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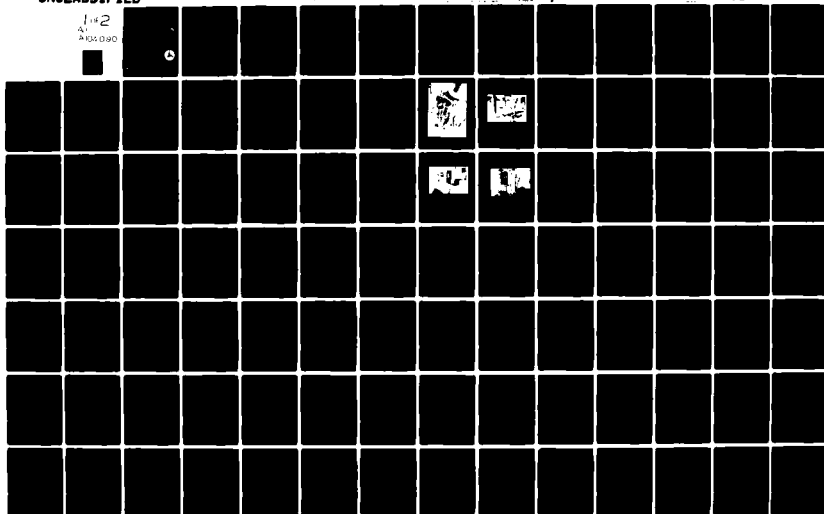
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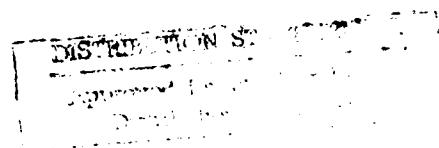
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**MULTICYLINDER
DIESEL ENGINE
TESTS WITH
UNSTABILIZED
WATER-IN-FUEL
EMULSIONS**



**REPRINT
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U.S. DEPARTMENT OF TRANSPORTATION

**RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
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**PREPARED FOR UNITED STATES COAST GUARD
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MULTICYLINDER DIESEL ENGINE TESTS
WITH UNSTABILIZED WATER-IN-FUEL EMULSIONS

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16. Abstract Two diesel engines representative of the four-stroke cycle and two-stroke cycle main propulsion units installed in U.S. Coast Guard WPB class cutters were operated in a test environment in an attempt to demonstrate significant fuel savings associated with water-in-fuel emulsions. The engines were connected to a dynamometer in a laboratory test cell. A prototype fuel system was assembled that would supply unstabilized emulsions for which the water concentration could range from zero to 25 percent of the total volume of liquid supplied to the engine as fuel. An analysis of boat operation was performed in order to identify the most frequently used engine settings, and both engines were operated at test points representative of boat prop load performance. The test results for the four-stroke cycle engine indicated that an average diesel fuel saving of about 2.5 percent could be obtained at the most frequently encountered operating conditions using water concentrations of 15-25 percent. Statistical analysis procedures suggest a 90 percent confidence in the measured results. Significant reductions in exhaust smoke were also observed, although the exhaust stream opacity was low throughout the tests. For the two-stroke cycle engine, no statistically significant reduction in fuel consumption could be identified. Measurements of gaseous exhaust emissions were obtained for both engines; in general, the emissions increased with the presence of water in the fuel. Measurements of particulate emissions for the two-stroke cycle engine suggested only a slight effect of water concentration. No adverse effect on engine hardware could be associated with the presence of water in the engine fuel system.					
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PREFACE

This work was performed for the U.S. Department of Transportation, U.S. Coast Guard, Office of Research and Development, under a contract issued by the Transportation Systems Center. The Technical Monitors were Fred Weidner (USCG) and Robert Walter (TSC). The laboratory tests were performed by Rodney Bauer of the Department of Engine and Vehicle Research, Southwest Research Institute.

Engines were made available to the program by the Cummins Engine Company, Inc., and by the Detroit Diesel Allison Division of General Motors Corporation. The cooperation of these organizations is sincerely appreciated.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures				Approximate Conversions from Metric Measures			
Symbol	When You Know	Multiply by	To Find	Symbol	When You Know	Multiply by	To Find
LENGTH				LENGTH			
in	inches	2.5	centimeters	mm	millimeters	0.04	inches
ft	feet	30	centimeters	cm	centimeters	0.4	inches
yd	yards	0.9	meters	m	meters	3.3	feet
mi	miles	1.6	kilometers	km	kilometers	1.1	yards
						0.6	miles
AREA				AREA			
sq in	square inches	6.5	square centimeters	sq cm	square centimeters	0.16	square inches
sq ft	square feet	0.09	square meters	sq m	square meters	1.2	square yards
sq yd	square yards	0.8	square meters	sq km	square kilometers	0.4	square miles
sq mi	square miles	2.6	square kilometers	ha	hectares (10,000 m ²)	2.5	acres
MASS (weight)				MASS (weight)			
oz	ounces	28	grams	g	grams	0.005	ounces
lb	pounds	0.45	kilograms	kg	kilograms	2.2	pounds
	short tons (2,000 lb)	0.9	tonnes	t	tonnes (1,000 kg)	1.1	short tons
VOLUME				VOLUME			
cup	cup	0.24	liters	l	liters	0.03	fluid ounces
qt	quarts	0.95	liters	l	liters	1.06	pints
gal	gallons	3.8	liters	l	liters	0.26	gallons
cu ft	cubic feet	0.03	cubic meters	m ³	cubic meters	36	cubic feet
cu yd	cubic yards	0.76	cubic meters	m ³	cubic meters	1.3	cubic yards
TEMPERATURE (exact)				TEMPERATURE (exact)			
F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature



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1. INTRODUCTION

The current emphasis on fuel conservation has prompted the study of many devices and techniques oriented toward a reduction in engine fuel consumption. This report describes the procedures used and the results obtained during a study of unstabilized water-in-fuel emulsions as fuels for engines representative of U.S. Coast Guard main propulsion systems.

The complete program involved an investigation of two high-speed diesel engines with nominal maximum power ratings in the 1000 hp range. A Cummins VTA-1710 engine was used to represent the military version (VT12-900M) that is utilized by the USCG. In addition, a Detroit Diesel 12V-149TI engine was employed for the acquisition of data representative of the 16 cylinder version installed in the USCG cutters.

1.1 BACKGROUND

The use of water-in-fuel emulsions for fuel conservation has been a subject of continuing interest for several years. During 1977, Southwest Research Institute conducted a program for the Department of Transportation in which fuel-water emulsions were examined in the context of a single-cylinder test engine. The results obtained during that study indicated that a reduction in fuel consumption on the order of five percent might be available for engines representative of marine propulsion.¹ It was recommended that the testing effort be continued using multi-cylinder engines, and the present study describes the partial fulfillment of that recommendation.

Various investigators have recommended the use of different devices and philosophies for the production of water-in-fuel emulsions used as engine fuels. One approach suggests the addition of surfactant compounds to the fuel-water mixture. The surfactants stabilize the emulsions and allow batch mixing of fuel supplies. For the present study, however, this approach was not considered feasible, since the USCG would prefer to avoid the requirement for precise blending of fuel additives with the large quantities of fuel utilized for patrol boats. Furthermore, it was considered necessary to view

the emulsified fuel as an option to clear diesel fuel, and the storage of a second bulk fuel aboard existing cutters was not considered appropriate.

This study deals with the use of unstabilized emulsions as engine fuels. The water and fuel were emulsified immediately prior to use by the engine, and emulsified fuel that was supplied to the engine but not burned was recycled through the emulsifier circuit.

1.2 OBJECTIVES

The initial goal of the study was the identification and the specification of an appropriate emulsification device. It had previously been observed that some devices offered for use as fuel emulsification systems were inappropriate to shipboard operation by virtue of physical size or power requirements. Furthermore, it was not clear that all devices were equally capable of providing useful emulsions. Therefore, the initial program phase was devoted to selection of an emulsification device.

Following the specification and purchase of a suitable emulsifier, the program objective was the determination of the effect of the emulsified fuels on engine operation. All tests were performed in a laboratory environment; the engines were connected to a dynamometer. Particular emphasis was placed upon fuel conservation, but measurements of exhaust emissions were also obtained. A further objective was the determination of results on a statistically significant basis in order that a numerical confidence could be placed in the results.

As an additional program objective, it was specified that encouraging results from the test bed studies would yield design information appropriate to the assembly of a prototype fuel emulsification system for shipboard use. The final program phase would involve field testing of the prototype on a USCG cutter.

1.3 APPROACH

The program was initiated with a selection process devoted to the definition of emulsification systems appropriate to the study. Invitations were sent to all individuals or companies known to be involved in the development of emulsification systems, and an advertisement was placed in the Commerce Business Daily that outlined the program requirements. Six prospective suppliers responded to the invitation and offered devices for evaluation in the SwRI laboratory.

A system was provided by SwRI that would supply metered quantities of fuel and water to the prototype systems on a uniform basis. The emulsification systems were exercised within their performance limits as defined by the supplier, and samples of water-in-fuel emulsion were obtained over the 0 to 25 percent concentration range that was of interest. Immediately following collection of each sample, the time required for accumulation of an obvious separation layer was observed. This process allowed the assessment of the capability of each device to produce an emulsion that would be useful during the engine studies.

In addition, each prospective emulsification device was evaluated on the basis of energy usage, physical size, complexity, compatibility with the shipboard environment, and the need for auxiliary hardware such as pumps and controllers. Individual evaluations were performed by representatives of SwRI, the Transportation Systems Center, and the USCG. As a result of the evaluation process, two emulsification systems were selected for use during the engine operation phase of the program, and purchase orders for units of an appropriate size were executed.

Since the response of the engine fuel system to the presence of water was unknown, a brief sequence of test runs was performed using stabilized emulsions containing 5 and 20 percent water by volume. The single purpose of these tests was the determination of any observable detrimental effects on engine operation as a result of water in the fuel system. No detrimental effects were observed, therefore the testing with unstabilized mixtures was initiated.

During all of the test sequences the laboratory engine was operated at controlled speeds and loads representative of the cutter prop load at each speed. On this basis, the maximum engine output would be observed only at the engine rated speed. Although some test runs were performed at maximum speed and load, the data were of interest only for certification of the fact that the engine met the ratings specified by the manufacturer. At the other test speeds the prop loads were considerably below the maximum possible engine output.

Throughout the bulk of the test program, the engine remained in the configuration appropriate to the use of diesel fuel alone. Since the fuel-water emulsion was regarded as an alternate fuel for boat operation, it was not considered appropriate to optimize the engine operating parameters for emulsified fuel use. It is possible that fuel consumption results different from those obtained could have been achieved by adjusting the engine operating parameters; the injection timing is particularly significant in this context, and some tests were performed with timing variation on the two-stroke cycle engine.

The emulsifier purchased for use during the tests was integrated into a fuel system capable of supplying the engine demand at any speed and load. The fuel system included ample provision for maintaining the state of the emulsions and for re-emulsifying fuel returned from the engine. In addition, a provision was included to allow sampling and subsequent observation of quantities of emulsified fuel immediately prior to introduction into the engine. Observation of these samples allowed additional verification of the water concentration of the emulsion.

During the test runs the engine was operated at selected points on the prop load curve with various water concentrations. Each test sequence, which occupied one day, involved operation of the engine at a single speed-load point. The first test run was performed with clear diesel fuel, followed by tests at 5, 10, 15, 20, and 25 percent water. Upon completion of these runs the fuel system was flushed and the test with clear diesel fuel was

repeated. During the performance of each test run, extensive observations of fuel consumption and other engine operating parameters were made.

The complete body of data includes information at speeds along the entire prop load curve for each test engine. In addition, the data include extensive testing at two speed-load points for the Cummins engine; the two points represent high utilization by operating USCG cutters. The data allow the determination of the optimum water concentration at each speed-load point; this information would be useful for the design of a shipboard control system.

2. EXPERIMENTAL APPARATUS AND TECHNIQUES

The performance of the experiments associated with this study involved specific equipment, test procedures, and data evaluation routines. The salient features of these items are described in this section.

2.1 EQUIPMENT

The equipment utilized for the evaluation of water-in-fuel emulsions consisted of engines installed in a laboratory test cell, a fuel system uniquely appropriate for the production and distribution of emulsified fuel, and a broad variety of instrumentation used for the acquisition of data. Each of these categories is worthy of an expanded description.

2.1.1 Engines

The engines used aboard USCG cutters of the 82-ft WPB class are manufactured by the Cummins Engine Company and characterized by Model No. VT12-900M. The units have a total displacement of 1710 cubic inches and are rated at 800 shaft horsepower at 2300 rpm. This rating corresponds to approximately 875 brake horsepower at the same speed.

The engine available to this effort was a Cummins Model VTA-1710-C800, the industrial version of the USCG engine described above. The engine is ordinarily rated at 800 brake horsepower at 2100 rpm. The engine was equipped with an automotive type AFC fuel pump rather than the older style marine pump. For the purposes of this study, the fuel pump and governor were modified to allow engine operation up to 2300 rpm, and a maximum power capability of 845 horsepower at 2300 rpm was demonstrated in the laboratory. This value is within the five percent tolerance specified by the manufacturer.

The military and industrial versions of the 1710 engine differ slightly in the timing at which the fuel injection event begins. This difference amounts to approximately three crank angle degrees, and this deviation was not deemed sufficient to warrant the major effort involved in a timing change.

The engines used to power 95-ft WPB cutters are manufactured by the Detroit Diesel Allison Division of the General Motors Corporation; the specific model designation is 16V-149TI. The displacement of each unit is 2384 cubic inches, and each engine is rated at 1235 shaft horsepower at 1800 rpm.

The engine that was available for use during this study was a Detroit Diesel Model 12V-149TI; this unit is a twelve-cylinder version of the USCG engine. During the testing program, the engine was operated at approximately the same horsepower output per cylinder that the marine version would produce. Thus, although the total output of the twelve-cylinder engine was low, the details of engine operation were quite representative of the sixteen-cylinder counterpart.

The major specifications of the engines used during the test program are outlined in Table 2-1, and data from the manufacturers is shown in Appendix A.

2.1.2 Dynamometer and Test Cell

Each engine was installed in a test cell at the SwRI laboratory and connected to an eddy-current dynamometer capable of absorbing up to 1000 horsepower. The engine installation is shown in Figures 2-1 and 2-2. The dynamometer utilized was an absorbing unit only; no motoring capability was available.

The engine speed was determined through the use of a magnetic pickup and a 60-tooth gear installed in the engine-dynamometer coupling. The speed signal was transmitted to a digital counter used as an output device, and, in addition, the signal was supplied to a dynamometer controller capable of maintaining engine speed within a tolerance of one rpm. The dynamometer beam load was measured through the use of a strain gauge type load-cell connected to an output device at the control console. The load-cell was subjected to a weekly deadweight calibration.

