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Tactical Vehicle Engine Emissions Investigations

INTERIM REPORT
TFLRF No. 365

by

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

for

U. S. Army Corps of Engineers
Engine Research & Development Center
Construction Engineering Research Laboratory
Champaign, IL 61826-9005

Under Contract to

U.S. Army TARDEC
Petroleum and Water Business Area
Warren, MI 48397-5000

Contract No. DAAE-07-99-C-L053 (WD 11)
SwRI® Project No. 03-03227

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Emissions from tactical vehicle engines contribute to local and regional particulate matter (PM) air pollution. Emissions from these sources are not well- understood, and the Army requires methods/models to predict PM10 and PM2.5 emissions from these military-unique sources. To develop these methods/models, the mass and chemical speciation of tactical vehicle engine emissions need to be characterized, which may also be useful in a method to determine the Army's contribution to atmospheric PM concentrations at receptor sites of concern. Because much of the Army ground force uses JP-8 fuel (1), engine emissions from the tactical vehicle fleet may be established as a distinctive PM source category. The establishment of an Army-unique PM source is the first step in the development of a receptor-model-based method that can apportion the PM contribution from all sources, including the Army's.

The objective of this program is to investigate procedures to be used in developing emissions factors for Army equipment. This project consists of the following tasks:

1. Perform a literature search to identify exhaust emissions data for JP-8 fuel used in Army engines and vehicles.
2. Examine the chemical and physical differences between JP-8 and diesel fuel (DF-2) (2).
3. Categorize groupings for Army wheeled and tracked vehicles to which a single emission estimation method/model can be applied.
4. Develop a plan for emissions testing of representative Army tactical vehicles using appropriate test cycle(s).

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EXECUTIVE SUMMARY

Emissions from tactical vehicle engines contribute to local and regional particulate matter (PM) air pollution. Emissions from these sources are not well-understood, and the U. S. Army requires methods/models to predict PM10 and PM2.5 emissions from these military-unique sources. To devleop these methods/models, the mass and chemical speciations of tactical vehicle engine emissions need to be characterized, which may also be useful in developing a method to determine the Army's contribution to atmospheric PM concentrations at receptor sites of concern. Because much of the Army ground force uses JP-8 fuel (1), engine emissions from the tactical vehicle fleet may be established as a distinctive PM source category. The establishment of an Army-unique PM source is the first step in the development of a receptor-model-based method that can apportion the PM contribution from all sources, including the Army's.

The objective of this program was to investigate procedures to be used in developing emissions factors for Army equipment. This project consisted of the following tasks:

1. A literature search was performed to identify exhaust emissions data for JP-8 fuel used in Army engines and vehicles. In general, lower exhaust emission levels were observed when using JP-8.
2. The chemical and physical differences between JP-8 and diesel fuel (DF-2) were examined and tabulated (2).
3. Groupings for Army wheeled and tracked vehicles were made to which a single emission estimation method/model can be applied.
4. A plan for emissions testing of representative Army tactical vehicles using appropriate test cycle(s) was developed.

FOREWORD/ACKNOWLEDGMENTS

This work was performed by the U. S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute® (SwRI®), San Antonio, Texas, during the period October 2001 through December 2002 under Contract No. DAAE-07-99-C-L053. The work was funded by the U. S. Army Corps of Engineers, Construction Engineering Research Laboratory (CERL), Champaign, Illinois. The project was administered by the U.S. Army Tank-Automotive RD&E Center (TARDEC), Petroleum and Water Business Area, Warren, Michigan. Mr. Luis Villahermosa (AMSRD-TAR) served as the TARDEC contracting officer's technical representative. Mr. Michael R. Kemme of CERL served as the project technical monitor.

