gas can then be converted to long-chain liquid hydrocarbons via the FT reaction. A commonly used acronym for conversion of synthesis gas to these FT-derived liquid hydrocarbons is "GTL", although some use this acronym to mean the conversion of natural gas to FT-derived liquid hydrocarbons; similarly, the acronyms commonly used for coal and biomass are "CTL" and "BTL", respectively. FT-derived fuels will contain no sulfur, and when a low-temperature FT reaction using a cobalt-based catalyst is used, the fuels will also contain no aromatic compounds. On the other hand, petroleum-derived fuels do typically contain both sulfur and aromatics; it is these differences between the "clean" FT fuels and petroleum fuels that raise some issues, particularly with respect to: (1) adequate lubrication of some engine fuel systems and other equipment, and (2) maintaining enough seal swell to avoid leakage when fuel systems are switched between petroleum and synthetic fuels. The objective of this program was to develop comparative data of the performance, fuel economy and exhaust emissions during side-by-side evaluations of military tactical generator sets used by all branches of the Armed Services. The generators identified as Tactical Quiet Generators, 10kW 60 Hz, MEP 803A were provided by the Mobile Electric Power Group at Ft. Belvoir, VA, and were operated on a FT synthetic aviation kerosene fuel (S-8), a 50:50 volumetric blend of S-8 and JP-8, JP-8, and certification ultra-low sulfur diesel fuel (ULSD) type DF-2.

Importance of Project

The Department of Defense has shown a keen interest in synthetic fuels as alternative fuels because their domestic production and use can lessen dependence on foreign crude oil (petroleum), while also reducing tailpipe exhaust emissions due to their cleaner burning nature. The successful demonstration of synthetic fuel in a high-density piece of military equipment such as the 10kW Tactical Quiet generator is an important and necessary step in determining the viability of the use of a synthetic alternative fuel.

Technical Approach

Three Tactical Quiet skid mounted 10kW generators were positioned side by side exposed to the elements in the same manner as they are deployed in a tactical situations. The generators were instrumented to yield operational data that would determine effects if any while using ULSD, S-8, JP-8, and 1:1 ratio blend of S-8 and JP-8 fuels (this blend designated as "S-8/JP-8"). A 25-hour break-in period was conducted on all three generators using ULSD. Preliminary ULSD fuel baseline data were established including power, performance, fuel economy, and emissions. After the break-in run, the generators were operated on a fuel-testing matrix. Generator sets No.1 and No. 3 operated on ULSD for a total of 100 hours. They were then operated on either JP-8 or the S-8/JP-8 blend for 450 hours of operation, and then switched to either JP-8 or the S-8/JP-8 blend for the remaining 450 hours of operation; the test matrix was set-up so that when one of the generators was running the JP-8 fuel, the other was running the S-8/JP-8 blend. Generator No. 2 was operated for the entire 1,000-hour test using S-8 fuel (after 25-hour break-in on ULSD). The generators operated at 50% rated capacity throughout the evaluation and three 10kW electrical load banks provided continuous and controlled load to the generators. Data acquisition systems were programmed to record selected parameters at 1-minute intervals and exhaust emissions were obtained periodically throughout the test. Engine oil and filters were changed every 250 hours and selected oil analyses were performed.

Accomplishments

As a result of these evaluations, it was determined that there were no adverse effects operating with 100% synthetic fuel (S-8), or switch-loading between ULSD, JP-8, S-8, and the S-8/JP-8 1:1 ratio blend. The generators operated satisfactorily with minimal problems and no significant changes were observed with any of the fuels used for testing

Military Impact

As the military moves forward to explore alternative fuel sources to reduce the dependency on petroleum fuel, non-conventionally produced fuels increase in viability. The synthetic fuel used in these evaluations is one such type fuel produced from a synthesis process developed early in the last century known as Fischer-Tropsch. Results of successful military equipment operability provided in this report play an important role in establishing that synthetic fuel is suitable for use. This, in turn, provides the possibility to convert U.S. Military ground equipment over to use of an alternative hydrocarbon fuel, thus increasing the energy security of the U.S. Military.

FOREWORD/ACKNOWLEDGMENTS

The U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute® (SwRI®), San Antonio, Texas, performed this work during the period September 2006 through September 2007 under Contract No. DAAE-07-99-C-L053. The U.S. Army Tank Automotive RD&E Center (TARDEC), Force Projection Technologies, Warren, Michigan administered the project. Mr. Luis Villahermosa (AMSRD-TAR-D) served as the TARDEC contracting officer's technical representative. The project was conducted for the Assured Fuels Initiative Team, National Automotive Center, TARDEC, and Mr. Eric Sattler and Ms. Pat Muzzell of this team provided technical advice and program direction.

The authors would like to acknowledge Mr. Thomas Dooley, Lead Project Engineer, 5-60kW Tactical Quiet Generator Program, Mobile Electric Power, Fort Belvoir, VA, for providing the three 10kW generator sets used in this project.

The authors would also like to recognize the contribution of Doug Yost for his technical support and dedication. Special thanks to Rodney Grinstead for his contribution in testing and rating injection pumps and fuel injectors, and to Max Reinhard, Kenneth Ellebracht, and Daniel Anctil for the day-to-day test monitoring. Finally, thanks to the administrative and report-processing support provided by Rebecca Emmot.

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ACRONYMS AND ABBREVIATIONS

°C	Degrees Centigrade
°F	Degrees Fahrenheit
AC	Alternating Current
ASTM	ASTM International
BTU/lb	British Thermal Units Per Pound
CO	Carbon Monoxide
CO2	Carbon Dioxide
cSt	Centistokes
dBa	Decibel(s)
DC	Direct Current
EOT	End of Test
FBP	Final Boiling Point
FT	Fischer-Tropsch
Gal/hr *or* gph	Gallons per Hour
HC	Hydrocarbons
Hz	Hertz
ICP	Inductively Coupled Plasma
IBP	Initial Boiling Point
JP-8	Jet Propulsion Fuel 8
kg	Kilogram
kW	Kilowatt
L	liter(s)
m^3	Cubic Meter(s)
MEP	Mobile Electric Power
mm^2	Millimeter(s) Squared
mmHg	Millimeter(s) Mercury
NOx	Nitrogen Oxide
NSN	National Stock Number
O2	Oxygen
PPM	Parts per Million
PSIG	Pounds per Square Inch Gauge
RDECOM	Research Development and Engineering Command
RPM	Revolutions per Minute
S	Second
S-8	Synthetic JP-8
SAE	Society of Automotive Engineers
SwRI®	Southwest Research Institute®
TACOM	Tank Automotive Command
TAN	Total Acid Number
TARDEC	Tank Automotive Research, Development and Engineering Center
TBN	Total Base Number
TFLRF	TARDEC Fuels and Lubricants Research Facility
TM	Technical Manual
TQ	Tactical Quiet
ULSD	Ultra Low Sulfur Diesel
vol	Volume

1.0 INTRODUCTION AND BACKGROUND

Fischer-Tropsch (FT) process synthetic fuels, first produced in 1927, were used by WWII Germany, and by South Africa during their embargoed period, to overcome petroleum shortages. Synthetic JP-8 is a clean fuel that contains no sulfur or aromatics, but has historically cost too much to compete with petroleum fuel. Since the mid-1990s, the world's major energy companies have begun developing updated FT processes that are less expensive to build and operate. The goal is to produce a sulfur-free product that helps meet air quality requirements from the conversion of various non-petroleum resources such as natural gas, coal, biomass, or other carbonaceous sources. Synthetic fuel chemistry can differ significantly from that of petroleum fuels since modern, low-temperature reaction FT synthetic fuels are free of aromatic and sulfur compounds. These differences raise some issues particularly in respect to: (1) adequate lubrication of some engine fuel systems and other equipment, and (2) maintaining enough seal swell to avoid leakage when fuel systems are switched between petroleum and synthetic fuels. These issues were investigated in this project.

2.0 OBJECTIVE/APPROACH

The objective of this program was to operate three tactical generators for 1,000 hours and develop comparative data of the performance, fuel economy and exhaust emissions during side-by-side evaluations of military generator sets, commonly used by all branches of the Armed Services, while operating on FT fuel (S-8), FT/JP-8 blend, JP-8 and certification ULSD type DF-2. The successful completion of this evaluation would also help determine the acceptability of switch-loading between these fuels.

Three Tactical Quiet, 10kW 60 Hz, MEP 803A generator sets were provided for this evaluation by the Mobile Electric Power Group at Ft. Belvoir, VA. The generators were set up side-by-side and each set was hooked to an individual load bank that provided continuous and controlled load to the generators. Data acquisition software provided electronic readings at specified intervals of engine rpm, electrical output, and exhaust, inlet fuel, and ambient temperatures. Exhaust emissions were measured at specified intervals throughout the evaluations.

3.0 EVALUATION DETAILS

3.1 Fuels and Properties

The four fuels that were used for these evaluations were (1) S-8 Synthetic Fuel, a fuel produced by Syntroleum Corporation using their gas-to-liquids technology to convert natural gas into liquid hydrocarbon fuel, (2) Aviation Turbine Fuel designated as JP-8 purchased from Age Refining Inc., San Antonio, Texas, (3) Ultra Low Sulfur Diesel purchased from Halterman Products, Deer Park, Texas, and (4) 1:1 Blend ratio of S-8 Synthetic Fuel and JP-8 Aviation Turbine Fuel, blended at Southwest Research Institute® (SwRI®). Table 1 shows the list of fuels utilized for the evaluation, while Tables 2–5 present Fuel Properties values of the fuels used.