2.1.3 Fuel System

A fuel supply system was assembled that would meter, premix, and emulsify the fuel and water in concentrations that were of interest. Although certain

TABLE 2-1. ENGINE SPECIFICATIONS

Cummins Engine Company, Inc.
Model: VTA-1710-C800 (VT12-900M)
Type: Four Stroke Cycle
Bore and Stroke: 5.5 x 6
No. of Cylinders: 12
Displacement: 1710 Cubic Inches
Rated Horsepower: 800 at prop shaft
Rated Speed: 2300 RPM

General Motors Corporation
Detroit Diesel Allison Division
Model: 12V-149TI (16V-149TI)
Type: Two Stroke Cycle
Bore and Stroke: 5.75 x 5.75
No. of Cylinders: 12 (16)
Displacement: 1788 Cubic Inches
Rated Horsepower: 900 (1200)
Rated Speed: 1800 RPM



FIGURE 2-1. ENGINE INSTALLATION; CUMMINS ENGINE TESTS

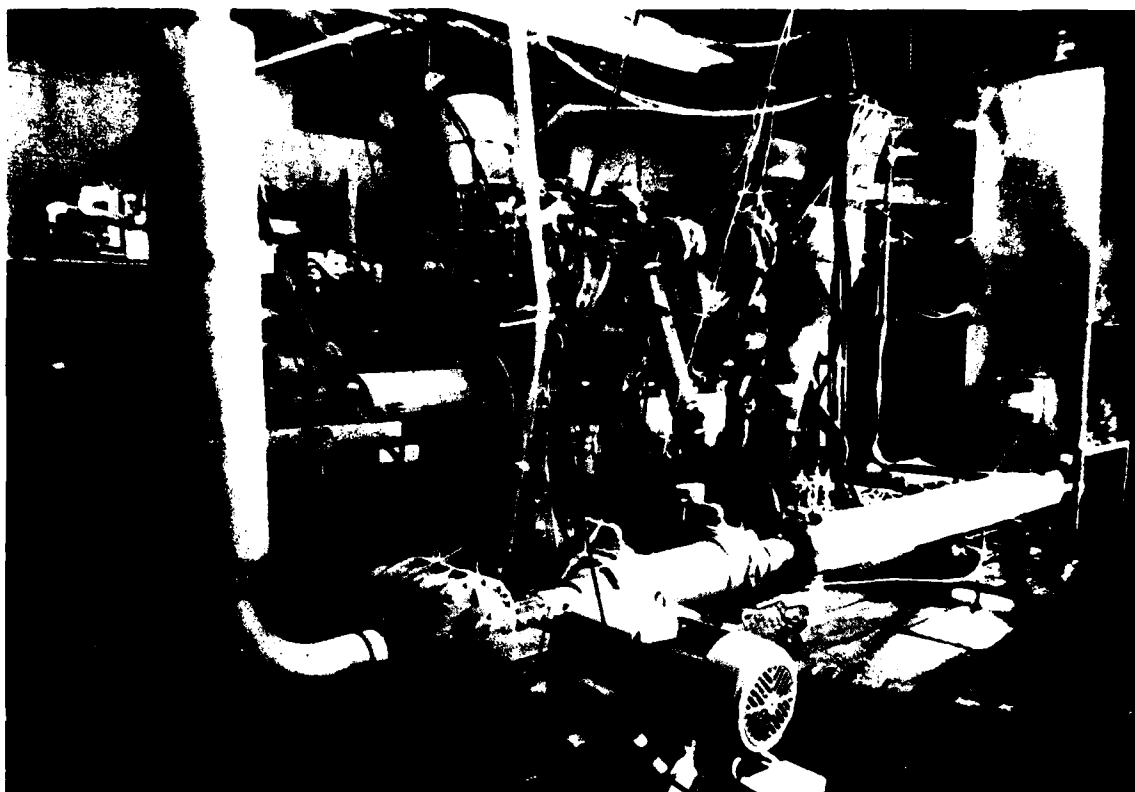


FIGURE 2-2. ENGINE INSTALLATION; DETROIT DIESEL TESTS

features of the system were designed specifically to accommodate the Cummins engine, the same system proved useful for both of the engines tested.

In ordinary operation the fuel would be supplied directly to the injection pump of the engine, and fuel not used by the engine would be returned to a storage tank. The Cummins injection system is unique in that the returned fuel typically contains quantities of gas which must be removed prior to recycling of the unburned fuel through the engine. In usual installations, this capability is provided by a vented storage tank.

For the purposes of this study, it was necessary to assemble a fuel system that would generate the fuel-water emulsion while simultaneously satisfying the requirement for degasification of the return fuel. A schematic diagram of the system used is shown in Figure 2-4, and the fuel system is visible in Figure 2-1. Fuel and water were supplied independently to a mixing tee; this device provided a crude mixture prior to emulsification. Tap water was utilized throughout, and the line pressure provided the driving force. Fuel was pumped from a storage tank into the mixing arrangement. A constant fuel level was maintained in a float-controlled tank having a volume of approximately one-half gallon. This open tank allowed gases trapped in the return fuel to escape prior to fuel recycling. Fuel was removed from the float-controlled tank by a one horsepower gear pump which supplied a pressure of approximately 100 psi to the fuel-water emulsifier. The emulsifier used in this system was a Hydroshear device supplied by Gaulin Corporation; the unit operates by subjecting the fuel-water mixture to an extremely high shear state. A drawing of a typical Hydroshear after Lawson¹¹ is shown in Figure 2-3. The pressure at the outlet of the emulsifier was typically 20 to 25 psi.

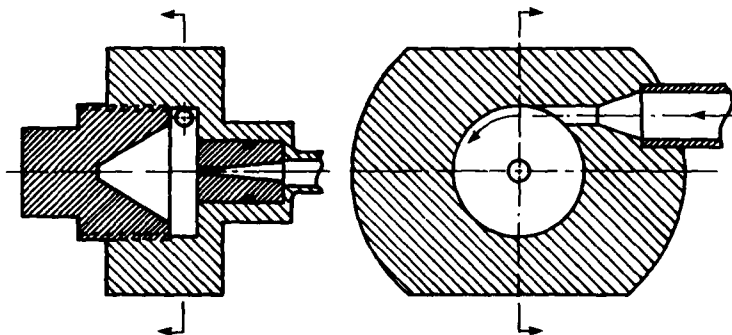


FIGURE 2-3. TYPICAL HYDROSHEAR

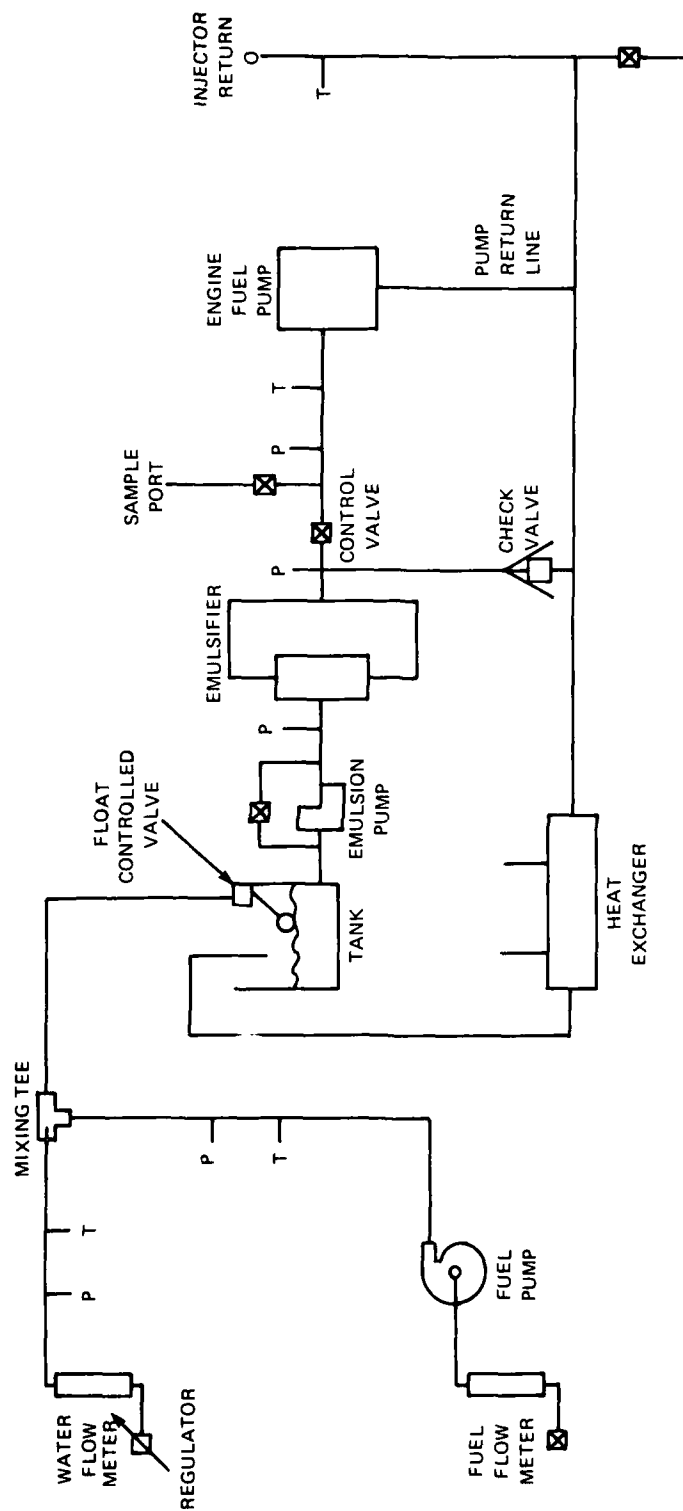


FIGURE 2-4. PROTOTYPE EMULSIFIED FUEL SYSTEM

At the emulsifier outlet, the fuel was directed either to the engine fuel pump or to a by-pass loop. Fuel directed toward the engine passed through a control valve which lowered the pressure to a value below 5 psi in order to meet the requirements of the engine fuel system. Fuel returned from either the engine fuel pump or the engine fuel injectors was routed into the by-pass portion of the system. The unused emulsion was conducted through a heat exchanger for cooling prior to return to the float-controlled tank. Pressures and temperatures were measured at points of interest throughout the fuel supply system, and a sample port was provided at the engine fuel pump for use in the verification of water concentrations.

During the tests, the fuel system was operated at a continuous flow rate approximately equal to the engine maximum demand. Thus, a substantial flow rate was always present in the by-pass loop, and the emulsifier was not subjected to varying conditions as the engine load changed. During steady-state operation, the flow rate of the fuel-water mixture to the float-controlled tank was equal to the rate at which the fuel was consumed by the engine, but the flow through the emulsifier loop was constant.

2.1.4 Instrumentation

The documentation of engine performance using emulsified fuels required the measurement of a number of quantities during engine operation. The individual parameters for which data were recorded during each test run are listed in Table 2-2.

The dry bulb and wet bulb temperatures used for calculation of humidity were measured using mercury-in-glass thermometers. Exhaust temperatures were measured with type K thermocouples, and other temperatures were measured using type J thermocouples. All of the thermocouple readings were obtained through the use of multi-point switches and readout devices appropriate to the thermocouple calibration.

Pressures were measured using Bourdon tube gauges, mercury manometers, or water manometers as appropriate for the value and range of the metered quantity. The value of barometric pressure was obtained during each test run.

TABLE 2-2. DATA OBTAINED FROM TEST CELL

Speed	Temperatures:
Load	Engine Coolant
Fuel Rate	Inlet
	Outlet
Pressures:	Oil Sump
Barometer	Fuel Inlet
Oil	Fuel Mixture
Fuel Rail	Return Fuel
Turbocharger Boost	Intake Air
Exhaust	Cylinder Exhaust
Turbine Inlet	Exhaust Manifold
Inlet Depression	Turbine Inlet
Fuel Inlet	Compressor Outlet
Air Flowmeter	Charge Air
Air Filter	Water
Emulsifier	Cell Air
Fuel Supply	Dry Bulb
Water Supply	Wet Bulb
	Return Fuel Cooler
Emissions:	
Hydrocarbons	
Carbon Monoxide	
Nitric Oxide	
Oxides of Nitrogen	
Carbon Dioxide	
Oxygen	
Smoke	
Water Flow Rate	
Water Concentration	

The flow rate of diesel fuel was continuously monitored through the use of a commercial linear mass flowmeter. However, the primary technique for determination of fuel flow was a direct mass measurement obtained using a platform balance and a stop watch. Using this technique, the time required for consumption of a known mass of fuel was recorded. The mass was adjusted in such a way that typical fuel times were on the order of two minutes, and several readings were obtained during each test run.

The water flow was monitored through the use of a variable area flowmeter installed in the water inlet line. The meter was calibrated prior to the beginning of the test program, and tables were prepared which listed the water flowmeter reading for each desired water concentration over a range of fuel rates applicable to each test point. To establish a particular water concentration in the fuel, the engine operator would read the fuel mass flowmeter, consult the table, and set the water flow rate accordingly. The water concentration was then verified by obtaining a sample of the emulsion at the engine inlet and allowing separation of the water and diesel fuel to occur.

The air flow to the engine was measured using a laminar flow element rated at 2000 cfm. The pressure drops across the flowmeter filter and across the metering element were measured using inclined water manometers, and the air flow rate was established from the meter calibration using corrections for ambient temperature and pressure.

During tests of the Detroit Diesel engine, additional air flowmetering capability was required. The 2000 cfm laminar flow element was used in the air supply to one-half of the engine (one bank of six cylinders). The air flow to the remaining engine cylinders was metered with an ASME flow nozzle installed in an inlet plenum chamber.

Instruments appropriate to diesel engine testing were used for the measurement of gaseous emissions. The concentration of unburned hydrocarbons in the exhaust stream was monitored using a heated flame ionization detector. Non-dispersive infrared analyzers were used for measurement of carbon monoxide and carbon dioxide, and a chemiluminescent analyzer was used to establish levels of nitric oxide and oxides of nitrogen. The oxygen level in the exhaust was monitored using a polarographic analyzer. Schematic diagrams of the components of the emissions instrumentation system are shown in Figures 2-5, 2-6, and 2-7, and descriptions of the individual hardware items are provided in Tables 2-3, 2-4, 2-5, and 2-6. Photographs of the instrument console are provided as Figures 2-8 and 2-9.

The exhaust smoke was measured through the use of a USPHS type opacity meter incorporated in the exhaust system at the boundary of the test cell.