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ACRONYMS & ABBREVIATIONS

ASME	American Society of Mechanical Engineers
AVL	Anstalt für Verbrennungskraftmaschinen
CVS	Constant Volume Sampling
DDC	Detroit Diesel Corporation
DF-2	Diesel Fuel
EPA	Environmental Protection Agency
ESC	European Stationary Cycle
FTP	Federal Test Procedure
HMMWV	High Mobility Multipurpose Wheeled Vehicles
g/bhp-hr	grams/brake horsepower-hour
GM	General Motors
hp	horsepower
ISO	International Organization for Standardization
JP-8	Jet Propellant-8
km/hr	kilometers/hour
mg/l	milligram/liter
NATO	North Atlantic Treaty Organization
NRTC	Nonroad Transient Test Cycle
PM	Particulate Matter
ppm	parts per million
SAE	Society of Automotive Engineers
SDA	Static Dissipator Addditive
SOF	Soluble Organic Fraction
SwRI	Southwest Research Institute®
TARDEC	Tank-Automotive Research Development and Engineering Center
TACOM	Tank-Automotive Armaments Command
TFLRF	U.S. Army TARDEC Fuels and Lubricants Research Facility
UDDS-HD	Urban Dynamometer Driving Schedule-Heavy Duty
vol%	volume percent

I. BACKGROUND

Emissions from tactical vehicle engines contribute to local and regional particulate matter (PM) air pollution. The emissions from these sources are not well understood, and the U. S. Army requires methods/models to predict PM10 and PM2.5 emissions from these military-unique sources. To develop these methods/models, the mass and chemical speciations of tactical vehicle engine emissions need to be characterized. The characterization of these emissions may also be useful in developing a method to determine the Army's contribution to atmospheric PM concentrations at receptor sites of concern. Because much of the Army ground force uses JP-8 fuel (1), engine emissions from the tactical vehicle fleet may be established as a distinctive PM source category. The establishment of an Army-unique PM source is the first step in the development of a receptor-model-based method that can apportion the PM contribution from all sources, including the Army's.

II. OBJECTIVE

The objective of this program is to investigate procedures to be used in developing emissions factors for Army equipment. This project consists of the following tasks:

1. Perform a literature search to identify exhaust emissions data for JP-8 fuel used in Army engines and vehicles.
2. Examine the chemical and physical differences between JP-8 and diesel fuel (DF-2) (2) that may influence engine emissions.
3. Categorize Army wheeled and tracked vehicles into groupings for which a single emission estimation method/model can be applied.
4. Develop a plan for emissions testing of representative Army tactical vehicles using appropriate test cycle(s).

Underscored numbers in parentheses indicate references at the end of the document.

III. DISCUSSION

A. Literature Review

A literature search was initiated to identify exhaust emissions data for JP-8 used in Army engines and vehicles. In the 1993 American Society of Mechanical Engineers (ASME) Paper No. 93-ICE-31, Montalvo and Ullman reported that JP-8 fuel produced approximately 35% lower PM emissions than DF-2 in a Detroit Diesel Corporation (DDC) Series 60 diesel engine. (3)

Society of Automotive Engineers (SAE) Paper No. 961981, entitled "U.S. Army Investigation of Diesel Exhaust Emissions Using JP-8 Fuels with Varying Sulfur Content," is a primary reference source. (4) The Army High Mobility Multipurpose Wheeled Vehicle (HMMWV) is powered by a General Motors (GM) 6.2L diesel engine. Exhaust emissions data from this type of engine were reported in SAE Paper No. 961981. In a 1990 GM 6.2L engine operated over the hot-start transient heavy-duty diesel engine cycle, JP-8 fuel produced 0.2288 g/bhp-hr PM. A reference DF-2 fuel produced 0.2905 g/bhp-hr PM over the same test cycle. Similar investigations in a DDC Series 60 (1991 prototype engine) produced 0.1320 g/bhp-hr PM with JP-8, and 0.1697 g/bhp-hr PM with DF-2. In both cases, the DF-2 fuel produced approximately 25 to 30% more PM. The PM contents were further analyzed for sulfate fraction and soluble organic fraction (SOF). In both engines, the sulfate fraction of the PM tracked with fuel sulfur content as expected. In the 6.2L engine, the SOF of PM was 40% for JP-8 and 32% for DF-2. In the DDC Series 60 engine, the %SOF was nearly the same for JP-8 and DF-2. Based on these data, the percent SOF of PM probably cannot be used to differentiate the PM source between JP-8 and DF-2.