Table 1. Fuels Utilized for Evaluation

Fuel Name	Description	Sample No.
S-8	Synthetic Fuel	AL-27239-F
JP-8	Aviation Turbine Fuel	AL-27618-F
ULSD	2007 Certification Diesel	AL-27621-F
S-8/JP-8	1:1 Blend Ratio S-8/JP-8	AL-27735-F

Table 2. S-8 Synthetic Fuel Properties

Property	Units	Method	Results
Distillation	°C @ vol% rec.	ASTM D 86	
	IBP		159
	10		171
	20		177
	30		—
	40		—
	50		201
	60		—
	70		—
	80		—
	90		248
	95		—
	FBP		272
	Residue		1.0
	Loss		0
Flash Point	°C	ASTM D 93	46
Freezing point	°C	ASTM D 5771	-58
Sulfur	ppm	ASTM D 5453	<1
Density @ 15°C	kg/m^3	ASTM D 4052	751.0
Color, Saybolt	Visual rating	ASTM D 156	+30
Cetane Index		ASTM D 4737	64
Kinematic Vis @ –20°C	mm^2/s	ASTM D 445	4.38
Net Heat of Combustion	BTU/lb	ASTM D 3338	18,975

Table 3. JP-8 Aviation Turbine Fuel Properties

AGE Refining, Inc.

REFINING OFFICE:
7811 S. Presa
San Antonio, Texas 78223
(210) 532-5300
(210) 532-7222 Fax

Product Name: JP-8

MIL-DTL-83133E

Tank: 424
Batch: 2007J
Date: 03/03/07

Analysis	ASTM Method	Specifications Min	Specifications Max	Tank Results
Color, Saybolt	D 156		Report	+30
Total Acid, mg KOH/g	D 3242		0.015	0.009
Aromatics, vol%	D 1319		25	16.1
Olefins, vol%	D 1319		5.0	1.1
Naphthalenes, vol%	D 1319		3.0	N/R
Sulfur, Doctor test	D 4952	Neg		Neg
Total Sulfur, mass%	D 2622		0.300	0.006
Distillation temperature, °C	D 86			
•IBP			Report	145
•10% recovered, temp			205	160
•20% recovered, temp			Report	166
•50% recovered, temp			Report	187
•90% recovered, temp			Report	239
•End Point, temp			300	262
•Residue, vol%			1.5	1.0
•Loss, vol%			1.5	1.0
Flash Point, °F	D 93	100		106
Gravity, API, at 15°C	D 1298	51.0	37.0	47.3
Freeze Point, °C	D 2386		-47	-48.60
Viscosity @ -20°C	D 445		8.0	3.06
Heat of combustion, BTU/lb	D 3338	18,400		18,643
Hydrogen content, mass%	D 3701	13.4		13.99
Smoke Point, mm	D 1322	19		26.0
Copper corrosion, 2 hr @ 100°C	D 130		1	1A
Thermal Stability test @ 275 C	D 3241			1
• Pressure drop, mm Hg			25	0.0
• Tube deposit code			3	1
Existent gum, mg/100 ml	D 381		7	0.6
Particulate matter, mg/L	D 5452		1	0.69
Filtration time, minutes	D 5452		15	5
Water reaction	D 1094			
•Interface rating			1b	1
Microseparometer	D 3948	70		92
Additives (Corrosion Inhibitor and Static Dissipator)				
Moisture, mg/Kg	D 6304		Report	51
Fuel System Icing Inhibitor	D 5006	0.10	0.15	0.125
Calculated Cetane Index	D 976		Report	42.4
SDA pS/m	D2624	150	450	

Report Date: 03/03/07

Analysis performed by: ____________________

Table 4. ULSD 2007 Certification Diesel Fuel Properties

Certificate 3397673 Haltermann Products Page 1

Date: 03/15/2007 Certificate of Analysis

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SOUTHWEST RESEARCH INSTITUTE Fax: COA ARCHIVE
6220 CULEBRA RD
SAN ANTONIO TX 78238-5166 UNITED STATES

Cust P.O.: 764932G Dlvy Note: 64029471 10
Cust Ref: Order No.: 21030941

Material: 2007 Certification Diesel
55 GALLON STEEL DRUM GMID: 229576
Cust Mtl:
Batch: UH2521LS10

Dlvy Qty:DR 7
Vehicle: SH

Ship from: JOHANN HALTERMANN LTD DEER PARK TX UNITED STATES

Feature	Units	Results UH2521LS10	Limits Minimum	Limits Maximum	Method
Distillation-IBP	degF	377	340	400	ASTM D86
Distillation-5%	degF	407	----	----	ASTM D86
Distillation-10%	degF	417	400	460	ASTM D86
Distillation-20%	degF	438	----	----	ASTM D86
Distillation-30%	degF	456	----	----	ASTM D86
Distillation-40%	degF	478	----	----	ASTM D86
Distillation-50%	degF	500	470	540	ASTM D86
Distillation-60%	degF	520	----	----	ASTM D86
Distillation-70%	degF	541	----	----	ASTM D86
Distillation-80%	degF	564	----	----	ASTM D86
Distillation-90%	degF	592	560	630	ASTM D86
Distillation-95%	degF	618	----	----	ASTM D86
Distillation-EP	degF	638	610	690	ASTM D86
Recovery	% vol	97.4	----	----	ASTM D86
Residue	% vol	2.1	----	----	ASTM D86
Loss	% vol	0.0	----	----	ASTM D86
Gravity, API	-	35.2	32.0	37.0	ASTM D4052
Specific Gravity	kg/L	0.849	0.840	0.865	ASTM D4052
Sulfur	ppm	10	7	15	ASTM D5453

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Table 4. (continued)

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Certificate 3397673       Haltermann Products                         Page      2

Date:  03/15/2007         Certificate of Analysis

File Copy**GLOBAL**DO NOT EDIT
SOUTHWEST RESEARCH INSTITUTE                 Fax: COA ARCHIVE
6220 CULEBRA RD
SAN ANTONIO               TX 78238-5166     UNITED STATES

Cust P.O.:  764932G                                   Dlvy Note: 64029471 10
Cust Ref:                                             Order No.: 21030941

Material:   2007 Certification Diesel
            55 GALLON STEEL DRUM                      GMID:     229576
Cust Mtl:

Dlvy Qty:DR          7
Vehicle:    SH

Ship from:  JOHANN HALTERMANN LTD          DEER PARK       TX UNITED STATES
```

Feature	Units	Results UH2521LS10	Limits Minimum	Limits Maximum	Method
Flash Point	degF	170	130	----	ASTM D93
Carbon	% wt	86.000	----	----	ASTM D5291
Hydrogen	% wt	14.000	----	----	ASTM D5291
Viscosity	cSt	2.5	2.0	3.2	ASTM D445
Aromatics	% vol	29.5	27.0	----	ASTM D1319
Olefins	% vol	1.0	----	----	ASTM D1319
Saturates	% vol	69.5	----	----	ASTM D1319
Cetane Number	-	44.4	40.0	50.0	ASTM D613
Cetane Index	-	50.0	40.0	50.0	ASTM D976
Net Heating Value	Btu/lb	18,493	----	----	ASTM D240
High Freg. Recip. R @ 60degC	mm	0.061	----	----	ASTM D6079

Table 5. 1:1 Blend Ratio of S-8 Synthetic Fuel and JP-8 Aviation Turbine Fuel Properties

Property	Units	Method	Results
Distillation	°C @ vol% rec.	ASTM D 86	
	IBP		145
	10		161
	20		168
	30		176
	40		184
	50		192

Table 5. (continued)

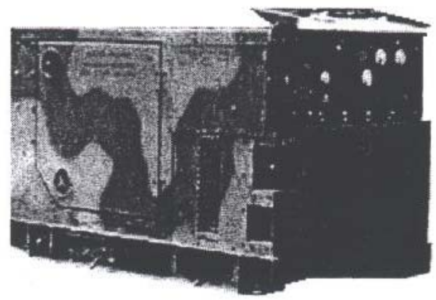
Property	Units	Method	Results
Distillation	°C @ vol% rec.	ASTM D 86	
	60		213
	70		202
	80		225
	90		240
	95		251
	FBP		259
	Residue		1.7
	Loss		1.6
Flash Point	°C	ASTM D 3858	37
Freezing point	°C	ASTM D 2386	-52
Sulfur	ppm	ASTM D 5453	46
Density @ 15°C	kg/m^3	ASTM D 4052	773.9
Color, Saybolt	Visual rating	ASTM D 156	+24
Cetane Number	—	ASTM D 613	54
Kinematic Vis @ –20°C	mm^2/s	ASTM D 445	3.72[a]
Net Heat of Combustion	BTU/lb	ASTM D 240	18,632
a = calculated value			

3.2 Equipment Specifications

The 10kW generator sets used for these evaluations are classified in the medium family of tactical quiet generator sets that range from 5 to 60 kilowatts of mobile electric power. They are used to supply electric power to a myriad of applications such as weapons systems, missile systems, refrigeration systems and numerous types of stationary equipment. They are a high density and significantly critical item in the Armed Forces inventory. Figure 1 shows the description of the MEP-803A generator set. Figures 2–3 show the arrangement of the generators during testing. Figure 4 shows the load banks that provided continuous and controlled electrical load to the generators.

GENERATOR SET, DIESEL ENGINE, MODEL MEP-803A

NSN: 6115-01-275-5061		Rev Date: 26 Apr 05



Functional Description

The 10kW generator set, MEP-803A, is a fully enclosed, self-contained, skid-mounted, portable unit. It is equipped with controls, instruments and accessories necessary for operation. The generator set consist of a diesel engine, brushless generator, excitation system, speed governing system, fuel system, 24VDC starting system, control system and fault system. The generator set is designed to be used with any equipment requiring a small source of AC power.

Technical Description

Generator Set		**Fuel**	
Manufacturer:	Fermont	Fuel Capacity:	9 Gal
Model:	MEP-803A	Fuel Consumption:	.97 GPH
Volts:	120/208/240	Fuel Requirement:	Diesel/JP-8
Hertz:	60		
Speed (RPM):	1800	**Dimensions**	
Phase:	1 and 3	Length (in.):	62
		Width (in.):	32
Engine		Height (in.):	37
Manufacturer:	Onan	Weight (lb):	
Model:	DN4M	Dry:	1091
Type:	4 Cycle	Wet:	1182
Cylinders:	4	Cube (ft.):	41
Displacement:	114 in. (1.9l)		
Horsepower:	24.1@1800 RPM	**Aural Signature**	
Compression:	18.5:1	Audio Rating:	70dBA @ 7 meters

Transportability: All variants of the M116 trailer.

Figure 1. 10kW Generator Set Specifications

Figure 2. 10kW Generator Sets, Front View

Figure 3. 10kW Generator Sets, Side View

Figure 4. AVTRON K595 Electric Load Bank

3.3 Equipment Preparation

In preparation for the evaluation, new injection pumps and injectors were installed in all three generator engines. The original components were removed, marked, and packed for reinstallation after the test. New fuel and oil filters were installed, and the generator engines were charged with AL27170-L SAE 15W40 Viscosity grade, MIL-PRF-2104G Army reference oil. Table 6 displays the manufacturer's properties data sheet on MIL-PRF-2104G engine oil. The engine oil and filters were changed every 250 hours as specified in TM 9-6115-642-10 [1]. The generators were connected to separate electrical load banks that would provide continuous and controlled load at 50% of the rated capacity of the generators. A SwRI PRISM Data Acquisition and Control System was installed in a test cell for automated data collection. Inlet fuel temperature, exhaust temperature, ambient temperature, engine speed, and electrical output were recorded by the system at one-minute intervals throughout the evaluation. In addition to the generator's built-in protection devices such as low oil pressure switch, coolant high temperature switch, and over voltage protector, upper and lower limits were defined for data parameters such as engine speed and electrical output. Any anomaly occurring in any pre-set parameter would prompt the PRISM system to automatically shut down all generators.