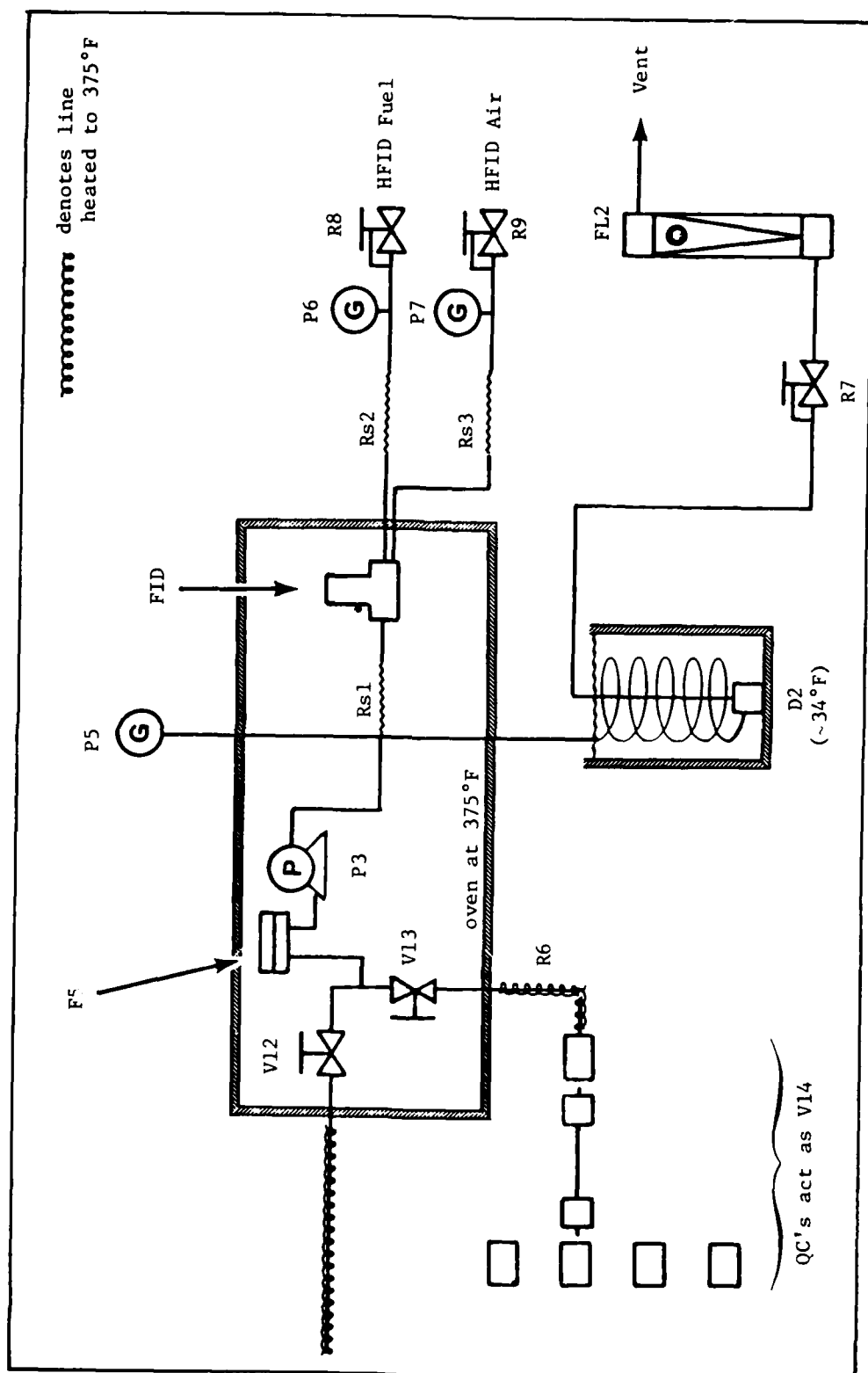


FIGURE 2-5. HYDROCARBON ANALYZER

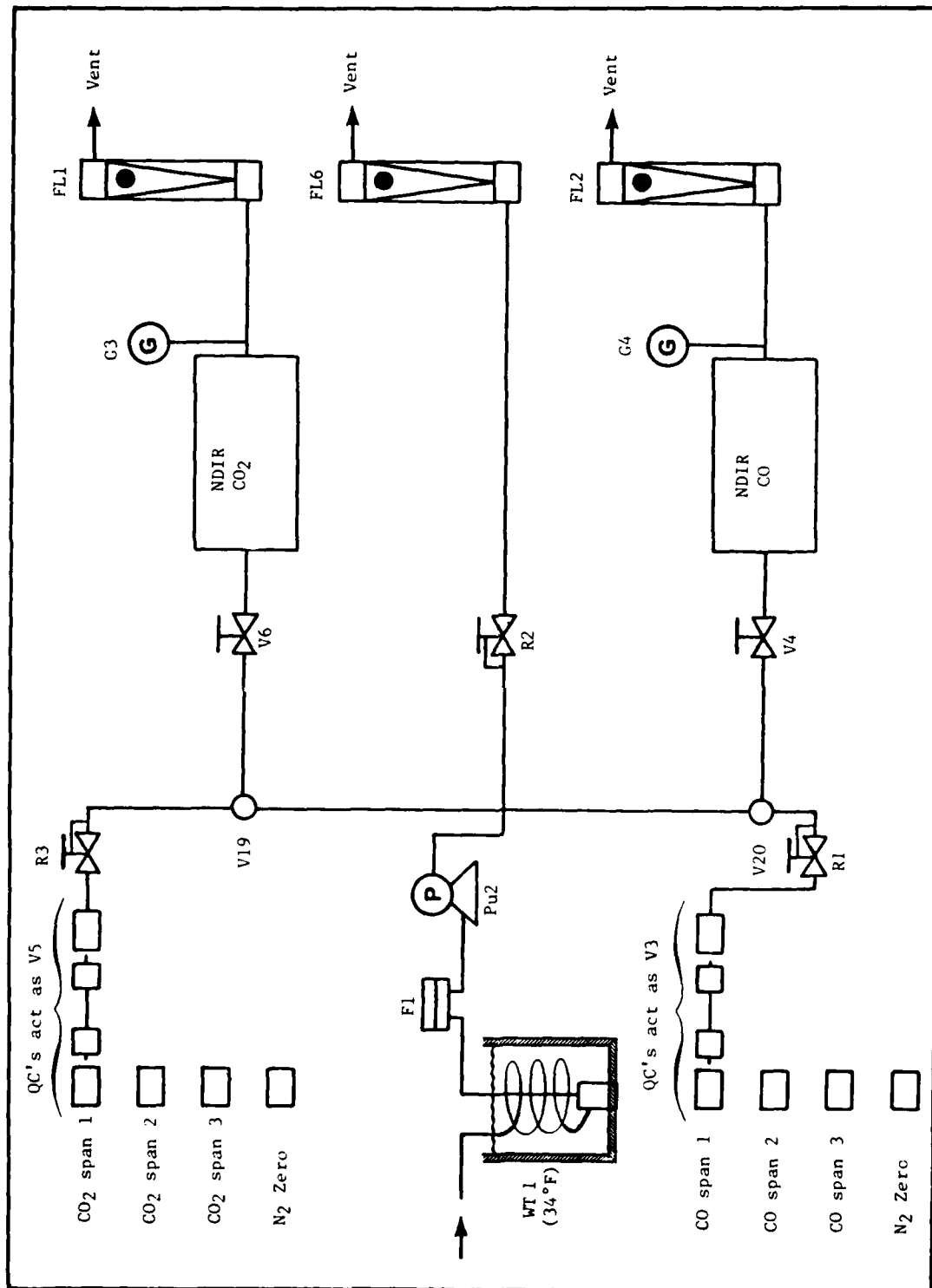


FIGURE 2-6. ANALYZER SYSTEM FOR CARBON MONOXIDE AND CARBON DIOXIDE

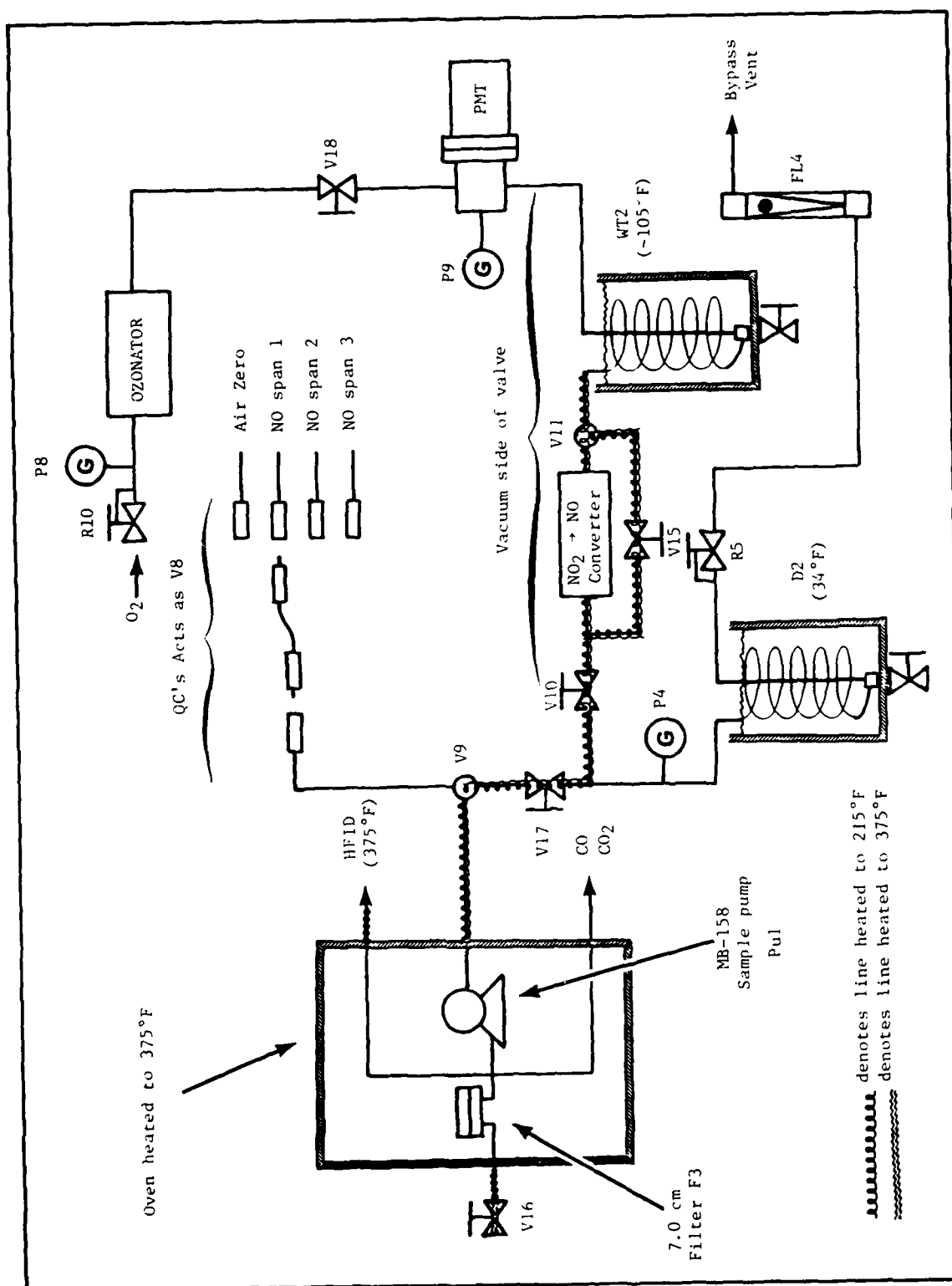


TABLE 2-3. INSTRUMENTS AND RANGES ON L-4 EMISSIONS CART

<u>Emission</u>	<u>Detection Method</u>	<u>Instrument</u>	<u>Range</u>	<u>Nominal Concentration</u>
Carbon Monoxide (S/N AIA-23)	NDIR	Horiba OPE-15	1	0 - 1000 ppm CO
			2	0 - 3000 ppm CO
			3	0 - 6000 ppm CO
Carbon Dioxide (S/N 15395)	NDIR	Horiba OPE-15	1	0 - 16% CO ₂
			2	0 - 6% CO ₂
			3	0 - 2% CO ₂
Oxides of Nitrogen (S/N LOAR-9691-110)	CL	TECO 10	1	0 - 250 ppm
			2	0 - 1000 ppm
			3	0 - 2500 ppm
Hydrocarbons (S/N 10010)	FID	Beckman 402	1	0 - 500 ppm C
			2	0 - 1000 ppm C
			3	0 - 5000 ppm C
Oxygen (S/N 271-001)	Polarographic	Beckman OM-11EA	1	0 - 25% O ₂
			2	0 - 5% O ₂

TABLE 2-4. SwRI HEATED HYDROCARBON ANALYZER FLOW SCHEMATIC
COMPONENT DESCRIPTION

<u>Component</u>	<u>Description</u>	<u>Description of Function</u>
Valve	V14	QC's act as span/zero selector valve
Valve	V13	Span/zero gas flow control valve
Valve	V12	Sample flow control valve
Gage	P5	Sample pressure
Gage	P6	HFID fuel pressure
Gage	P7	HFID air pressure
Restrictor	Rs1	Sample capillary (Beckman)
Restrictor	Rs2	HFID fuel restrictor (Beckman)
Restrictor	Rs3	HFID air restrictor (Beckman)
Detector	HFID	Beckman 402 HFID detector
Water trap	D2	Bypass flow water trap (~34°F)
Flowmeter	FL3	Bypass flowmeter (~5 CFH)
Filter	F5	7.0 cm stainless steel flip top filter
Pump	Pu3	Metal bellows MB-158 pump
Regulator	R7	Sample backpressure regulator
Regulator	R8	HFID fuel regulator
Regulator	R9	HFID air regulator

TABLE 2-5. NDIR CO AND CO₂ FLOW SCHEMATIC
COMPONENT DESCRIPTION

<u>Component</u>	<u>Description</u>	<u>Description of Function</u>
Valve	V3	QC's act as CO selector valve V3
Valve	V4	CO flow control valve
Valve	V5	QC's act as CO ₂ selector valve V5
Valve	V6	CO ₂ flow control valve
Valve	V19	CO ₂ sample/calibrate selector valve
Valve	V20	CO sample/calibrate selector valve
Gage	G3	CO ₂ instrument pressure
Gage	G4	CO instrument pressure
Gage	P2	CO sample/span pressure
Gage	P3	CO ₂ sample/span pressure
Regulator	R1	CO span/zero pressure regulator
Regulator	R2	Bypass backpressure regulator
Regulator	R3	CO ₂ span/zero pressure regulator
Flowmeter	FL1	CO ₂ instrument flow
Flowmeter	FL2	CO/CO ₂ bypass flow
Flowmeter	FL6	CO instrument flow
Water trap	WT1	Water trap (34°F) for CO/CO ₂ instrument
Filter	F1	7.0 cm stainless steel flip top filter holder
Pump	Pu2	Sample pump

TABLE 2-6. HEATED CHEMILUMINESCENT NO_x ANALYZER FLOW
SCHEMATIC COMPONENT DESCRIPTION

<u>Component</u>	<u>Description</u>	<u>Description of Oven</u>
Valve	V8	QC's act as selector valve V8
Valve	V9	Sample/calibrate selector valve
Valve	V10	Sample flow control valve
Valve	V11	NO/NO _x selector valve
Valve	V15	NO flow control valve
Valve	V16	System leak check valve
Valve	V17	NO/NO _x total flow controller
Valve	V18	Ozone flow control valve
Gage	P4	Sample backpressure
Gage	P8	Oxygen pressure gage
Gage	P9	Reaction chamber vacuum
Flowmeter	FL4	Sample bypass flowmeter
Regulator	R5	Sample backpressure regulator
Regulator	R10	Oxygen pressure regulator
Dryer	D2	Bypass flow water trap (~34°F)
Water Trap	WT2	NO _x /NO water trap (IPA•CO ₂ @ -105°F)
Filter	F3	7.0 stainless steel flip top filter holder
Pump	Pu1	Sample pump