The following papers, which addressed the development of test cycles for determining exhaust emissions of off-road vehicles and equipment, were reviewed:

SAE Paper No. 1999-01-2800, "Non-road Engine Activity Analysis and Transient Cycle Generation," by T. L. Ullman, C. C. Webb, C. C. Jackson, Jr, and M. H. Doorlag. (5)

A representative transient test cycle for each of three different pieces of off-road equipment (agricultural tractor, backhoe-loader, and crawler tractor) was developed and utilized to perform a laboratory assessment of non-road engine emissions.

SAE Paper No. 2001-01-3637, "Development of Relevant Work-Cycles and Emissions Factors for Off-Road Machines" by O. Pettersson and O. Noren. (6)

Pettersson and Noren found that work cycles like EURO R49 and ISO 8178 do not agree with reality for off-road machines. They state an urgent need for relevant work cycles and emission factors for off-road machines related to different work operations. This is an on-going program that consists of determining in-field driving patterns and relating them to engine dynamometer static test conditions.

ASME Paper, "Development of Transient Test Cycles for Selected Non-road Diesel Engines," by M. E. Starr, J. P. Buckingham, and C. C. Jackson, Jr. , from the ASME Proceedings of Spring 1999 Internal Combustion Engine Division, ICE Vol. 32-1. (7)

This EPA-funded work involved developing transient duty cycles for the following types of 1997 model-year, non-road equipment: a wheel loader, an arc welder, and a skid steer loader. In-use field data were collected and statistically analyzed to develop two typical duty cycles and two highly transient duty cycles for these three types of equipment.

SAE Paper No. 2002-01-1716, "Development of a Transient Duty Cycle for Large Non-road SI Engines," by V. Ulmet, J. J. White, A. Stout, and D. Salardino. (8)

This paper presented measurements to characterize normal operation of forklift trucks. While this work involved LPG-fueled (spark-ignition) forklift trucks, the duty cycle defined should be very similar to Army diesel-powered forklift operation. Field measurements showed that these types of engines operate with a very high degree of transient operation. The South Coast Air Quality Management District funded the development of this transient test cycle. This new 20-minute cycle includes both constant and variable speed operation.

B. JP-8 and DF-2 Property Differences

Chemical and physical differences between JP-8 (1) and DF-2 (2) were examined. In general, JP-8 has a lower temperature boiling range (less high boiling material) and a lower density than DF-2. JP-8 also contains corrosion inhibitor, static dissipator (SDA), and fuel-system icing inhibitor (FSII) additives.

Fuel survey data were examined to compare average JP-8 and diesel fuel properties. Table 1 contains the average fuel properties. The lower aromatic content, lower 90% off distillation, and lower end point distillation of JP-8 are the key properties expected to impact and reduce exhaust emissions compared to diesel fuel.

Table 1. Average Fuel Properties

Fuel Type	DF-2	JP-8	JP-8
Survey Date	2001	1995	1996
Properties			
API Gravity	34.3	ND	43.3
Kinematic Viscosity, @ 40°C, cSt	2.70	1.29	ND
Sulfur, %	0.035	0.05	0.031
Aromatics, %	32.8	18.8	17.8
Distillation, °C			
@ 90% off	319	237	241
@ End Point	344	262	ND
Reference	9	10	11

The feasibility of tracing JP-8 contribution to overall collected atmospheric particulate matter was investigated. JP-8 fuel contains corrosion inhibitor, FSII additives and SDA. The corrosion inhibitor additive is generally a dimer acid, such as dilinoleic acid, and is usually present in the range of 12-30 mg/L. The FSII additive is diethylene glycol monomethyl ether and is typically added in the range of 0.1 to 0.15 vol%. The SDA is a proprietary blend of chemicals that is added at 1mg/L and contains approximately 100 ppm sodium. Given the chemical nature and low concentrations of these additives, tracing JP-8 fuel to measured atmospheric particulate matter does not appear feasible.