Fuel usage was not included in the automated data collection system due to the filling system of the generators. The fuel in the main tank is maintained at full level by activation of an auxiliary fuel pump as fuel is consumed during operation. Fuel to the generators was gravity fed from designated 55-gallon drums in a contained area and transducers could not be employed due to low pressure at the fill point. Therefore, fuel consumption was determined by weighing the fuel drum at initial fill and each time the fuel was replenished or changed, then calculating the difference in weights.

Before installing into the engines, all fuel injectors were pressure tested in accordance with TM 9-2815-253-24 [2] for pressure and spray pattern and results recorded. Injectors would undergo a re-test after 1,000 hours of operation for comparison.

The injection pumps on these generators do not have calibration standards to determine serviceability. Serviceability is determined by obtaining > 3,000 psi pump pressure during cranking. If 3,000 psi is not obtained, the pump is replaced. A modified method to determine pre and post-test differences was developed. The pumps were pressurized for four cranking seconds and depressurization was timed for two minutes. Obtained pressures were recorded and the testing would be repeated after 1,000 hours for comparison.

Table 6. PRF-2104G Manufacturer Properties Data Sheet

Product: SAE Grade 15W40 **Source Tank:** 35 **Manufacturer:** Imperial Oil Co., Inc.

Specification: MIL – PRF – 2104G **Batch:** 940 **Manufacturer Location:** Morganville, New Jersey

Qualification: PRI EO 0022 **Certification:** 1140 **Date:** October 06, 2005

Amount Sample Represents: 16,000 gals. AL-27170-#L

	Spec./ Qual.	Results		Spec./ Qual. Tend.	Spec./ Qual. Stab.	Results Tend.	Results Stab.
Gravity API°	26.9 – 28.9	28.2	Foam:				
Flash Point °C	215 min.	230° C	Sequence 1	10 max.	0	0	0
Viscosity @ 100°C cSt.	14.58 – 15.58	14.83	Sequence 2	20 max.	0	10	0
Viscosity @ 40°C cSt.	99.02 – 129.02	116.69	Sequence 3	10 max.	0	0	0
Viscosity Index	Report	137	Sequence 4	50 max.	0	10	0
Vis. Cp @ - 15°C CCS.	3500 max.	3240	Total Base Number	Report		8.129	
Vis. Cp @ - 20°C CCS.	3500 min.	5970	Total Acid Number	Report		1.91	
Pumpability,Vis., CP@ - 25°C	Report	< 30,000	Phosphorous Wt. %	0.1053 – 0.1404		0.1247	
Hi Temp., Hi Shear, Vis. CP	3.7 min.	4.29	Magnesium Wt. %	0.00 - < 0.01		0.0039	
Ramsbottom Carbon Wt. %	0.97 - 1.27	1.015	Silicone Wt. %	0.00 - < 0.01		0.0034	
Sulfated Ash Wt. %	1.143 – 1.524	1.212	Chlorine Wt. %	0.01 - < 0.03		0.0179	
Sulfur Wt. %	0.56 – 0.84	0.693	Nitrogen Wt. %	0.0685 min.		0.0817	
Sulfur (additive) Wt. %	0.387 – 0.516	0.454	Boron Wt. %	0.00 - < 0.01		0.00	
Calcium Wt. %	0.2619 – 0.3492	0.2844	Copper Wt. %	0.00 - < 0.01		0.00	
Zinc Wt. %	0.1161 – 0.1548	0.1303	Potassium Wt. %	0.00 - < 0.01		0.00	
Pour Point °C	- 23 max.	< - 23° C	Barium Wt. %	0.00 - < 0.01		0.00	
Stable Pour Point °C	- 23 max.	< - 23° C	Sodium Wt. %	0.00 - < 0.01		0.00	

Laboratory Supervisor: Antonio O. Enriquez

Government Inspector: **Date:** October 06, 2005

Product Meets Specifications For Tests Performed.

Imperial Oil Co., Inc. G. Gilroy 2003

3.4 Test Procedure Specifics and Test Matrix

The generators were set up side-by-side, as shown in Figures 2–3, and operated for a total of 25 hours of break-in testing using ULSD during which baseline data was collected to include power, performance, fuel economy, and exhaust emissions. After the 25-hour break-in period, one generator was scheduled to operate on S-8 fuel for the remainder of the 1,000-hour test. The remaining two generators remained on ULSD for a period of 100 hours, after which one generator was operated on JP-8 and the other on S-8/JP-8 Blend for 450 hours. At the end of 450 hours, the fuels were switched on the generator sets No. 1 and No. 3 and operated for the remaining 450 hours. The test matrix is presented in Table 7.

Table 7. Test Matrix

Generator Set 1		**Generator Set 2**		**Generator Set 3**	
Run Time	Fuel	Run Time	Fuel	Run Time	Fuel
25 hrs Break-in	ULSD	25 hrs Break-in	ULSD	25 hrs break-in	ULSD
100 hrs	ULSD	1000 hrs	S-8	100 hrs	ULSD
450 hrs	JP-8			450 hrs	S-8/JP-8
450 hrs	S-8/JP-8			450 hrs	JP-8

4.0 DISCUSSION OF RESULTS AND COMPARISONS

4.1 General