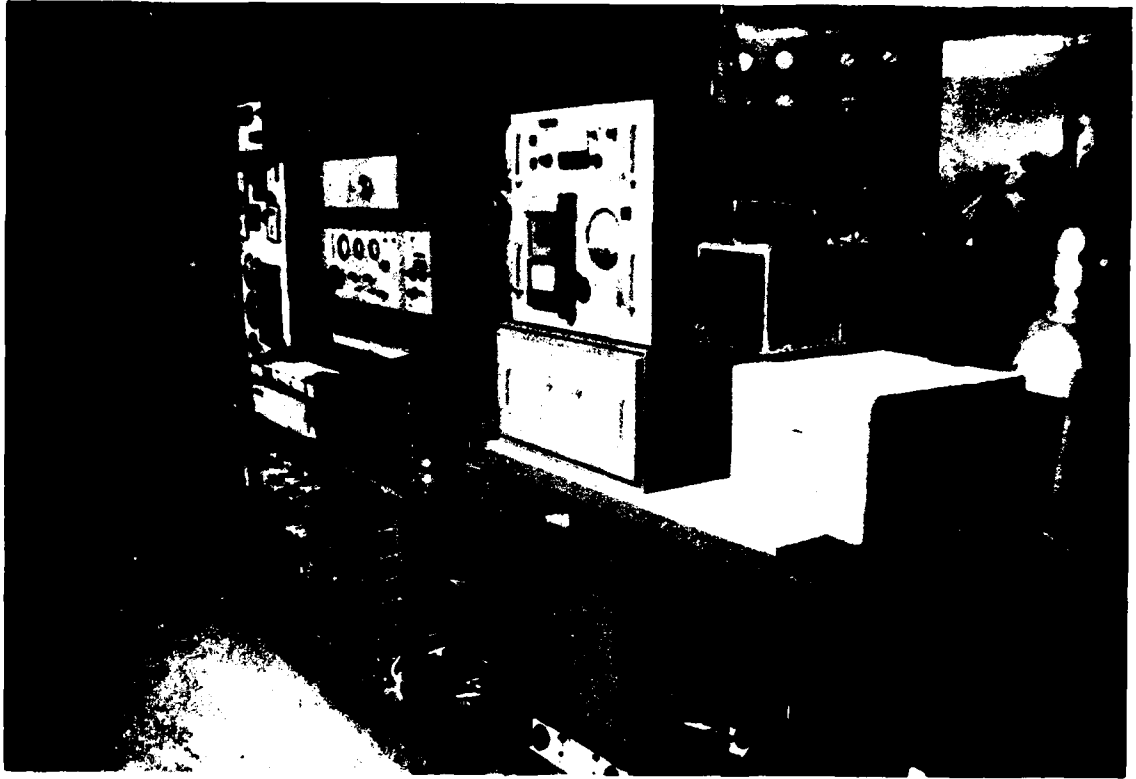


FIGURE 2-8. EMISSION INSTRUMENT CONSOLE, FRONT VIEW

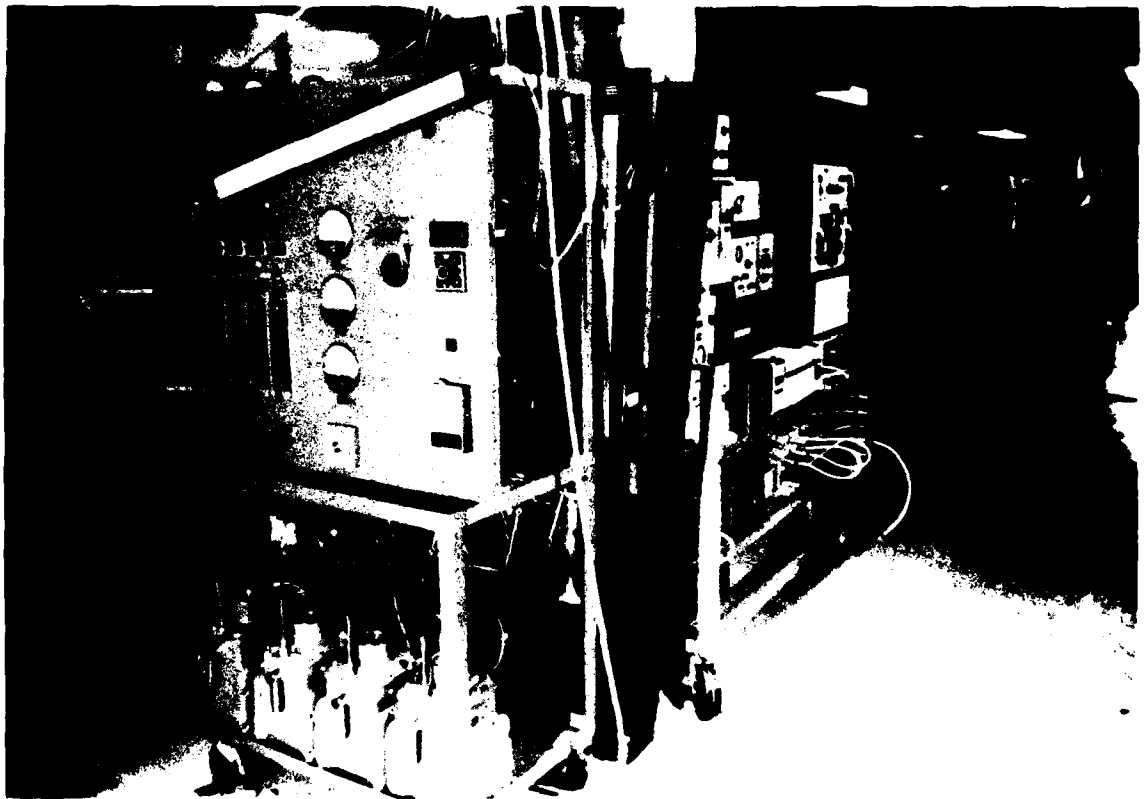


FIGURE 2-9. EMISSION INSTRUMENT CONSOLE, END VIEW

Measurements of exhaust particulate emissions were obtained during some of the tests of the Detroit Diesel engine. The primary tool utilized for this series of measurements was a dilution tunnel of the type shown in Figures 2-2 and 2-10; the dilution of the sample stream is utilized for cooling and mixing prior to the accumulation of a particulate sample. In order to obtain a sample of the exhaust, probes were located in each of the engine exhaust ducts at a point downstream from the turbocharger outlets. A regulating valve was located in each sample line, and the pressure drop across the valve was used as a means of equating the sample line flow rates. Thus, a single sample representative of both engine exhaust ducts was obtained and supplied to the particulate tunnel. The tunnel had a nominal diameter of eight inches, and air flow rates sufficient for a dilution ratio of 10 to 20 were utilized. Within the tunnel, the exhaust sample was mixed with the dilution air and cooled to 125°F. A metered sample of the diluted stream was obtained and applied to a 47 millimeter Pallflex T60A20 filter that was weighed prior to the beginning of the test. Subsequent weighing, along with the measured flow of the air stream, allowed the calculation of the particulate weight per standard cubic foot of engine exhaust. In general, only one sample filter was used during this test series; the multiple filters shown in Figure 2-10 would be utilized when more elaborate analyses of the particulate matter were required.

2.2 TEST PROCEDURE

The general philosophy that governed the performance of the alternate fuel tests was closely related to the ultimate use of fuel-water emulsions on USCG cutters; thus, it was desired to obtain data that would be representative of boat operation. A sample of engine speeds and loads was obtained for one USCG cutter powered by Cummins engines, and the prop load curve for the engine was calculated. This curve is shown, along with the engine maximum output, in Figure 2-11. The specific test points for consideration during the evaluation program were selected from locations along the prop load curve.

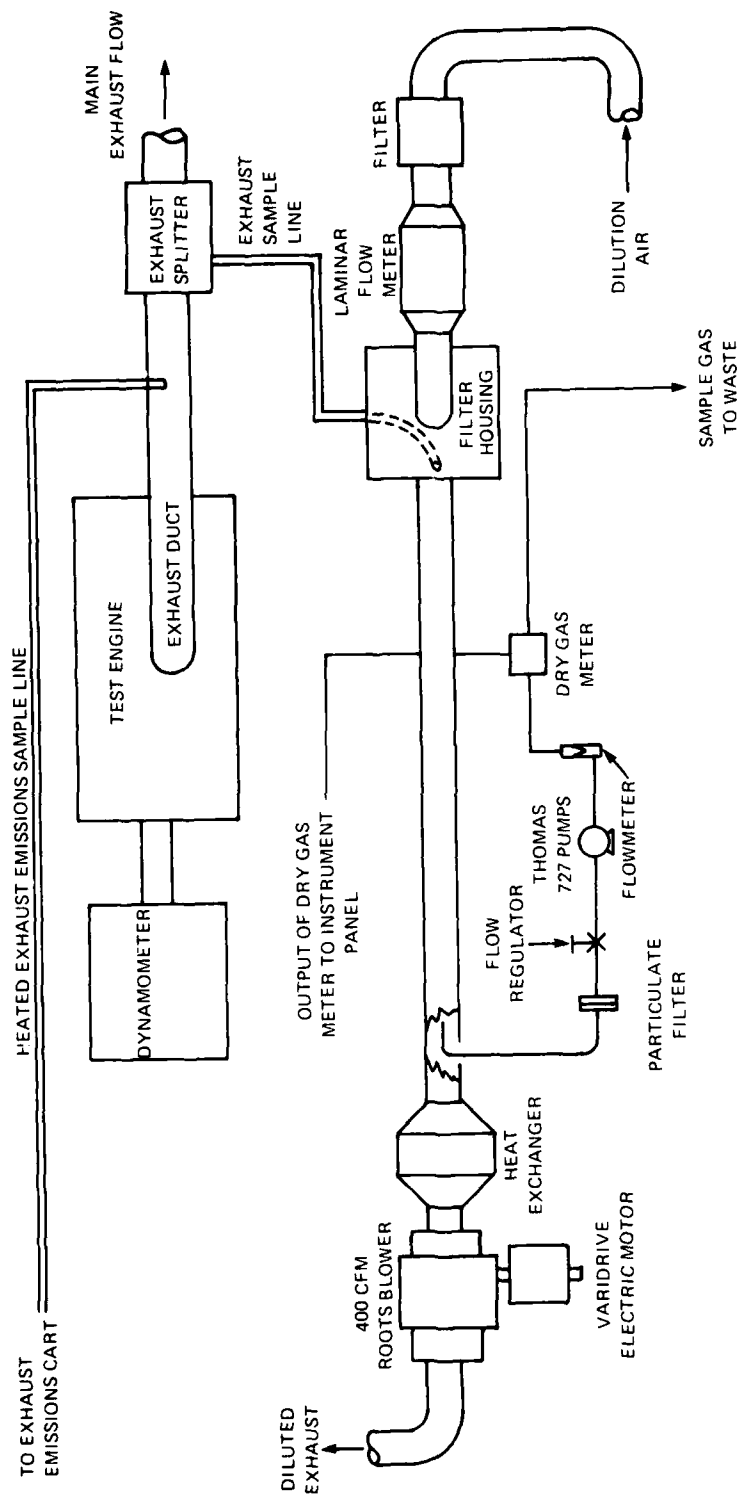


FIGURE 2-10. PARTICULATE MEASURING SYSTEM

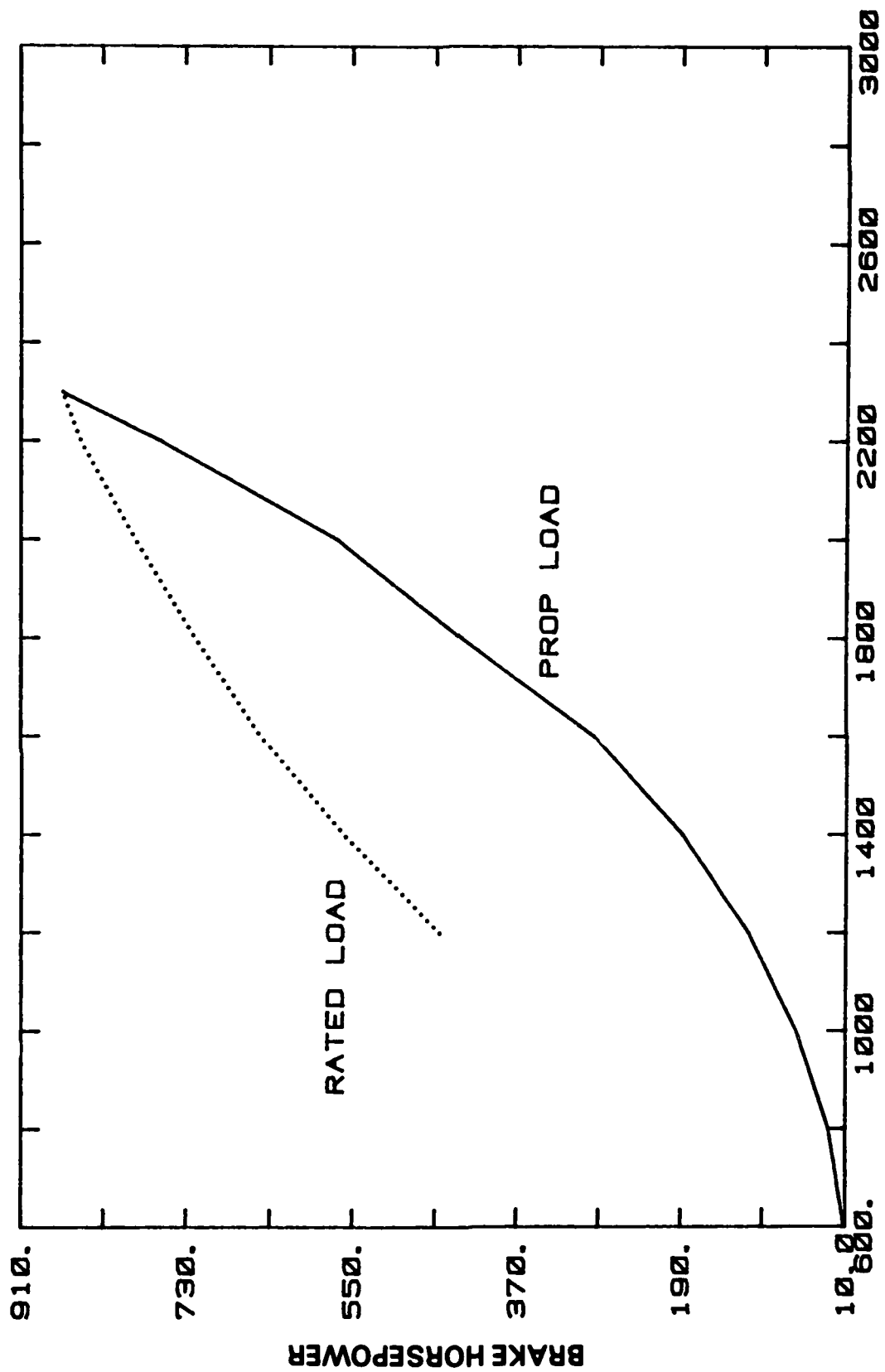


FIGURE 2-11. ENGINE SPEED AND POWER OUTPUT, MAXIMUM HORSEPOWER
AND PROP LOAD, CUMMINS ENGINE

In order to establish appropriate test points for comprehensive evaluation, records representative of over 4900 hours of operation of 14 cutters powered by Cummins engines were evaluated. Figure 2-12 shows engine speed plotted against the percentage of the total operating time that was spent at each speed. It is apparent from this representation that engine speeds of 1200 and 1800 rpm are particularly important during boat operation; a fuel system designed for conservation of diesel fuel should exhibit a significant effect at these speeds in order to be effective from an overall viewpoint. The most comprehensive testing, therefore, was performed at speeds of 1200 and 1800 rpm and the prop load associated with each speed. In addition, some test data were obtained at 900 rpm and prop load.

For the tests involving the Detroit Diesel engine, the propeller load curve supplied by the manufacturer for the 16V-149TI engine was used. The loads were multiplied by 0.75 in order to account for the difference in the number of cylinders between the test engine and the marine engine; the result is shown in Figure 2-13. Tests were performed at 200 rpm increments along the prop load curve, but the comprehensive evaluation of specific points was not conducted. No data was available to evaluate the 95-ft. WPB duty-cycle with Detroit Diesel engines.

The procedure used during each test run began with a check of the instruments associated with data acquisition. In each case calibrations were performed as required. The engine was started and allowed to warm up, and then the speed and load selected for that day of testing were established by adjusting the diesel fuel-flow rate and the dynamometer controller. The initial engine operation was performed with clear No. 2 diesel fuel having specifications as shown in Appendix A, and baseline data were recorded prior to the introduction of water into the fuel system.