C. Grouping of Army Vehicles and Equipment

Categorization techniques for grouping Army vehicles were considered. The EPA categories for non-road emissions standards are based on engine power output and include the following: vehicles; construction, industrial, lawn-and-garden, farm, airport-service light-commercial, logging and underground-mining equipment; and, other items.

The EPA has reported that the types of technology employed by engine manufacturers are different for engines rated below 50 hp than for those over 50 hp. Engines in the under 50 hp class are typically naturally aspirated (>99%), while many engines over 100 hp employ a turbocharger. Most engines under 50 hp tend to be indirect injection, while over 80% of the non-road diesel engines with greater than 50 hp are direct injection. These basic engine-configuration differences can impact a variety of engine-design parameters, such as fuel injectors, injection strategy, injection-spray inclusion angle, and piston-crown design. (12) Based on this information, the proposed Army categories were revised. Because 2-stroke cycle truck engines have different exhaust emission characteristics than 4-stroke cycle engines, the following recommended emissions categories for Army ground equipment are proposed:

4-stroke cycle

- Bhp
- <50
- >50 to 300
- >300 to 600
- >600

2-stroke cycle

- Bhp
- <300
- >300

A listing of high-density Army diesel equipment is presented in Table 2. Representative equipment and engine type are shown for the proposed emissions categories.

Table 2. High Density Army Diesel Equipment			
Model No.	**Nomenclature**	**Engine Model No.**	**Horsepower**
Less Than 50 Horsepower 4-stroke Engine			
5 kW	Generator Set	Onan Div DN2M	7
		Onan Div DJE-99E/9485	
		Deutz FIL208D	
10 kW	Generator Set	Onan Div DN4M1	13
		Onan Div DJE-99E/9487	
		Hercules D198ERX51	
15kW	Generator Set	Isuzu C240	20
		US Motors HD260	
		Hercules D198ERX51	
		Deutz F3L-912	
M4K	Truck Fork Lift	J.I. Case DT46B	20
M40XL4K	Truck Fork Lift	Isuzu C240	20
30 kW	Generator Set	Hercules D298ERX37	40
		John Deere 4039T	
		Deutz F4L-912	
50 to 300 Horsepower 4-stroke Engine			
60 kW	Generator Set	Allis Chalmers 3500	80
		John Deere 6059	
		Cummins C180B1	
VRRTFL6K	Truck Forklift	Cummins 6BT5.9-C	98
130G	Grader, Road Motorized	Caterpillar 3304	140
M998 (All Series)	HMMWV	GM 6.2/6.5 L	150
M1078-1081	Truck, LMTV 2½ Ton	Caterpillar 3116	225
W24C	Loader, Scoop	Caterpillar 3306	250
D7G	Tractor, Full Track	Caterpillar 3306	250
M923A2 Series	Truck, Cargo 5 Ton	Cummins 6CTA8.3	260
M10A	Truck, Fork Lift	I.H. DT46B	275
M1083-1094	Truck, MTV 5 Ton	Caterpillar 3116	290
301 – 600 Horsepower 4-stroke Engine			
M2/3A1-3	Bradley Fighting Vehicle (c)	Cummins VTA903T	600
M915 (916)	Truck, Tractor	Cummins NTC	400
More Than 600 Horsepower 4-stroke Engine			
M88A1	Recovery Vehicle FT (c)	Continental AVDS 1790-2DR	750
M88A2	Recovery Vehicle FT Heavy (c)	Continental AVDS 1790-8CR	1,050
50 to 300 Horsepower 2-stroke Engine			
LAV	Light Armored Vehicle (c)	Detroit Diesel 6V53T	275
M113/548/577A3	Carrier, Tracked (c)	Detroit Diesel 6V53T	275
301 – 500 Horsepower 2-stroke Engine			
M578	Recovery Vehicle, Light (c)	Detroit Diesel 8V71T	440
M977-985	Truck, 10 Ton HEMTT	Detroit Diesel 8V92T	450
M1074-1075	Palletized Load Sys PLS	Detroit Diesel 8V92T	500
M1070	Heavy Equip Transporter	Detroit Diesel 8V92T	500
M915A2	Tractor, Line Haul	Detroit Diesel 8V92T	
(c) = combat vehicle			