The generators for the most part, operated a total of 25 hours of break-in period operation and 1,000 hours of testing with only a few problems. Generator Set 10-1 exhibited an exhaust temperature increase at approximately 200 hours running time due to air filter restriction. The problem was resolved in less than 100 hours running time and air filters were replaced. The problem did not recur. For Generator Set 10-2, the handle on the starter selection switch sheared and a new switch was ordered and replaced. No other problems were noted. Early into the test, Generator Set 10-3 developed a faulty auxiliary fuel pump, whose function is to automatically fill the on-board fuel tank. The fuel tank was manually filled until the pump was replaced at less than 90 hours into the test. Also, an electrical charging problem in the beginning of the test caused intermittent down times when engine rpm and or electrical output would decrease below the test threshold and shut all generators off. The problem was resolved by repairing the alternator adjusting bracket.

Overall, despite the previously mentioned problems, it was determined that there were no adverse effects operating with neat synthetic fuel or switch-loading between ultra low sulfur diesel, JP-8 , S-8, and S-8/JP-8 1:1 ratio blend. No leaks were observed at anytime throughout the test. The generators operated satisfactorily with minimal problems and no significant changes in generator operation were observed with any of the fuels used for this testing.

4.2 Injection Pump and Fuel Injector Performance

4.2.1 Injection Pumps

The 4-cylinder Onan engine that powers the 10kW generator set is fueled by a cam actuated block injection pump and fuel injector for each individual cylinder. The only test specified in the engine technical manual is a pump pressure test performed by connecting a pressure gage to the top of the pump and cranking the engine and observing pressure gage. If the pump pressure reaches 3000 psi, the pump is serviceable, if not, the pump is replaced. There are no calibration standards for the injection pump to measure pre- and post-test wear and performance. Therefore, a modified method to determine pre- and post-test differences was developed. The pumps were pressurized for four cranking seconds and leak-down timed for two minutes. Obtained pressures were recorded and the test was repeated at EOT for comparison. The new injection pumps installed for cylinders 2 and 3 of generator 10-1 were removed due to immediate leak-down prohibiting depressurization readings at the 2-minute mark and replaced with the original pumps.

Table 8 shows the results of the pre- and post-pump pressure tests. The readings on all the pumps indicate that the pumps performed extremely well regardless of the fuel used. The four-second pressurization is very consistent in all pumps; however observing the pressure-drop leak-down numbers, the best is Gen Set 10-2, followed by Gen Set 10-1, and Gen Set 10-3.

Table 8. Injection Pump Pressure Test

Pump Number	Pressure @ 4 Seconds >3000 psig		Pressure Drop @ 2 Minutes Report	
	Pre-Test	Post-Test	Pre-Test	Post-Test
Generator Set 10-1: ULSD, JP-8, and S-8/JP-8 Blend				
1	7067	7200	400	517
2	9833	6533	667	867
3	11467	10533	767	617
4	6500	8633	400	2200
Generator Set 10-2: S-8				
1	6633	6783	400	633
2	7233	7600	483	1433
3	6617	6450	433	417
4	7567	7267	450	383
Generator Set 10-3: ULSD, S-8/JP-8 Blend, and JP-8				
1	6433	7467	517	633
2	6667	6867	533	1583
3	7400	7400	1150	2567
4	7067	7667	583	2300
All pumps were serviceable at EOT. No pass or fail criterion established for depressurization				

In addition to the pressure tests described above, a tear-down inspection of all injection pumps was performed and a random wear rating (0 to 5 scale, with 5 being a "fail") was assigned to compare differences between pumps. Table 9 shows the visual inspection checks and demerits ratings assigned to each pump. Results of visual inspection show that generator 10-1 received 2 average demerits, generator 10-2 received 1.9 average demerits, while generator 10-3 received 2.8 average demerits. The wear observed is consistent with the number of hours the generators were operated and not attributable to the fuel used. The pumps were fully functional at EOT.

Table 9. Injection Pump Post-Test Wear Ratings

Pump No	Inspection Results	Demerits Assigned
Generator Set 10-1: ULSD, JP-8, and S-8/JP-8 Blend		
1	Scoring and polishing at helix. Some scratches at opposite side of helix. Small groove in valve.	3.5
2	Very slight visible wear. No wear showing on D-valve seat	1
3	Very slight visible wear. No wear showing on D-valve seat	1
4	Light scratches at helix. Polishing at 180° from groove at top of plunger and plunger midsection. Small groove at D-valve.	2.5 Average Demerits: 2

Table 9. (continued)

Pump No	Inspection Results	Demerits Assigned
Generator Set 10-2: S-8		
1	Light scoring at helix. Normal wear on D-valve	2
2	Light scoring at helix. Normal wear on D-valve	2.5