Upon completion of the baseline data acquisition, a water flow appropriate to a five percent concentration was initiated. The dynamometer load was adjusted to the prop load test point by adjusting the output of the engine fuel pump, and a sample of the emulsion was obtained for verification of water concentration. Data were recorded at the five percent concentration;

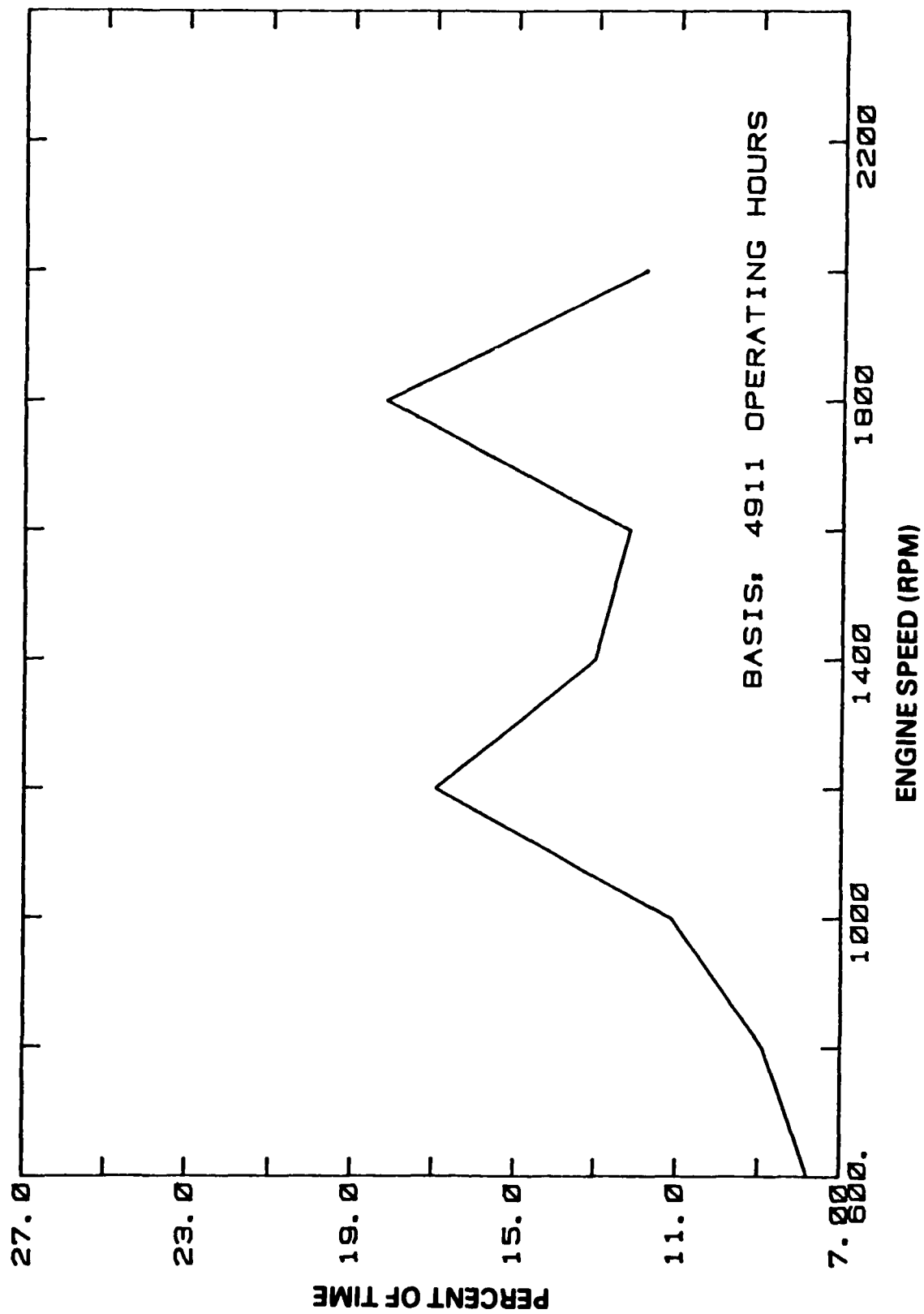


FIGURE 2-12. OPERATING TIME AS FUNCTION OF ENGINE SPEED FOR CUMMINS ENGINE-POWERED CUTTERS

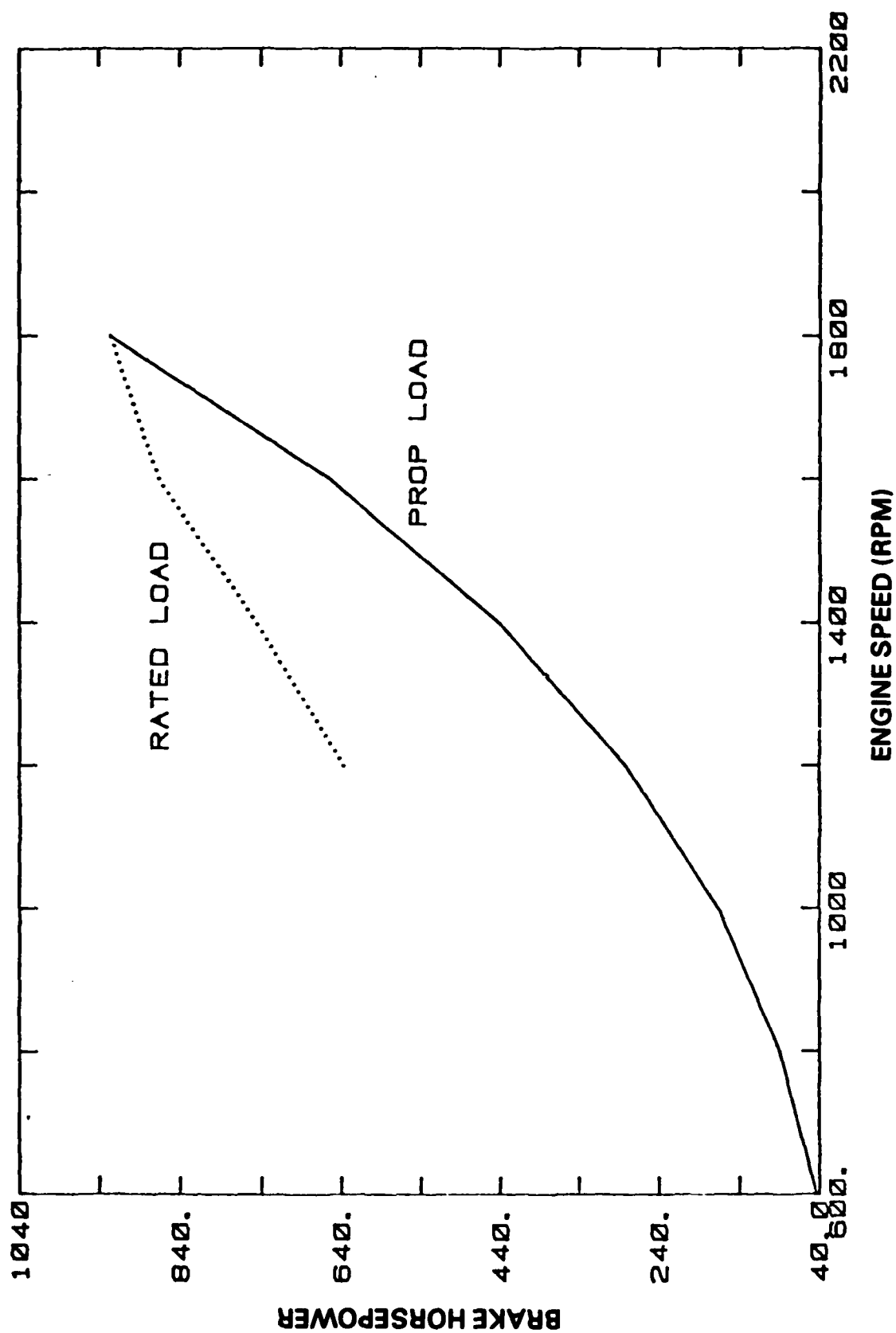


FIGURE 2-13. ENGINE SPEED AND POWER OUTPUT, MAXIMUM HORSEPOWER AND PROP LOAD, DETROIT DIESEL TWELVE-CYLINDER ENGINE

this process involved repeated measurements of the fuel rate. This sequence was then repeated at water concentrations of 10, 15, 20, and 25 percent by volume. Upon completion of the test run at the highest water concentration, the fuel system was flushed with clear diesel fuel, and the baseline test run was repeated. Subsequent days of testing involved repetition of this entire process at other speed and load conditions.

All data were recorded on a permanent record sheet, and individual values were subsequently introduced into a computer data reduction program.

2.3 DATA REDUCTION AND CALCULATIONS

A computer routine was utilized for the calculation of performance quantities and for the comparison of data obtained under the same operating conditions. A set of sample calculations is included in Appendix B. The sample calculations reflect the computations made by the computer program for each test run.

The basic performance quantities, such as horsepower, torque, and specific fuel consumption, were calculated using conventional relationships and constants appropriate to the specific instruments employed. These basic parameters are listed, along with measured quantities, in the tabulations of the results shown in Appendix C.

At the test points described by 1200 rpm and 1800 rpm for the Cummins engine, the test sequence over the spectrum of water concentrations was repeated several times in order to build a statistical basis for the data. Thus, a single point, such as 1200 rpm and 15 percent water, was evaluated on several test days, and three to five individual runs were performed at that point. Since each individual test run included several fuel rate measurements, the flow rate of diesel fuel specified for each run in Appendix C represents an average of several measurements. These averages for each run were then included in an overall average applicable to each test point defined by speed, load, and water concentration.

The raw data from the emission measurement procedures was interpreted through calibration curves developed for each instrument in terms of the concentration of the contaminant species in the exhaust stream. The values for each test run are reported in terms of parts per million or percent in Appendix C. During each test run for which emissions were measured, the data on exhaust emissions allowed the calculation of a carbon balance fuel-air ratio. This value was compared to the fuel-air ratio obtained by direct measurement of fuel flow rate and air flow rate. The results of the comparison for the Cummins engine are shown in Figure 2-14, which describes the error between the two values using the measured value as a standard. It should be noted that the Federal procedure for certification of diesel engines allows a tolerance of 10 percent in the comparison between calculated and measured fuel-air ratios.

During both the Cummins and GM engine tests, comprehensive data were obtained at selected test points. The average diesel fuel flow rate at each test point defined by speed, load, and water concentration was obtained from the collection of fuel rates for the individual test runs. Then, the standard deviation at each test point was calculated. As a further step, a 90 percent confidence band was calculated for each test point using the Student's t-distribution. This step allowed an indication of the significance that could be attached to the test results. The percentage change in diesel fuel flow rate was then calculated for each test point using the zero water concentration data as the baseline for each test point.

A further statistical test based upon the Student's t-distribution was applied to the fuel consumption data. For those test points where the presence of water indicated a significant change in diesel fuel consumption, a test was applied which measured the confidence with which it could be stated that the mean of the fuel consumption measurements was, in fact, different from the mean of the fuel flow measurements at zero water concentration. The results of this test allow the attachment of a numerical confidence to the statement that the presence of water in the fuel actually causes a change in the flow rate of diesel fuel.