D. Exhaust Emissions Test Plan

1. Investigation of Possible Test Cycles for Determining Army Diesel Engine Emission Factors

Possible test cycles for determining Army diesel emission factors were investigated. Information on the following test cycles was collected and summarized: (13)

- EUROII, R49 steady-state, heavy-duty highway engines
- European stationary cycle (ESC) for heavy-duty diesel engines (replaces R49)
- U.S. 13-mode steady-state duty cycle
- AVL 8-mode steady-state cycle
- ISO 8178 steady-state cycle
- NATO AEP-5 military engine test cycle (14)
- EPA Urban Dynamometer Driving Schedule (UDDS-HD)
- EPA heavy-duty FTP Transient Test Cycle

The EPA Heavy Duty FTP Transient Test Cycle is based on vehicle operation on non-freeway and freeway routes. Test duration is 20 minutes, and the average load factor for any given speed is approximately 20 to 25%, with an average vehicle speed of approximately 30 km/hr.

The UDDS-HD cycle employs a chassis dynamometer to test heavy-duty vehicles. The test characteristics are 1060 seconds, 8.9 km, 30.4 km/hr avg. speed, and 93.3 km/hr max. speed.

Information on the steady-state test cycles has been tabulated for comparison (Table 3).

The EPA has developed non-regulatory non-road duty cycles for the following equipment: (15)

- Agricultural tractors
- Backhoe loaders
- Crawler tractors
- Excavators
- Arc welding machines
- Skid steer loaders
- Wheel loaders

Table 3. Information on the Steady-State Cycles																	
	Test Cycle																
	ISO 8178 (C-1)			U.S. 13 Mode/EURO R49				NATO Endurance			AVL8			ESC			
Mode	Speed	%load	wtg	speed	%load	US wtg	EURO wtg	speed	%load	Relative Time	%speed	%load	wtg	speed	%load	wtg
1	Rated	100	0.15	Idle	0	0.2/3	0.25/3	Idle	0	1	0 (low idle)	0	0.35	low idle	0	0.15
2	Rated	75	0.15	max tq	10	0.08	0.08	rated	100	4	11	25	0.063	A	100	0.08
3	Rated	50	0.15	max tq	25	0.08	0.08	govrd	0	1	21	63	0.03	B	50	0.10
4	Rated	25	0	max tq	50	0.08	0.08	75% rated	100	2	32	84	0.03	B	75	0.10
5	Intermed	10	0.1	max tq	75	0.08	0.08	0-100%	0-100%	4	100	18	0.084	A	50	0.05
6	Intermed	100	0.1	max tq	100	0.08	0.25	60% rated	100	1	95	40	0.105	A	75	0.05
7	Intermed	75	0.1	idle	0	0.2/3	0.25/3	idle	0	1	95	69	0.102	A	25	0.05
8	Intermed	50	0.1	rated pwr	100	0.08	0.10	govrd	70%	1	89	95	0.073	B	100	0.09
9	Intermed	25	0	rated pwr	75	0.08	0.02	MaxTq	100	4				B	25	0.10
10	Intermed	10	0	rated pwr	50	0.08	0.02	60% rated	50	1				C	100	0.08
11	Low Idle	0	0.15	rated pwr	25	0.08	0.02							C	25	0.05
12				rated pwr	10	0.08	0.02							C	75	0.05
13				idle	0	0.2/3	0.25/3							C	50	0.05

Based on those equipment operational profiles, the EPA has been developing a transient driving cycle for mobile non-road diesel engines. The non-road transient cycle (NRTC) test is still under development and has not yet been formalized or adopted for use in emission standards. The version described here represents the EPA draft of May 2002. (13) The cycle is an engine dynamometer transient driving schedule with a total duration of about 1200 seconds. The normalized speed and torque during the NRTC test are shown in the Figure 1.