3	Light scratches at helix. Polished square area opposite side of groove.	1
4	Light to medium scoring at helix.	2 Average Demerits: 1.9
Generator Set 10-3: ULSD, S-8/JP-8 Blend, and JP-8		
1	Light scratches all over plunger. Light scoring and machining marks at helix. Two light scoring marks opposite side of groove.	2.5
2	Light uniform scratches all over plunger. Scoring at helix. D-valve shows normal wear.	3
3	Uniform scuffing scratching and polishing all over plunger and helix area with heaviest concentration opposite groove. Groove on D-valve area.	4
4	Very light scoring at helix. Groove in D-valve at contact with seat.	1.5 Average Demerits 2.8

Photo documentation was made on two injection pump plungers from each generator set identifying the generator set, type fuel utilized, cylinder number and plunger labeled as best and worst. The documented injection pump plungers are shown in Figures 5–7. The six views show the plunger's helix area where the wear is evident; however, none of the plungers show unusual wear and the scoring, scuffing, and scratches seen are consistent with the number of hours the generators were operated. Wear differences between types of fuel used were not apparent.

Tactical Generator 1,000-Hour Performance Evaluation

Fuel Code:	AL-27621-F AL-27618-F AL-27735-F	**EOT Date:**	20071014
Test No.:	WD23G0001 GEN SET 10-1	**Test:**	1,000

Fuel Plunger Best Cyl. 2

Fuel Plunger Worst Cyl. 1

Figure 5. Fuel Plungers Generator Set 10-1

Fuel Code:	AL-27239-F	**EOT Date:**	20071014
Test No.:	WD23G0001 GEN SET 10-2	**Test:**	1,000

Fuel Plunger Best Cyl. 3

Fuel Plunger Worst Cyl. 2

Figure 6. Fuel Plungers Generator Set 10-2

Tactical Generator 1,000-Hour Performance Evaluation

Fuel Code:	AL-27621-F AL-27735-F AL-27618-F	**EOT Date:**	20071014
Test No.:	WD23G0001 GEN SET 10-3	**Test:**	1,000

Fuel Plunger Best Cyl. 4

Fuel Plunger Worst Cyl. 3

Figure 7. Fuel Plungers Generator Set 10-3

4.2.2 Fuel Injectors

New Model LJBT00301EZT injectors were used for the test. Table 10 shows data for injectors used with all fuels designated in the test matrix. While all of the injectors failed the post-test evaluations for Opening Pressure (their opening pressure was < 3480 psig – used), it is not indicative of the type of fuel used. Frequently an injector with decreased opening pressure will probably "fail' the Chatter Test and more than likely "fail" the Spray Pattern Test. This, as seen in Table 10, was not the case with any of the injectors as all of them were given a "pass" in the Chatter Test and the Spray Pattern Test. In addition, all injectors passed the leakage test. These injectors operated in excess of 1,000 hours, which, in a typical deployment application, would be considered as "very good" service. At no time during the test were there any indications of erratic engine performance or power loss. A simple installation of available shims would have increased injector spinning pressures to pre-test levels. Averaged percent changes from the post-test to the pre-test Opening Pressures shows that the least amount of change occurred on Gen Set 10-3 at 6.5% followed by Gen Set 10-1 at 7.1%, and Gen Set 2 at 10.9%.

Table 10. Injector Nozzle Test

Injector No.	**Opening Pressure 3552-3697psig- new 3480 psig- used**		**Leakage Test No drops for 10 sec. @ 2205 psig.**		**Chatter Test Audible Chatter**		**Spray Pattern Fine Spray**	
	Pre-Test	**Post-Test**	**Pre-Test**	**Post-Test**	**Pre-Test**	**Post-Test**	**Pre-Test**	**Post-Test**
Generator Set 10-1 ULSD, JP-8, JP-8/S-8 Blend								
1	3600	**3375 (Fail)**	Pass	Pass	Pass	Pass	Pass	Pass
2	3600	**3350 (Fail)**	Pass	Pass	Pass	Pass	Pass	Pass
3	3650	**3425 (Fail)**	Pass	Pass	Pass	Pass	Pass	Pass
4	3600	**3350 (Fail)**	Pass	Pass	Pass	Pass	Pass	Pass
Generator Set 10-2 S-8								
1	3650	**3200 (Fail)**	Pass	Pass	Pass	Pass	Pass	Pass
2	3650	**3375 (Fail)**	Pass	Pass	Pass	Pass	Pass	Pass
3	3600	**3150 (Fail)**	Pass	Pass	Pass	Pass	Pass	Pass
4	3600	**3350 (Fail)**	Pass	Pass	Pass	Pass	Pass	Pass
Generator Set 10-3 ULSD, JP-8/S-8 Blend, JP-8								
1	3625	**3400 (Fail)**	Pass	Pass	Pass	Pass	Pass	Pass
2	3600	**3375 (Fail)**	Pass	Pass	Pass	Pass	Pass	Pass
3	3625	**3400 (Fail)**	Pass	Pass	Pass	Pass	Pass	Pass
4	3600	**3400 (Fail)**	Pass	Pass	Pass	Pass	Pass	Pass
Bold Values = Fail Averaged % change in post-test to pre-test Opening Pressures: Gen Set 10-1 = 7.1 Gen Set 10-2 = 10.9 Gen Set 10-3= 6.5								

4.3 Fuel Consumption