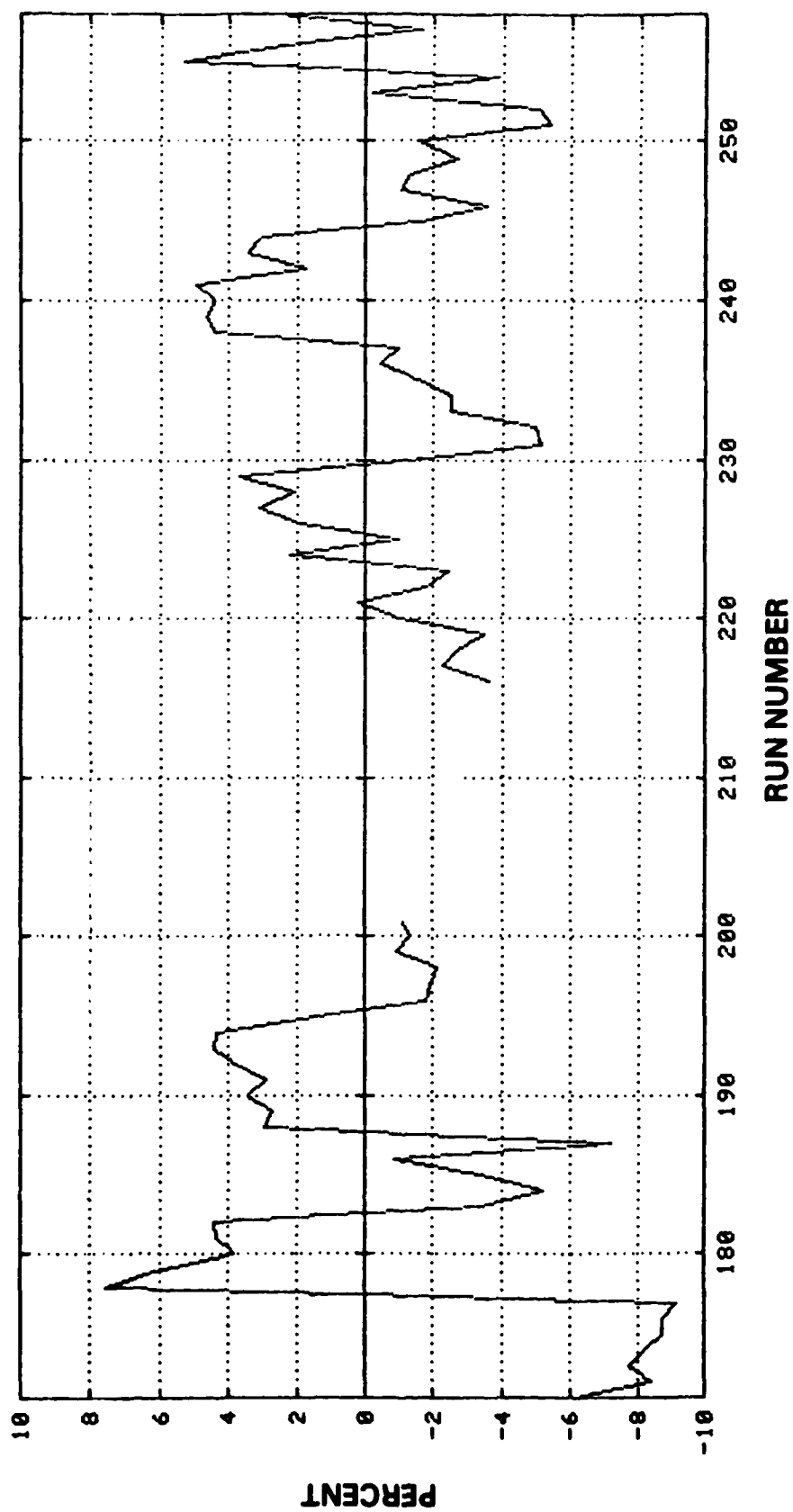


FIGURE 2-14. COMPARISON OF CARBON BALANCE AND MEASURED FUEL-AIR RATIO, CUMMINS ENGINE TESTS

3. RESULTS

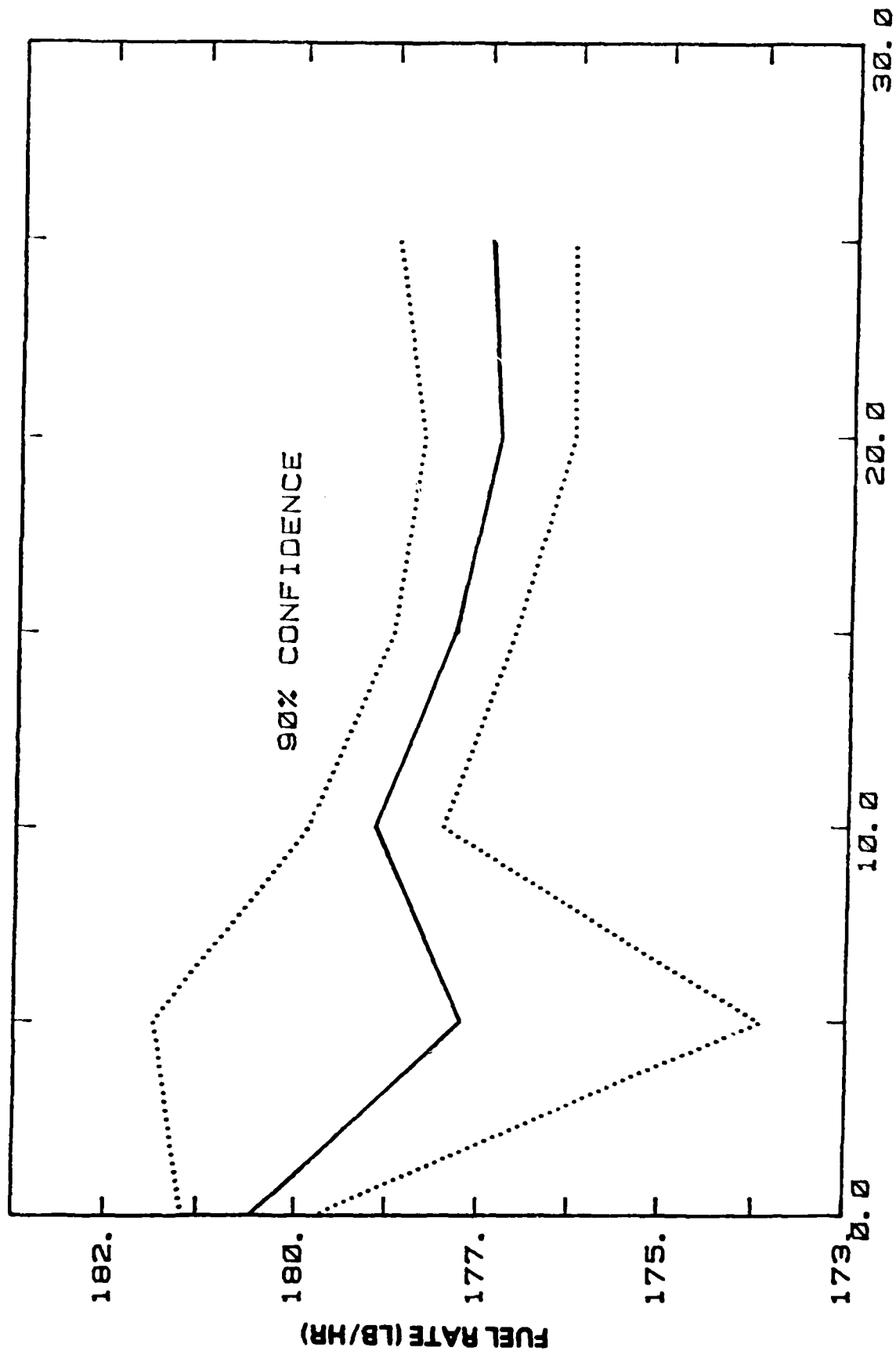
The results of the testing program are phrased in terms of fuel consumption, smoke, gaseous emissions, and engine operating parameters. Each of these qualities are discussed in detail in the following sections.

3.1 FUEL CONSUMPTION

The primary thrust of the entire program was an assessment of the effect of water in the fuel on the quantity of diesel fuel consumed by the engine at a particular speed and load. The fuel consumption results, therefore, are of particular interest in the context of the overall program goals.

The fuel consumption measurements at the 1800 rpm prop load test point for the Cummins engine are shown in Figure 3-1. The solid curve is drawn through the mean values of all test runs at each water concentration, and the 90 percent confidence band is shown by broken lines. The curve indicates that the maximum effect of the presence of water was obtained at a concentration of 20 percent by volume, where the 20 percent figure represents the comparison between water volume and the total volume of liquid entering the engine. With 20 percent water present in the fuel, the diesel fuel flow rate was reduced by 1.7 percent by comparison with the flow rate of clear diesel fuel without water addition. The statistical analysis allows the statement that a 95 percent confidence exists that the means of the test runs at zero percent water and 20 percent water are actually different. Or, in other words, there is a 95 percent confidence that the sample populations at zero percent water and 20 percent water are different, and the observed change did in fact occur.

Results for the test runs at 1200 rpm and prop load are shown in Figure 3-2. The presentation format is identical to that used for the 1800 rpm tests. In this case, the minimum diesel fuel consumption occurred at a water concentration of 15 percent, and the reduction in diesel fuel flow by comparison to test runs during which no water was added was 3.3 percent. Again, a 95 percent confidence exists that the mean values of the samples



WATER CONCENTRATION (PERCENT BY VOLUME)

FIGURE 3-1. FUEL CONSUMPTION, CUMMINS ENGINE, 1800 RPM

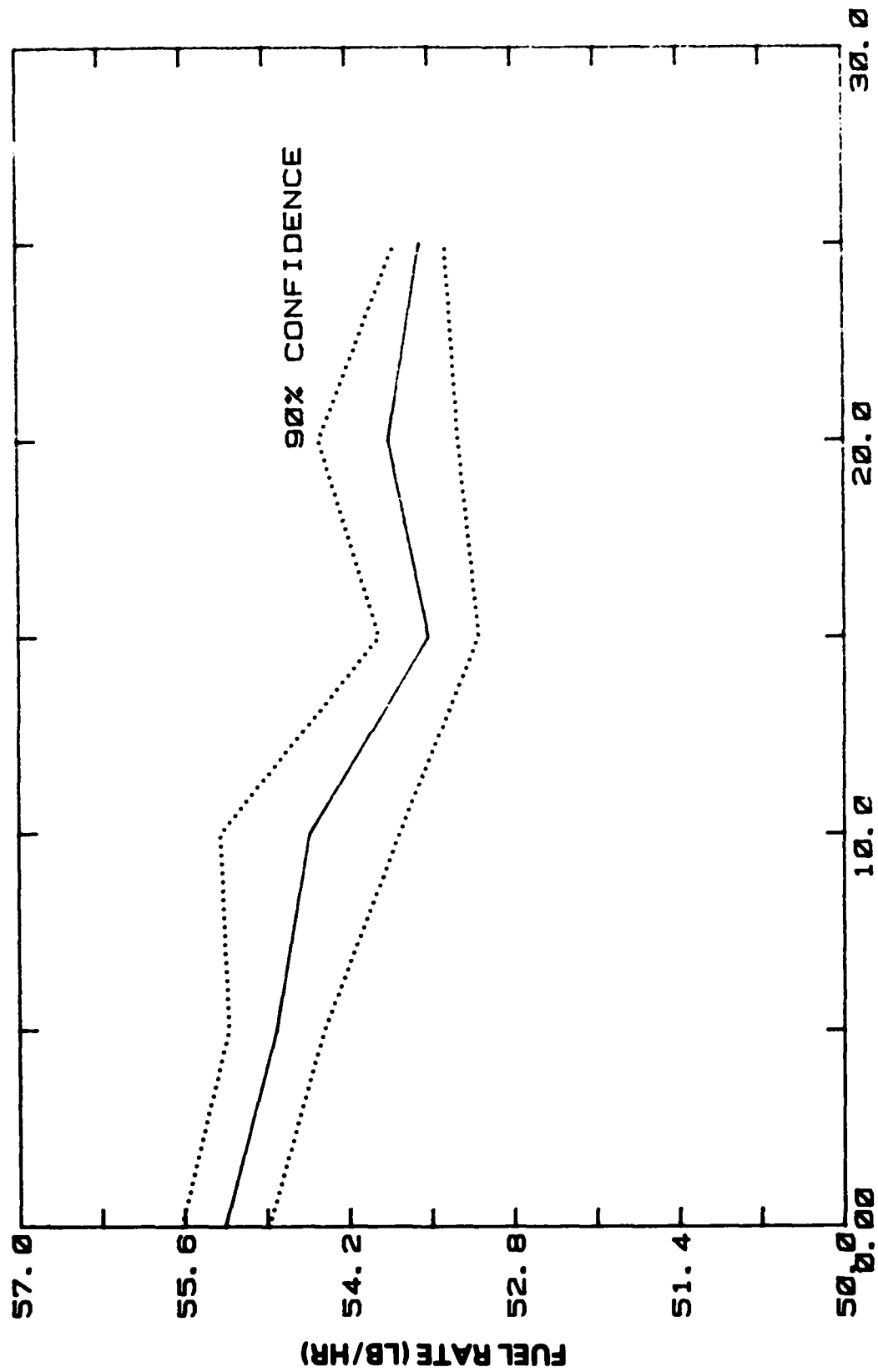


FIGURE 3-2. FUEL CONSUMPTION, CUMMINS ENGINE, 1200 RPM

obtained without water addition and with 15 percent water addition in fact represent different populations.

Some data were obtained for evaluation of the effect of water addition on fuel consumption at a speed of 900 rpm and prop load. The results are shown in Figure 3-3, using the same format as that described above. During these tests the reduction in diesel fuel flow was found to be 2.5 percent.

For the Detroit Diesel engine, fuel consumption results were obtained at several points along the prop load curve. At the 1000 rpm test point, the body of data was sufficiently extensive to allow statistical analysis; the results are shown in Figure 3-4. For this case, the general tendency was for the water to increase fuel consumption. The same trend was observed for the tests conducted at other speeds; the results are shown in Figure 3-5. No significant improvement in the rate of diesel fuel consumption could be inferred from these tests.

The configuration of the Detroit Diesel engine did allow an assessment of the effect of injection timing on the performance of water-in-fuel emulsions. Since the timing change can be effected through an injector adjustment, rather than a camshaft change, it was possible to obtain data at several values of the injection timing. Figure 3-6 describes the relationship between the fuel injector adjustment dimension and injection timing; the standard value for the engine was 2.205 inches. Tests were performed for values of the beginning of injection from about 25° BTDC to about 15° BTDC; the specific dimensions and timing angles are shown in Table 3-1. Most of the tests were performed at 1000 rpm, and examination of Figure 3-7 indicates that the timing change did not affect the relationship between fuel consumption and water addition. One series of tests was performed at 1400 rpm (Figure 3-8); the results again indicate that the timing change did not improve the ability of the engine to benefit from the addition of water to the fuel. In both Figure 3-7 and Figure 3-8, the curves designated as baseline are reproduced from Figures 3-4 and 3-5.