It is not known if this test cycle is representative of typical Army off-road operation. Army operation may include more time at engine idle than this cycle.

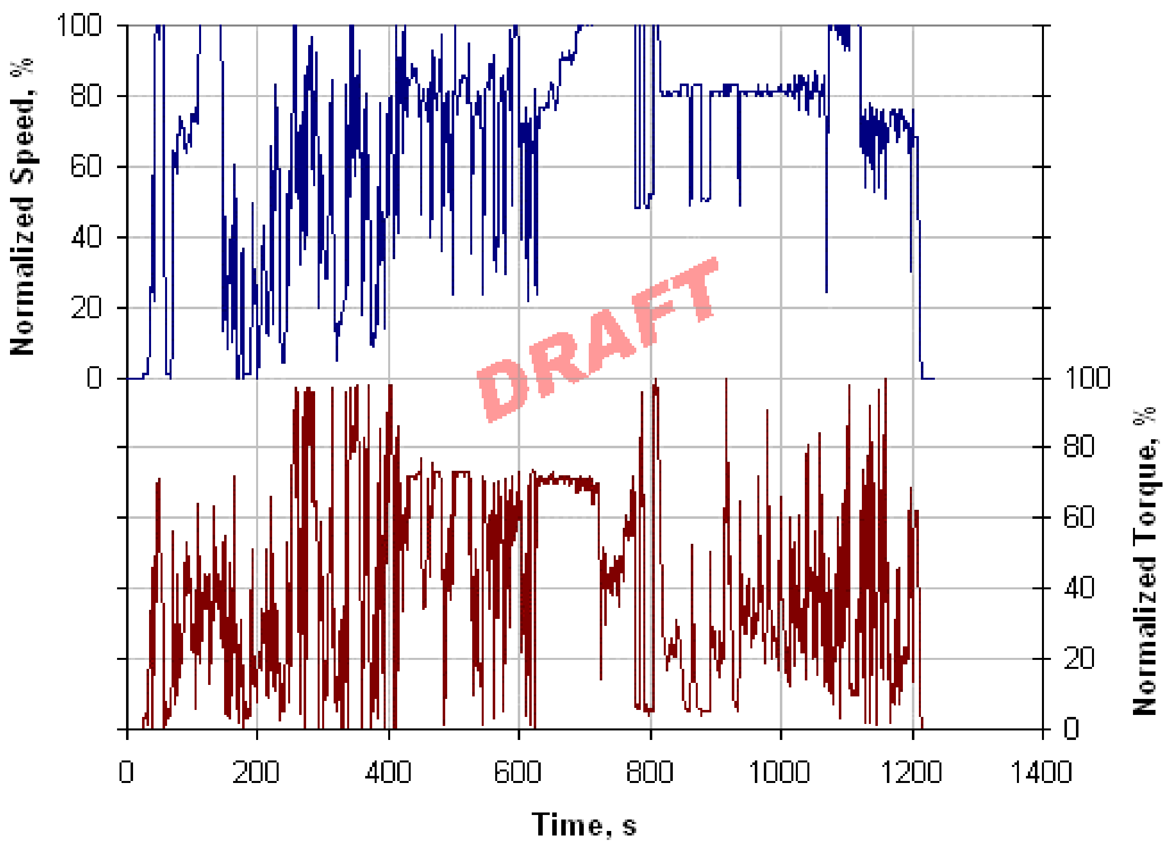

Figure 1. Normalized Speed and Torque During the NRTC Test

2. Recommended Test Plan for Army Ground Equipment Emission Factors

The exhaust emissions from Army ground equipment are not well-documented and will likely differ substantially from similar civilian sources because of unique fuel (JP-8), vehicle and equipment usage patterns, and engine technologies.