Fuel to the generators was gravity fed from designated 55-gallon drums and fuel consumption was determined by weighing the fuel drum at initial fill and each time the fuel was replenished or changed. The weight difference was calculated to determine fuel usage. In the beginning of the program the auxiliary pump that automatically fills the fuel tank failed on generator set 10-3. Therefore the fuel tank was manually filled as necessary until the pump was replaced. The method used to calculate fuel consumption is by no means an exact method therefore the fuel consumption figures presented in Table 11 are best estimate of the actual consumption.

Table 11. Generator Operating Parameters and Fuel Consumption

Generator Set 10-1: ULSD, JP-8, and S-8/JP-8 Blend Generator Set 10-2: S-8 Generator Set 10-3: ULSD, S-8/JP-8 Blend, and JP-8			
25 Hour Break-in Run (all generator sets operating on ULSD)			
	Average RPM	**Average Watts**	**Fuel Consumption, gal/hr**
Gen Set 10-1	1798	4942	0.58
Gen Set 10-2	1798	4953	0.62
Gen Set 10-3	1798	4946	0.66
100 Hour Run ULSD			
	Average RPM	Average Watts	Fuel Consumption, gal/hr
Gen Set 10-1	1799	4949	0.66
Gen Set 10-3	1798	4927	0.66
1,000 Hour Run S-8			
	Average RPM	Average Watts	Fuel Consumption, gal/hr
Gen Set 10-2	1799	4955	0.67
450 Hour Run JP-8			
	Average RPM	Average Watts	Fuel Consumption, gal/hr
Gen Set 10-1	1797	4949	0.63
450 Hour Run S-8/JP-8 Blend			
	Average RPM	Average Watts	Fuel Consumption, gal/hr
Gen Set 10-3	1799	4950	0.67
450 Hour Run JP-8			
	Average RPM	Average Watts	Fuel Consumption, gal/hr
Gen Set 10-3	1797	4949	0.67
450 Hour Run S-8/JP-8 Blend			
	Average RPM	Average Watts	Fuel Consumption, gal/hr
Gen Set 10-1	1799	4950	0.67

4.4 Exhaust Emissions

The exhaust gasses that were tracked were nitrogen oxides (NOx), oxygen (O2%), carbon dioxide CO2%), carbon monoxide (CO), and hydrocarbons (HC). As seen in Table 12, the data shows that O2 and CO2 gasses did not vary substantially with any fuel. However, as shown in Figures 8–10, NOx and CO emissions varied considerably, depending on the fuel used. Since the generators were tested outside, the ambient temperature fluctuated continuously throughout the days; therefore, hydrocarbon (HC) results were not reliable and are listed for information only.

Table 12. Generator Sets Exhaust Emission Results

Gen Set 10-1

Test Hours	NOx, ppm	02, %	CO2, %	CO, ppm	HC, ppm	Fuel Type
24	588.0	14.99	4.29	417	ND	ULSD
97	497.0	18.46	4.86	396.8	ND	ULSD
Minimum	497.0	14.99	4.29	396.8	N/A	
Maximum	588.0	18.46	4.86	417	N/A	
Average	542.5	16.7	4.6	406.9	N/A	
Std Dev	64.4	2.45	0.40	14.28	N/A	
194	491.0	14.76	4.46	334	610	JP-8
292	607.0	12.95	5.76	518	570	JP-8
328	445.0	14.91	4.35	393	460	JP-8
412	426.0	15.08	4.22	378	690	JP-8
489	420.0	14.95	4.32	365	490	JP-8
545	426.0	15.1	4.21	378	400	JP-8
Minimum	420.0	13.0	4.2	334.0	N/A	
Maximum	607.0	15.1	5.8	518.0	N/A	
Average	469.2	14.6	4.6	394.3	N/A	
Std Dev	72.4	0.8	0.6	63.8	N/A	
630	406.0	15.01	4.28	284	220	JP-8/S-8
712	373.0	15.1	4.21	307	190	JP-8/S-8
795	371.0	15.06	4.24	310	520	JP-8/S-8
883	396.0	15	4.28	276	500	JP-8/S-8
965	378.0	15.13	4.19	293	690	JP-8/S-8
999	391.0	15.17	4.16	288	400	JP-8/S-8
Minimum	371.0	15	4.16	276	N/A	
Maximum	406.0	15.17	4.28	310	N/A	
Average	385.8	15.1	4.2	293	N/A	
Std Dev	14.0	0.1	0.1	13.3	N/A	

Table 12. (continued)

Gen Set 10-2

Test Hours	NOx, ppm	02, %	CO2, %	CO, ppm	HC, ppm	Fuel Type
24	548.0	14.79	4.43	415	110	ULSD
97	342.4	18.17	4.69	245	ND	S-8
194	471.0	14.48	4.66	254	710	S-8
292	442.0	14.55	4.61	279	710	S-8
328	385.0	15.21	4.13	247	490	S-8
412	371.0	15.32	4.05	243	880	S-8
489	369.0	15.17	4.16	240	600	S-8
545	370.0	15.18	4.15	252	370	S-8
630	388.0	15.15	4.18	238	250	S-8
712	372.0	15.22	4.12	249	220	S-8
795	382.0	15.12	4.19	258	370	S-8
883	378.0	14.99	4.29	260	680	S-8
965	368.0	15.13	4.19	264	740	S-8
999	389.0	15.14	4.18	259	630	S-8
Minimum	342.4	14.48	4.05	238	N/A	
Maximum	471.0	18.17	4.69	279	N/A	
Average	386.7	15.3	4.3	252.9	N/A	
Std Dev	33.7	0.90	0.22	11.25	N/A	

Gen Set 10-3

Test Hours	NOx, ppm	02, %	CO2, %	CO, ppm	HC, ppm	Fuel Type
24	540.0	14.83	4.41	540	ND	ULSD
97	390.8	18.59	4.69	491.8	ND	ULSD
Minimum	390.8	14.83	4.41	491.8	N/A	
Maximum	540.0	18.59	4.69	540	N/A	
Average	465.4	16.7	4.6	515.9	N/A	
Std Dev	105.5	2.66	0.20	34.08	N/A	
194	347.0	14.91	4.35	357	800	JP-8/S-8
292	354.0	14.51	4.64	441	810	JP-8/S-8
328	338.0	15.09	4.22	363	610	JP-8/S-8
412	320.0	15.26	4.1	398	970	JP-8/S-8
489	320.0	15.09	4.22	380	750	JP-8/S-8
545	313.0	15.23	4.12	429	450	
Minimum	313.0	14.5	4.1	357.0	N/A	
Maximum	354.0	15.3	4.6	441.0	N/A	
Average	332.0	15.0	4.3	394.7	N/A	
Std Dev	16.7	0.3	0.2	34.6	N/A	
630	369.0	15.07	4.23	489	350	JP-8
712	346.0	15.16	4.17	498	310	JP-8
795	346.0	15.12	4.2	530	290	JP-8
883	365.0	14.99	4.29	469	830	JP-8
965	358.0	15.14	4.19	507	850	JP-8
999	364.0	15.12	4.2	505	740	JP-8
Minimum	346.0	14.99	4.17	469	N/A	
Maximum	369.0	15.16	4.29	530	N/A	
Average	358.0	15.1	4.2	499.7	N/A	
Std Dev	9.9	0.06	0.04	20.29	N/A	

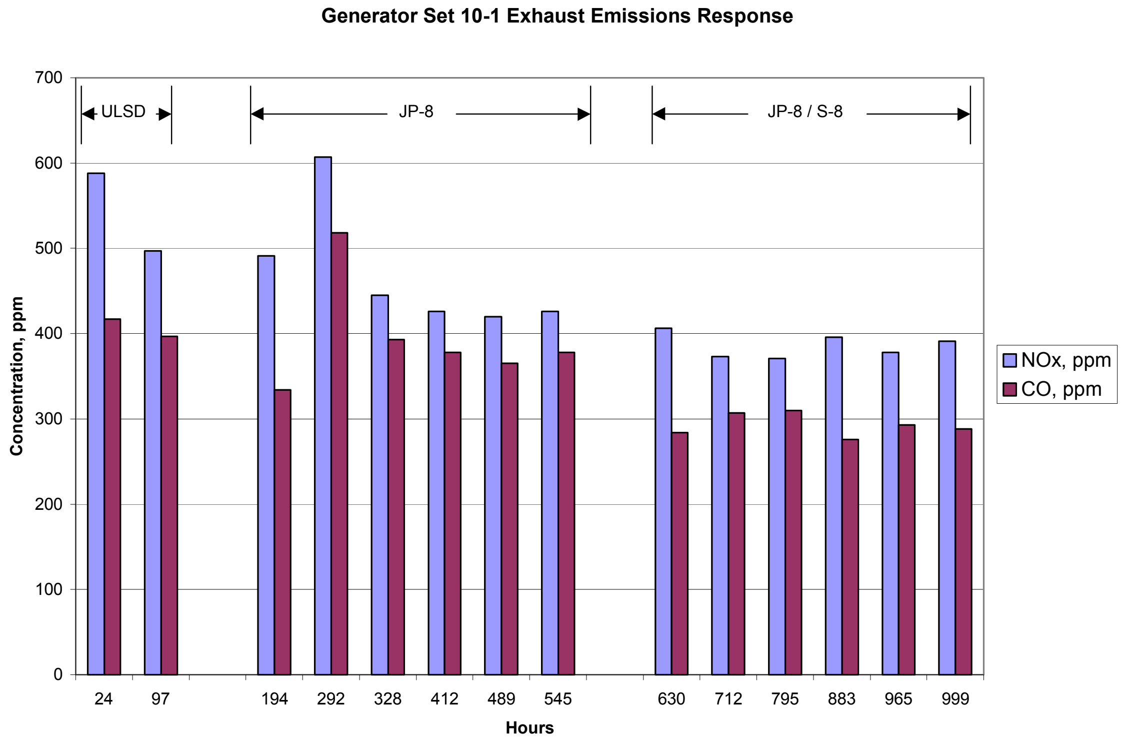


Figure 8. Generator Set 10-1 Exhaust Emissions Response