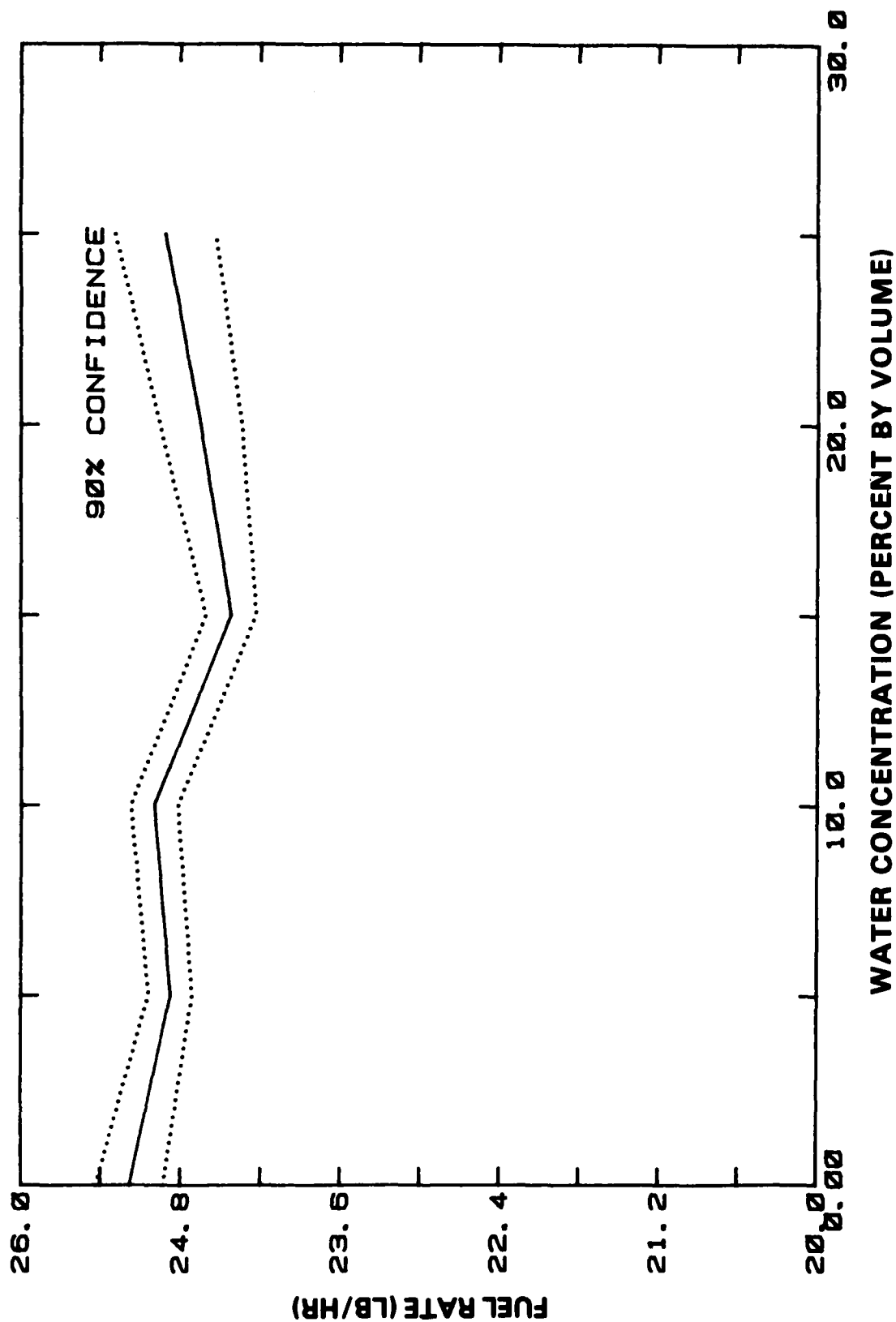


FIGURE 3-3. FUEL CONSUMPTION, CUMMINS ENGINE, 900 RPM

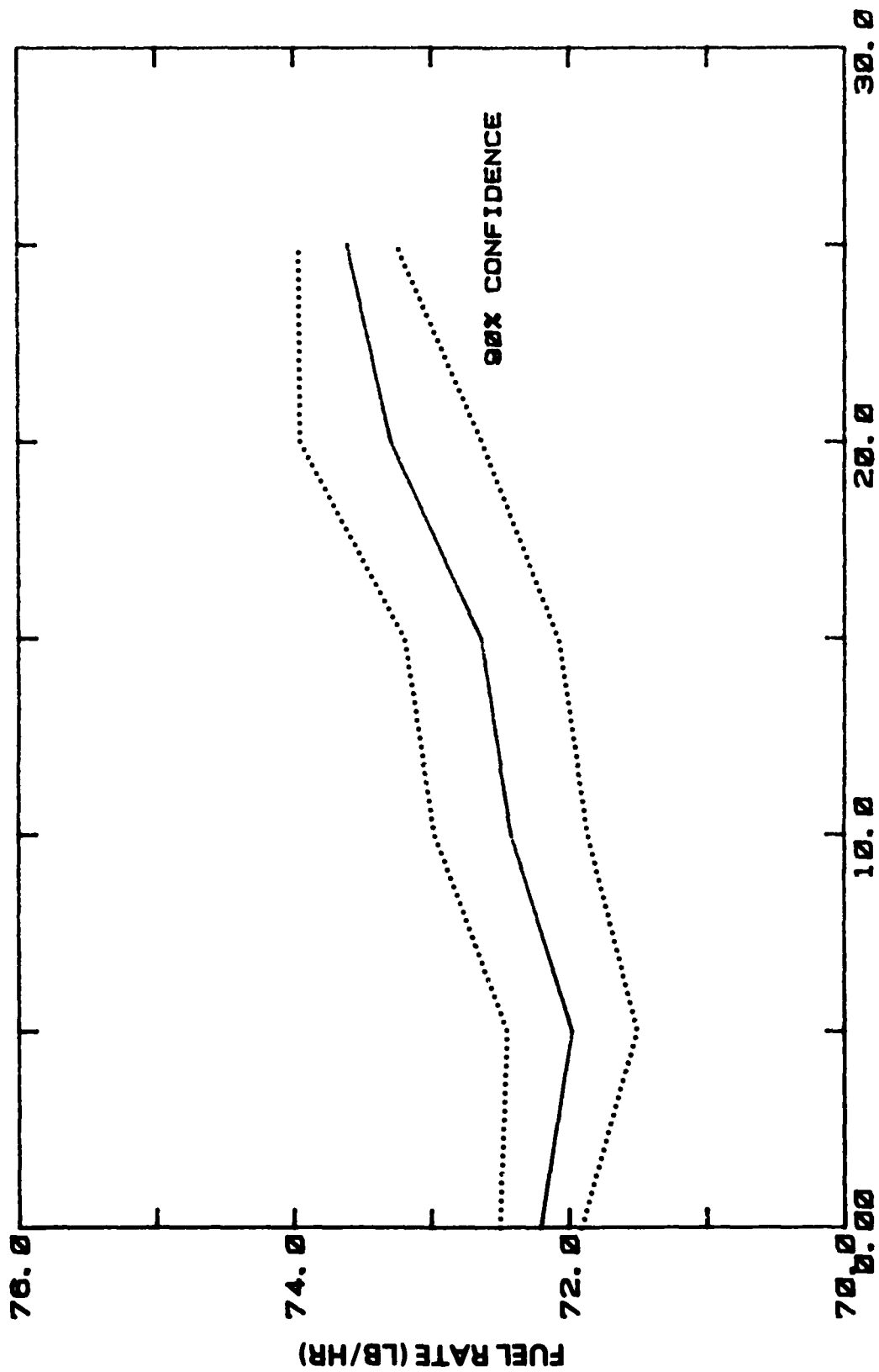
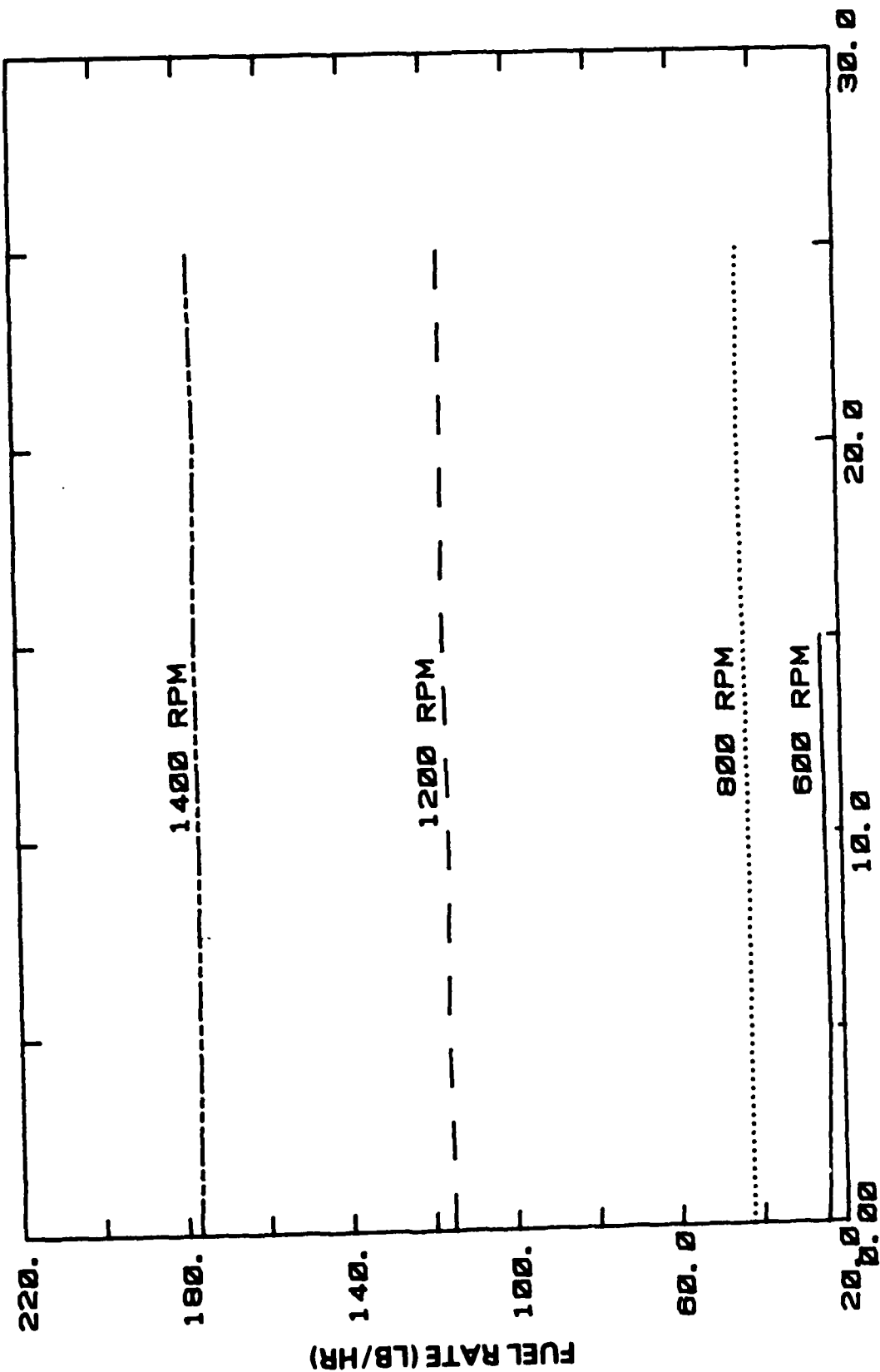


FIGURE 3-4. FUEL CONSUMPTION, DETROIT DIESEL ENGINE, 1000 RPM

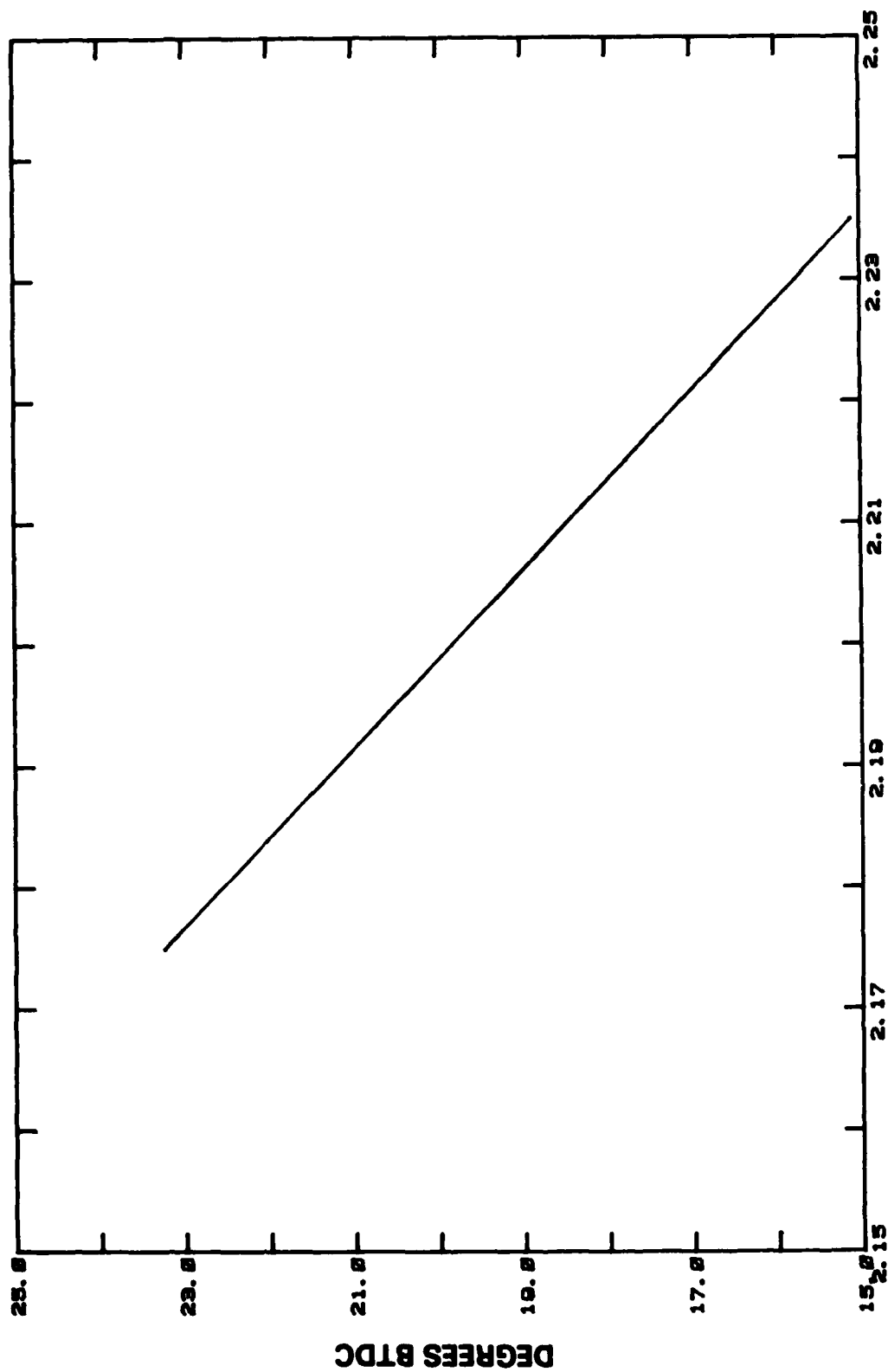


WATER CONCENTRATION (PERCENT BY VOLUME)

FIGURE 3-5. FUEL CONSUMPTION, DETROIT DIESEL ENGINE, FOUR SPEEDS

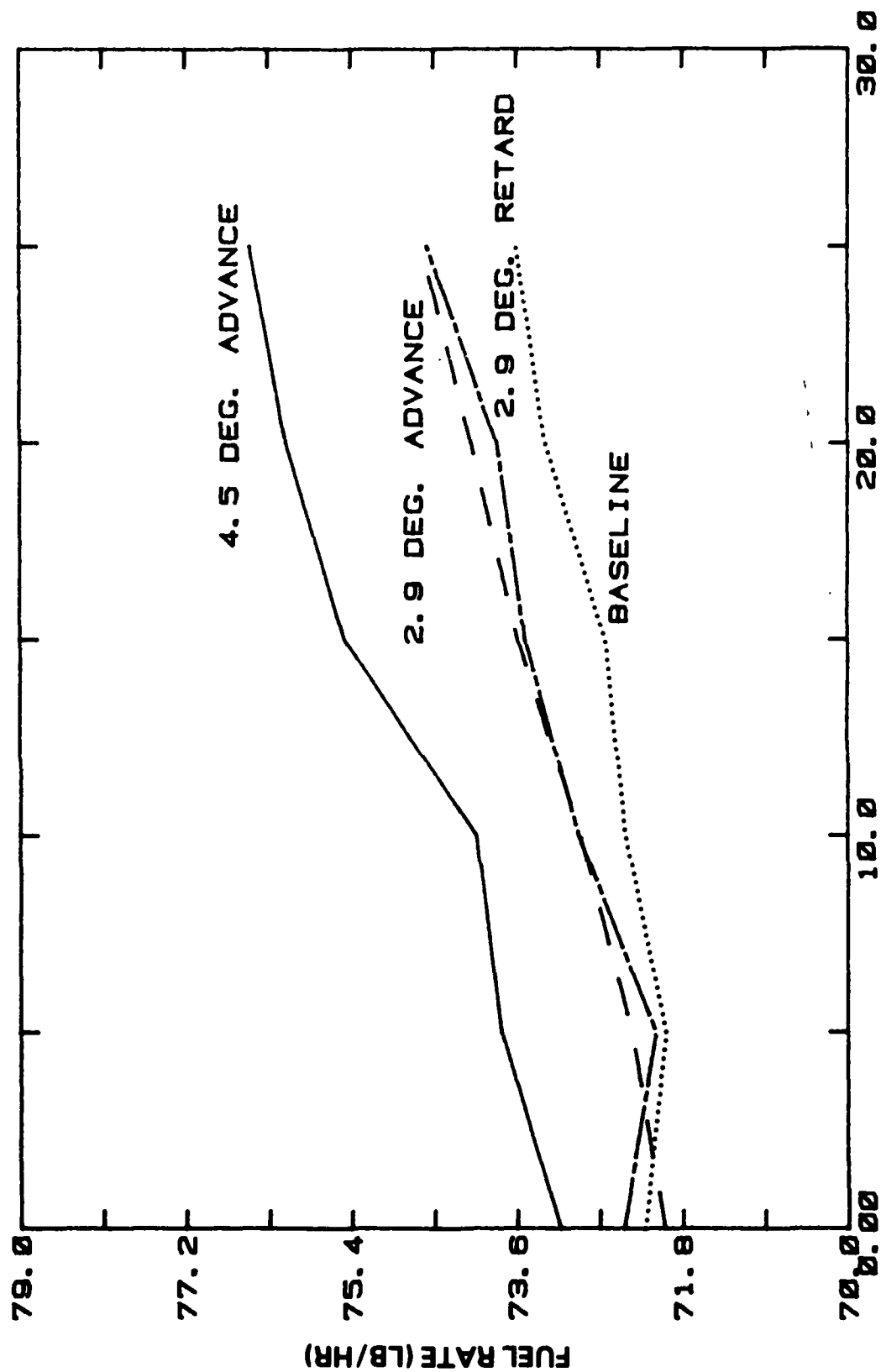
TABLE 3-1. DETROIT DIESEL 12V-149TI ENGINE
FUEL INJECTION TIMING

Injector Adjustment Dimension (inches)	Timing of Injection Event (degrees)
2.165	5.5 advance
2.185	2.8 advance
2.205	0
2.223	2.4 retard
2.235	4.1 retard



ADJUSTMENT DIMENSION

FIGURE 3-6. FUEL INJECTION TIMING AS FUNCTION OF ADJUSTMENT DIMENSION, DETROIT DIESEL ENGINE, 12V-149TI (180 INJECTORS)



WATER CONCENTRATION (PERCENT BY VOLUME)