a. Approach

A two-phase approach for determining emissions factors for U. S. Army ground equipment (including vehicles) is proposed. For the first phase, it was recommended that exhaust emissions be determined for selected engines of Army equipment following the 11-mode, steady-state ISO 8178 procedure. A weighting factor will be developed and applied for each mode during the second phase of the approach. Field-operating conditions and usage patterns will be monitored for selected Army equipment. This information will be used to develop weighting factors to be applied to the 11-mode ISO 8178 exhaust emissions. It is anticipated that a given vehicle class, such as the HMMWV, may have several different usage patterns based on the vehicle mission. A benefit of the proposed approach is that different weighting factors based on equipment mission could be developed and applied for the same class of equipment. In other words, exhaust emissions will be determined once for each of the 11 modes, then weighted appropriately to fit equipment mission.

One shortcoming of this approach is that emissions generated during transient operations are not measured. In the longer term, a composite off-road transient test cycle for Army equipment should be developed. The cycle should contain portions that reflect the wide variety of Army equipment operating modes. It is anticipated that a modification of the draft EPA Off-road Transient Test Cycle could be made that reflects Army equipment-operating profiles.

b. Proposed Testing and Procedures

The HMWWV is the most populous Army vehicle and has a high utilization rate (16). For these reasons, the 6.5L diesel engine from the HMMWV was selected for the initial investigations. The engine will be installed in a dynamometer test cell, and exhaust emissions will be measured over the 11 steady-state modes of the ISO 8178 procedure. Emissions measurements will be made using JP-8 and reference DF-2. Figure 2 is a schematic of the setup for exhaust emissions sampling. This figure includes the sampling locations for “toxics” and polyaromatic hydrocarbons.