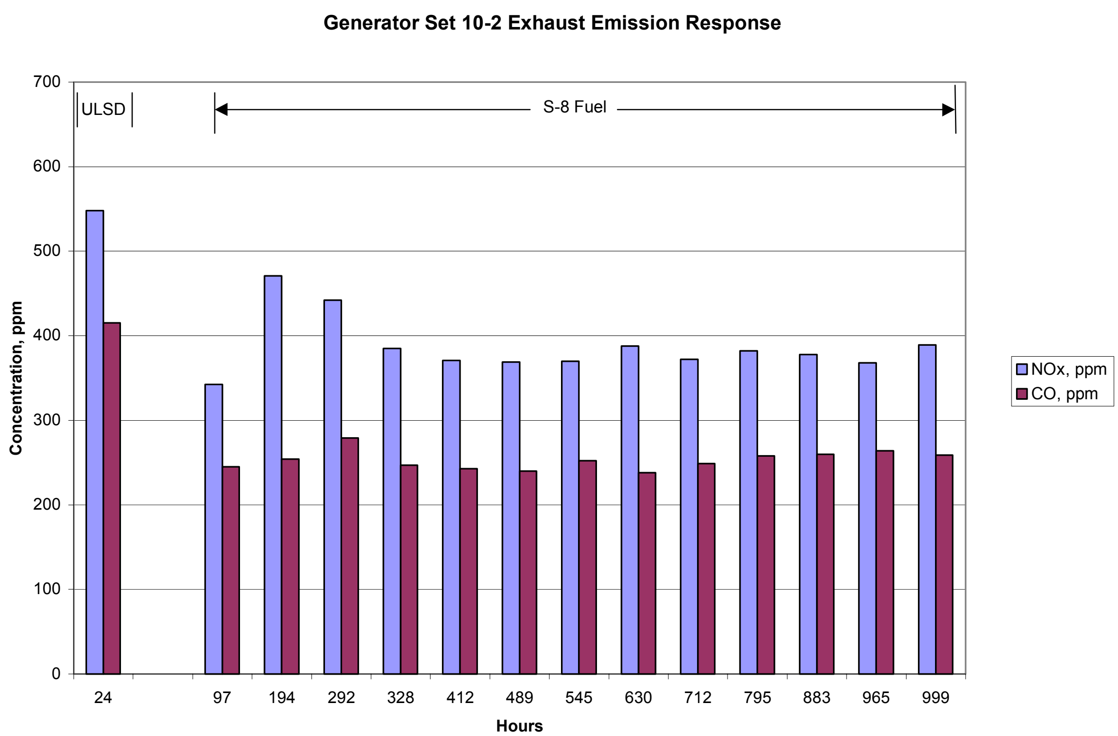


Figure 9. Generator Set 10-2 Exhaust Emissions Response

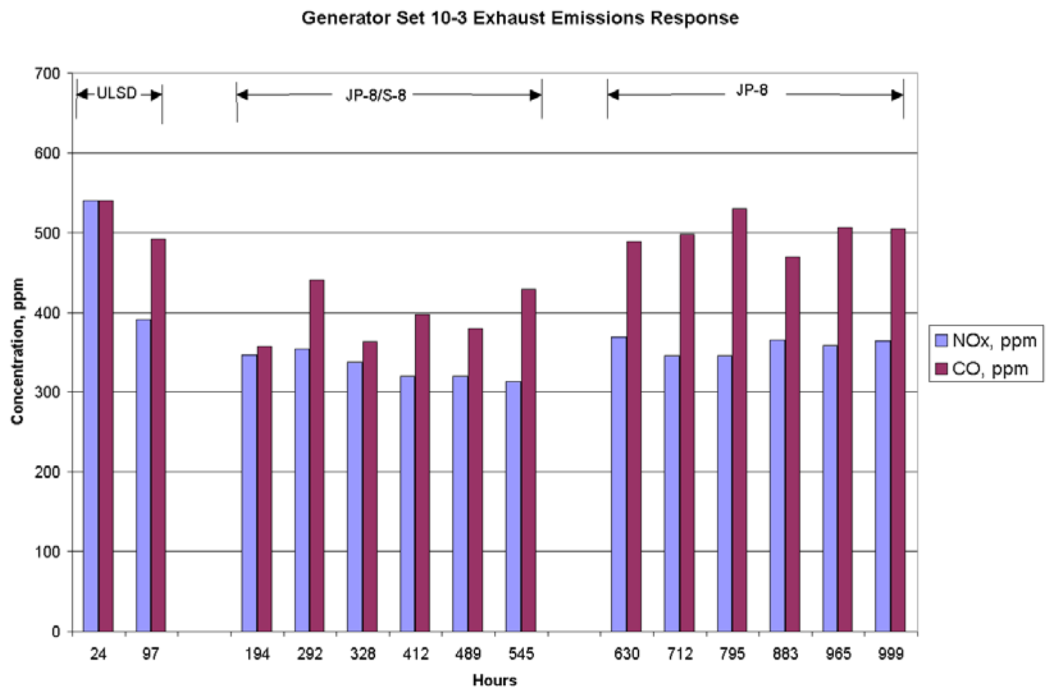


Figure 10. Generator Set 10-3 Exhaust Emissions Response

Examination of the generator set emission species data reveals a deviation of the NOx and CO response between generator sets 10-1 and 10-3 for each of the test fuels. As shown in Figure 11 for the NOx response, the variations appear to be statistically significant between generator sets 10-1 and 10-3 at the 95% confidence level for the JP-8 and S-8/JP-8 fuels. Shown in Figure 12 for the CO response, the variations appear to be statistically significant between generator sets 10-1 and 10-3 at the 95% confidence level for all the fuels. Generator set 10-2 response with ULSD fuel is similar to generator set 10-1 response for both the NOx and CO species.

Although the operating data appeared consistent for both the 10-1 and 10-3 generator sets, the overall average exhaust temperature was statistically lower at 95% confidence by 48°F for generator set 10-3 throughout the testing, as shown in Figure 13. As CO emissions are a measure of incomplete combustion, the lower NOX and higher CO trade-off are consistent responses with lower exhaust temperatures for generator 10-3. Generator 10-3 had previously accumulated around 1000 hours prior to fuels testing. As the fuel injection system hardware was changed at the start of testing for all generator sets, the differences in emissions and exhaust temperatures could be due to cam wear, valve train wear, and timing gear wear of generator set 3 due to previous operation.

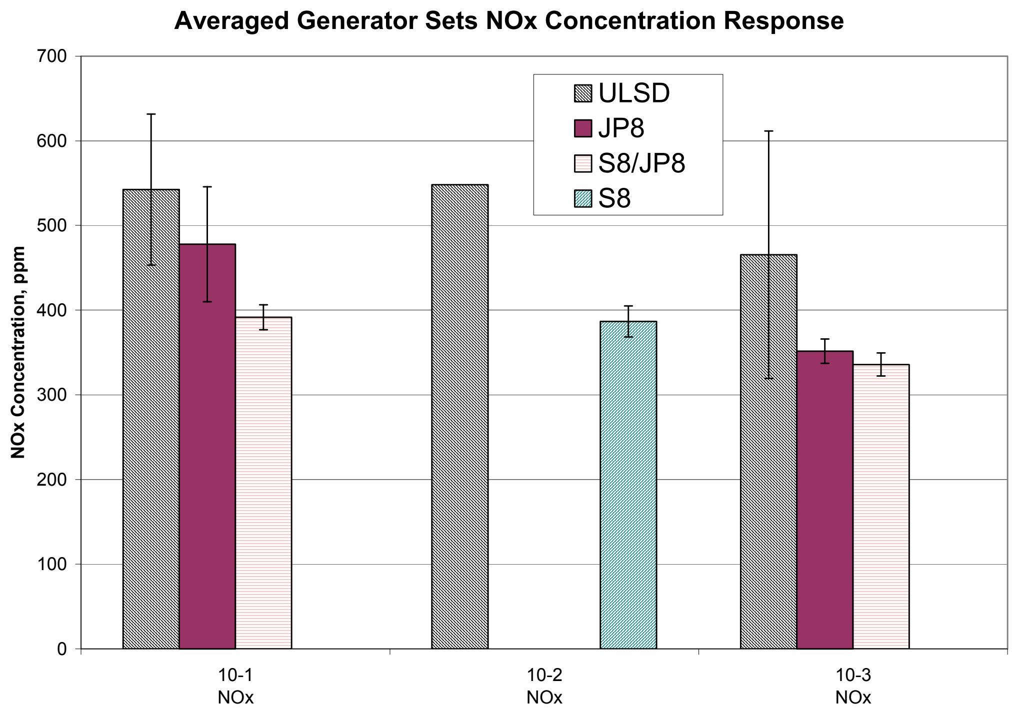


Figure 11. NOx (ppm) Response for the Three Generator Sets for Each Test Fuel

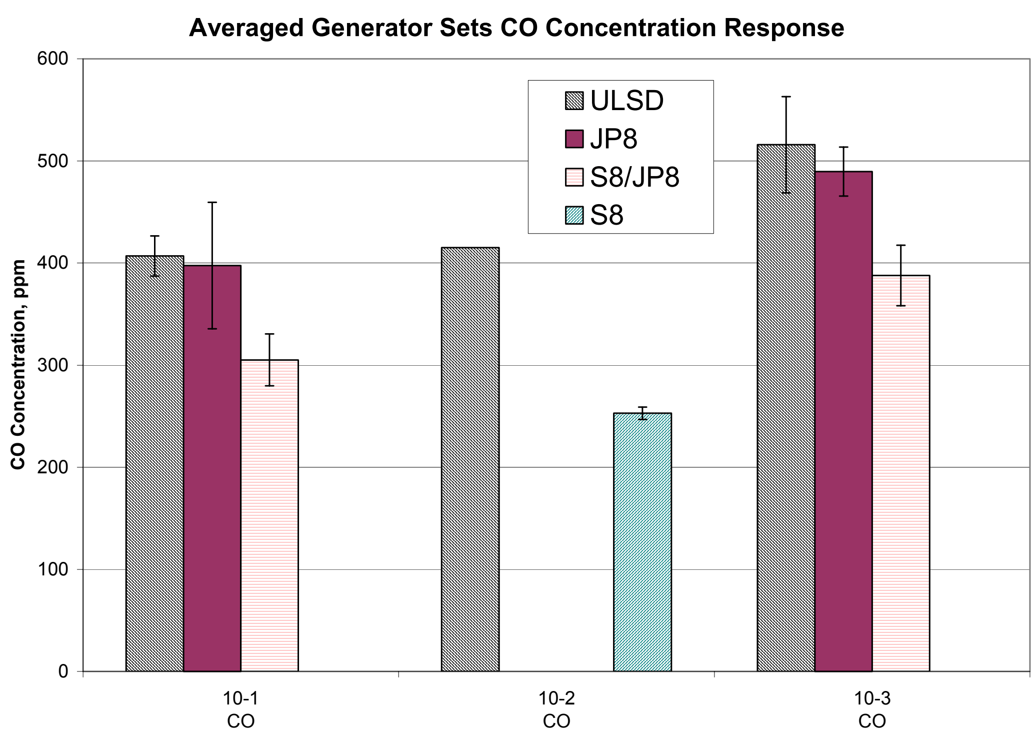


Figure 12. CO (ppm) Response for the Three Generator Sets for Each Test Fuel

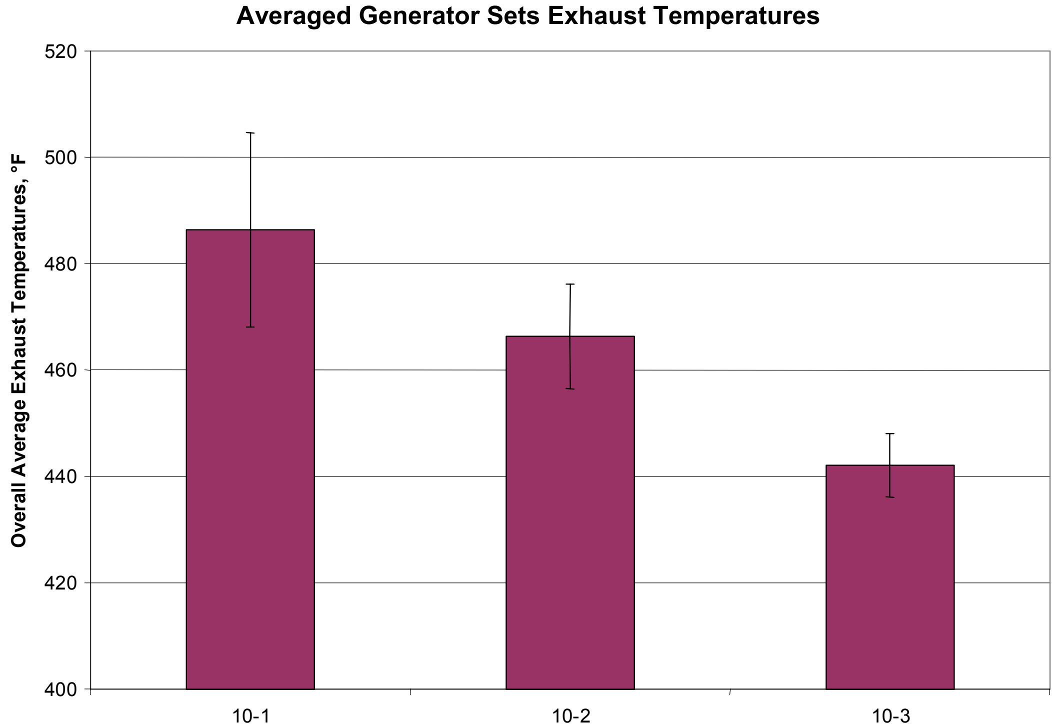


Figure 13. Exhaust Temperature (°F) Overall Average for the Three Generator Sets

4.5 Used Oil Analysis

Used oil samples were obtained and analyzed at pre-determined intervals to ensure that no engine related wear anomalies were occurring. The engine oil and filter were changed at the beginning of the break-in run and every 250 operating hours thereafter. All analysis results were in the normal range throughout the evaluation. Table 13 shows the operating hour sampling intervals and ASTM method and type analysis performed while Figures 14–17 present the analysis results for viscosity, total base number and total acid number. Wear metal results are not graphically shown due to the appearance of the chart, however, all sample results were well within the normal wear range.

Table 13. Used Oil Sampling and Analysis Interval

Hours	Amount of Sample	Analyses to be Performed
100	1 oz	D5185 Elements by ICP
250	16 oz	D445 VIS @40° and 100°C, TAN D664, TBN D4739, Elements D5185
400	1 oz	D5185 Elements by ICP
500	16 oz	D445 VIS @40° and 100°C, TAN D664, TBN D4739, Elements D5185
650	1 oz	D5185 Elements by ICP
750	16 oz	D445 VIS @40° and 100°C, TAN D664, TBN D4739, Elements D5185
900	1 oz	D5185 Elements by ICP
1000 EOT	16 oz	D445 VIS @40° and 100°C, TAN D664, TBN D4739, Elements D5185

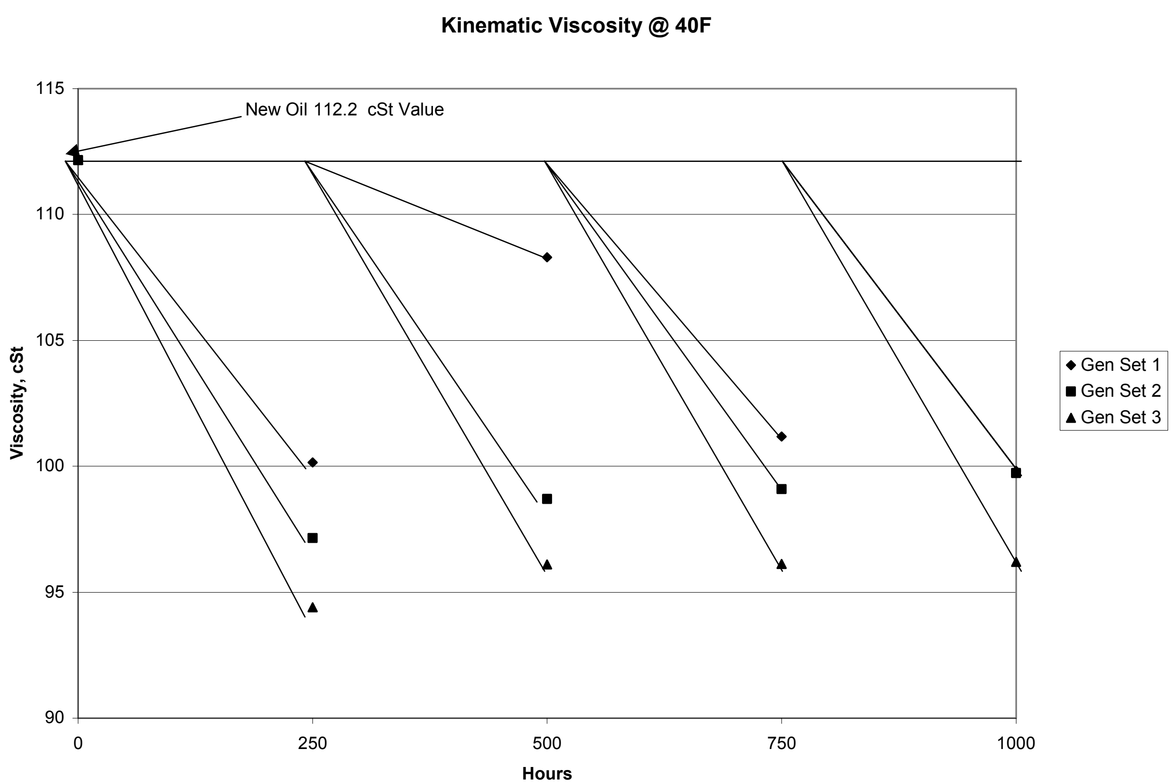


Figure 14. Kinematic Viscosity @ 40°F

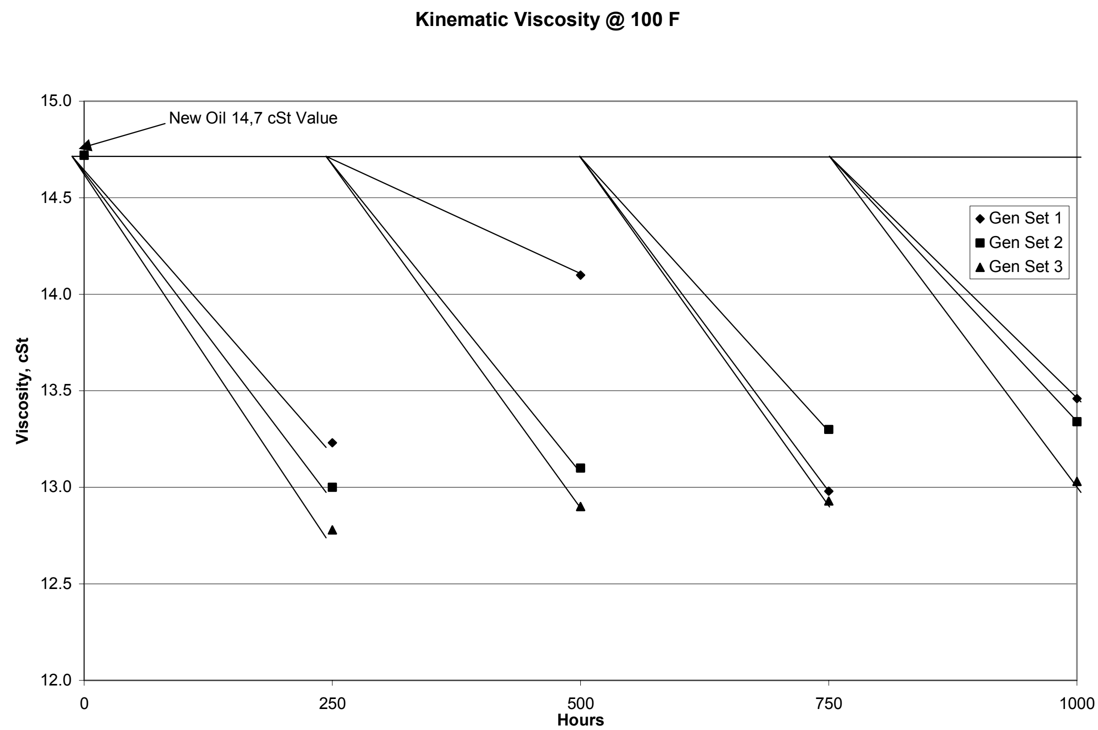


Figure 15. Kinematic Viscosity @ 100°F

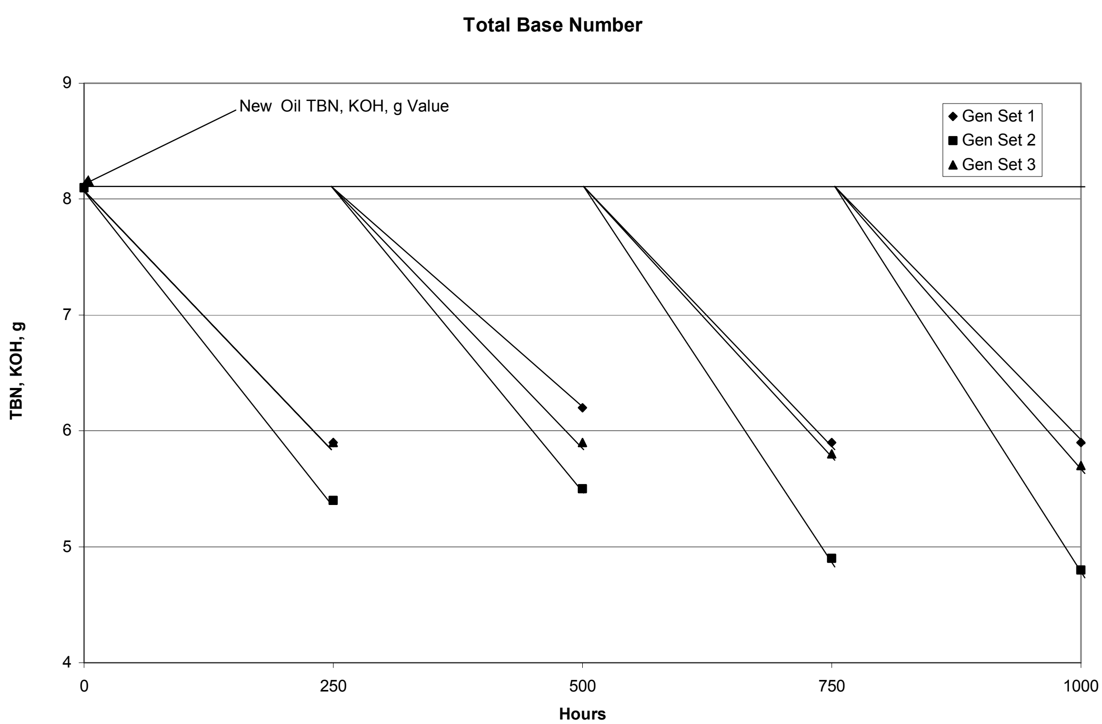


Figure 16. Total Base Number

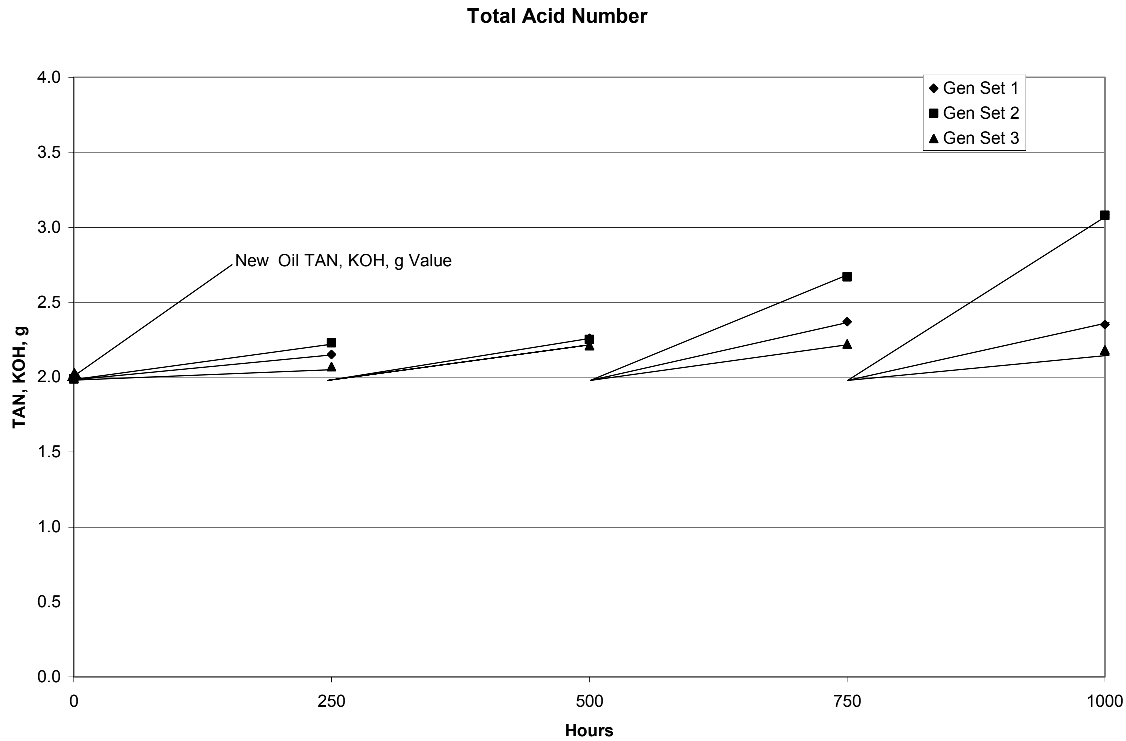


Figure 17. Total Acid Number

5.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be reached from the evaluation of synthetic fuel in tactical generators:

- The program was successful in that it clearly demonstrated that in this particular piece of tactical equipment, 100% synthetic fuel and a 1:1 blend of synthetic fuel and JP-8 aviation fuel can be utilized with no discernable differences in performance, except the expected reductions in emissions (CO, NOx) are evident when operating on the 100% synthetic fuel and also on the S-8/JP-8 blend fuel.
- No leaks were noted in any of the fuel-wetted components.
- Teardown and visual inspection of injection pumps did not exhibit unusual wear with any of the fuels used.
- It is recommended that further demonstration type evaluations be conducted in high density equipment that utilizes rotary and in-line injection pump systems.

6.0 REFERENCES

1. TM 9-6115-642-24 Unit, Direct Support and General Support Maintenance Manual, Generator Set, Skid Mounted, Tactical Quiet 10 KW, 60 HZ, MEP 803A NSN 6115-01-275-5061

2. TM 9-2815-254-24 Unit, Direct Support and General Support Maintenance Instructions, Diesel Engine Model DN4M 4-Cylinder 1.2 Liter NSN 2815-01-350-2206