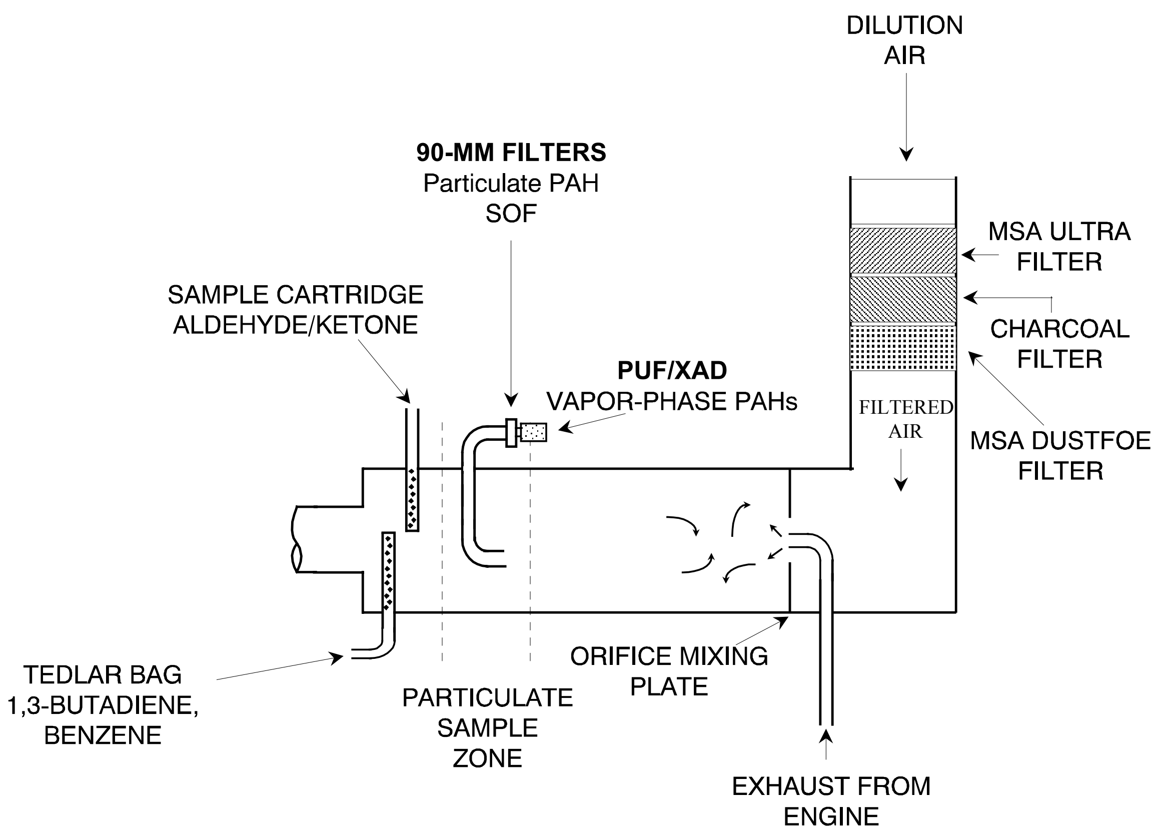

Figure 2. Schematic Representation for Toxic Emissions Sampling

The gaseous emissions sampling will be performed in accordance with the guidelines outlined in 40 CFR Part 86, Subpart D. The engine exhaust will be coupled to the laboratory-house exhaust system and a Constant Volume Sampling (CVS) system. The CVS system consists of a 203-mm dilution tunnel, with a variable-speed, roots-type blower. In order to attain a 125°F filter face temperature with the CVS system, the engine exhaust will be split between the house exhaust and the dilution tunnel. The constituents to be measured and the respective analysis method for each are presented in Table 4.

Table 4. Analytical Instrumentation for Exhaust Emissions	
Constituent	**Analysis Method**
Total Hydrocarbon	Heated Flame Ionization Detector
Carbon Monoxide	Non-Dispersive Infrared Analysis
Carbon Dioxide	Non-Dispersive Infrared Analysis
Oxides of Nitrogen	Chemiluminescent Analysis
Particulate Matter	Gravimetric, CVS, CO2 tracer
Soluble Organic Fraction of PM	Gravimetric, Soxhlet Extraction Toluene/Ethanol

Measurement and analysis of non-regulated species such as polyaromatic hydrocarbons and EPA toxics will not be made during this initial investigation because of funding limitations.

For the second phase of the investigation, field data will be collected concerning the operating modes of a HMMWV during training exercises at an Army base. Based on discussions with Army personnel, a HMMWV that is expected to experience "typical" utilization during training will be selected. The selected vehicle will be instrumented for data acquisition, and operating data will be collected over a period of training. The collected data will be analyzed for speed and estimated load points to be used in weighting the ISO 8178 data points for typical HMMWV operation.

IV. SUMMARY AND CONCLUSIONS

The following summary and conclusions are offered:

> There is limited data in the literature concerning the comparison of JP-8 and DF-2 exhaust emissions Army equipment. In general, DF-2 produced approximately 30% more particulate matter exhaust emissions than JP-8.

> Test cycle procedures for measuring exhaust emissions of off-road equipment have been developed by the federal government. A draft non-road transient cycle (NRTC) has been developed. It is not known if the NRTC is representative of Army off-road operation.

It does not appear to be feasible to trace collected ambient PM to JP-8 as a source based on the additives present in JP-8.

Proposed groupings of Army equipment and vehicles for exhaust emission purposes were made based on engine power for two- and four-cycle diesel engines.

A draft test plan for determining exhaust emission factors for the high-population density and high-utilization HMMWV was prepared.

V. RECOMMENDATIONS

The following is a list of recommendations:

- The test plan utilizing the ISO 8178 steady-state test procedure should be implemented using a HMMWV engine (6.5L).
- An actual Army field-operational utilization plan should be determined for the HMMWV because of its high fleet density and usage.
- As a long-term goal, an Army NRTC should be developed that could be used for all Army ground equipment.
- Non-regulated exhaust emissions such as EPA toxics and polyaromatic hydrocarbons should be determined for Army ground equipment and vehicles as funding allows.
- The EPA transient adjustment emission factors should be applied where feasible to the steady-state exhaust emissions that will be determined for Army equipment. EPA deterioration-adjusted emission factors should also be investigated as applied to Army vehicles and equipment.

VI. REFERENCES

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