FIGURE 3-7. EFFECT OF INJECTION TIMING ON FUEL CONSUMPTION,
DETROIT DIESEL ENGINE, 1000 RPM

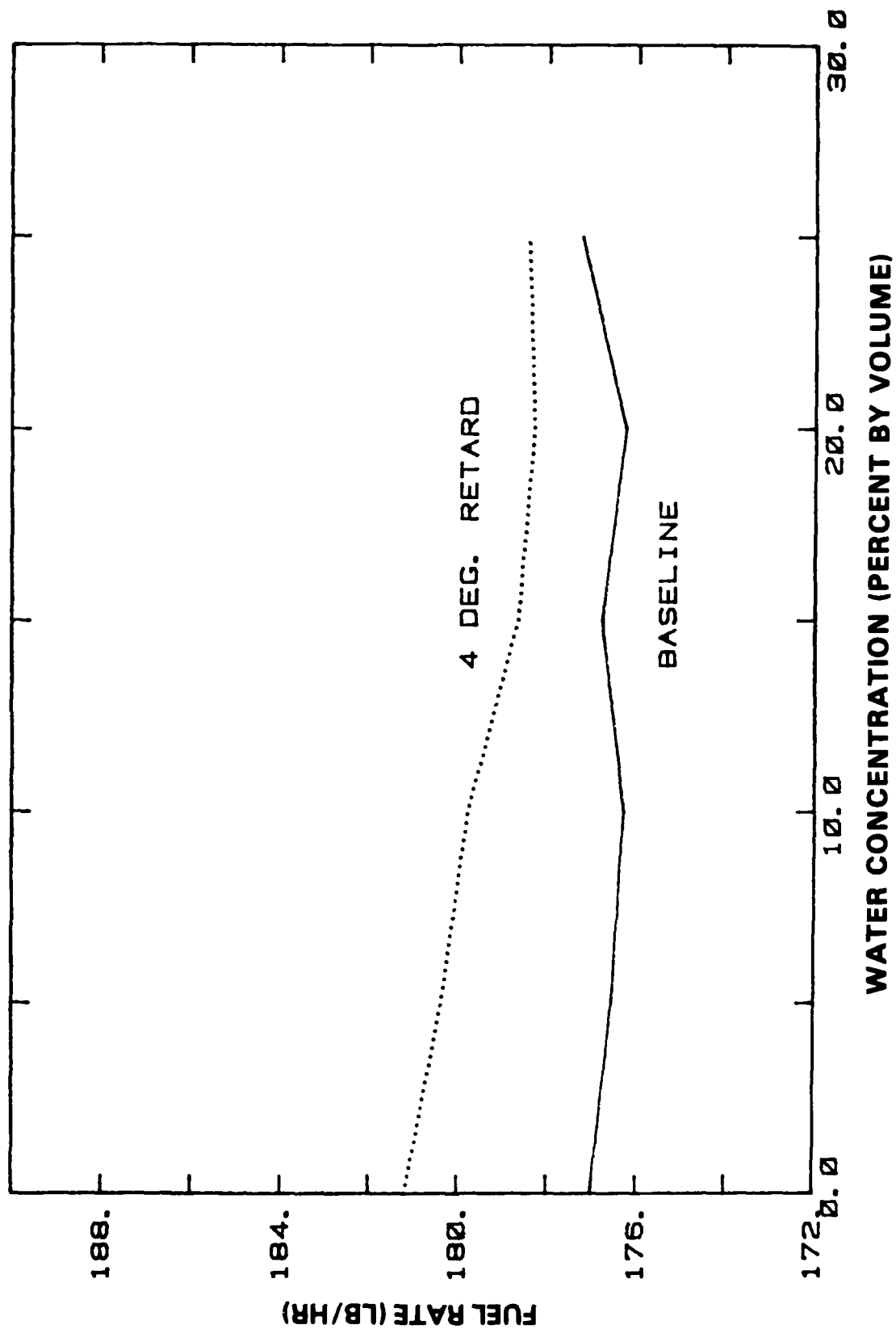


FIGURE 3-8. EFFECT OF INJECTION TIMING ON FUEL CONSUMPTION,
DETROIT DIESEL ENGINE, 1400 RPM

3.2 EXHAUST SMOKE

During the performance of the test runs on the Cummins engine, it was observed that the presence of water in the fuel caused a significant percentage reduction in the presence of exhaust smoke. The test results are shown in Figure 3-9 for the test point at 1800 rpm, and in Figure 3-10 for the test run at 1200 rpm. In both cases, it may be observed that the smoke reduction increased as water was added to the fuel. Although the percentage reductions are dramatic, it must be noted that the opacity of the exhaust stream was quite low even without water addition. Therefore, the effect of water addition on smoke reduction is questionable from a practical viewpoint, although the magnitude of the effect is statistically significant.

3.3 PARTICULATE EMISSIONS

During some of the Detroit Diesel engine tests, measurements were made of the particulate emissions using the procedures outlined in Section 2. A sample of the exhaust was obtained from each of the engine exhaust pipes, diluted with air, and passed through a pre-weighed filter. The difference in filter weights, combined with gas flow measurements, provided an assessment of the particulate loading per standard cubic foot of exhaust.

The results obtained from the particulate measurements are shown in Figures 3-11 and 3-12 as a function of both water concentration and engine speed. It may be observed from the data presented that the addition of water to the fuel has no positive effect on the particulate emissions.

3.4 OXIDES OF NITROGEN

The potential of water addition in terms of reduction of emissions of oxides of nitrogen from an operating engine was of particular interest at the outset of the program; other investigators have suggested that the use of water-in-fuel emulsions can provide a significant change in the emission levels of this particular contaminant.

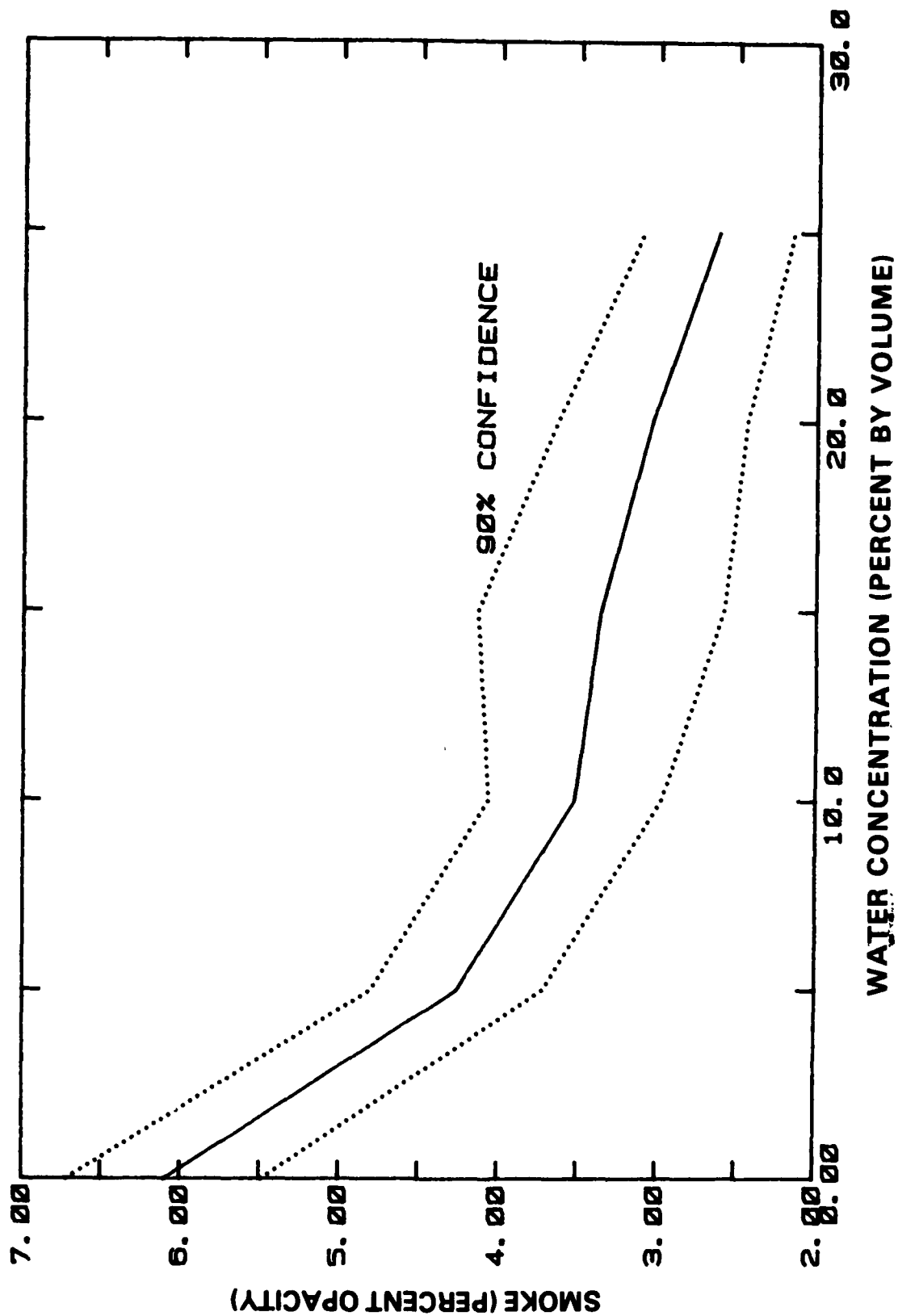


FIGURE 3-9. EXHAUST SMOKE, CUMMINS ENGINE, 1800 RPM

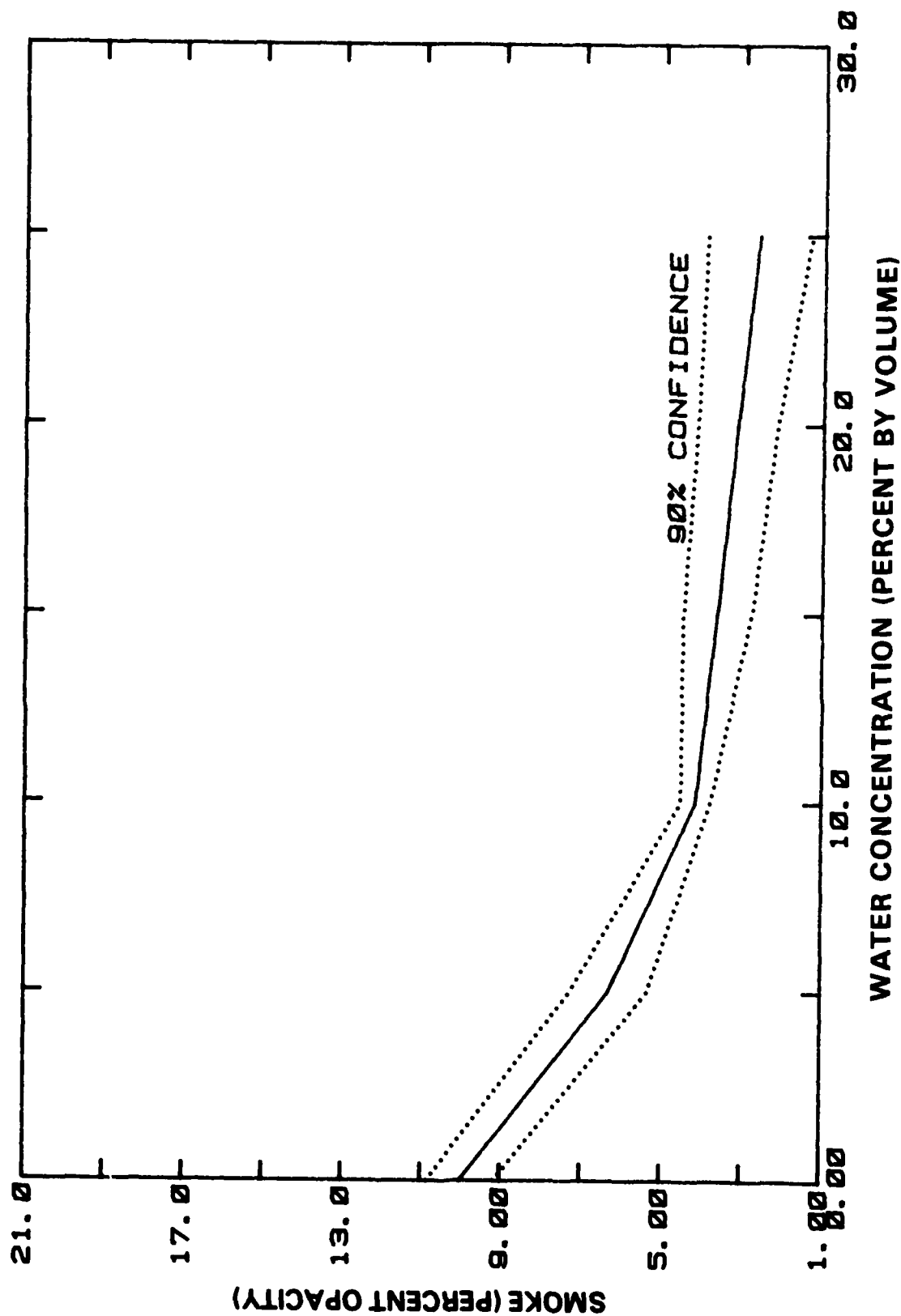


FIGURE 3-10. EXHAUST SMOKE, CUMMINS ENGINE, 1200 RPM

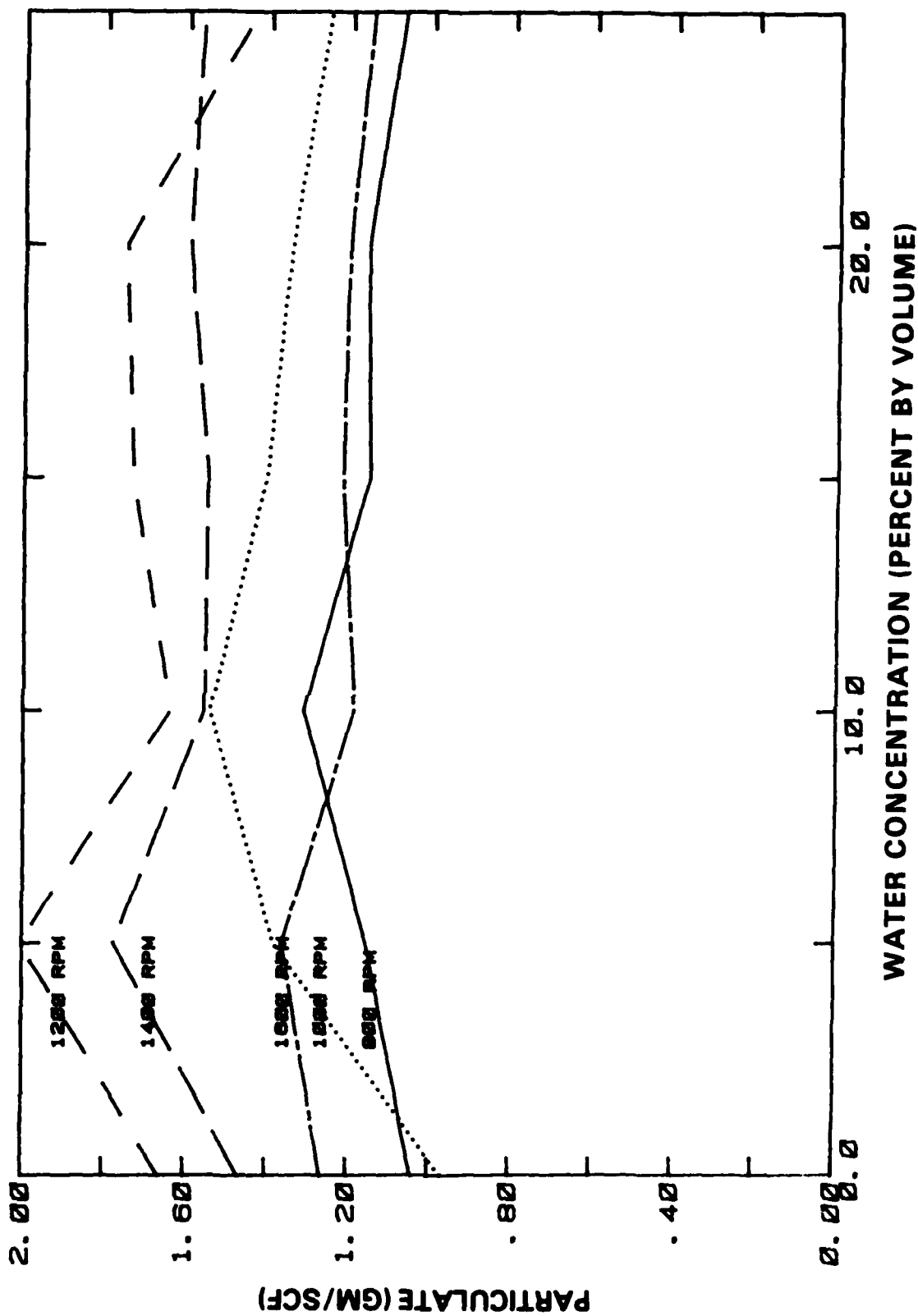


FIGURE 3-11. EXHAUST PARTICULATE EMISSIONS AS FUNCTION OF PERCENT WATER, DETROIT DIESEL ENGINE

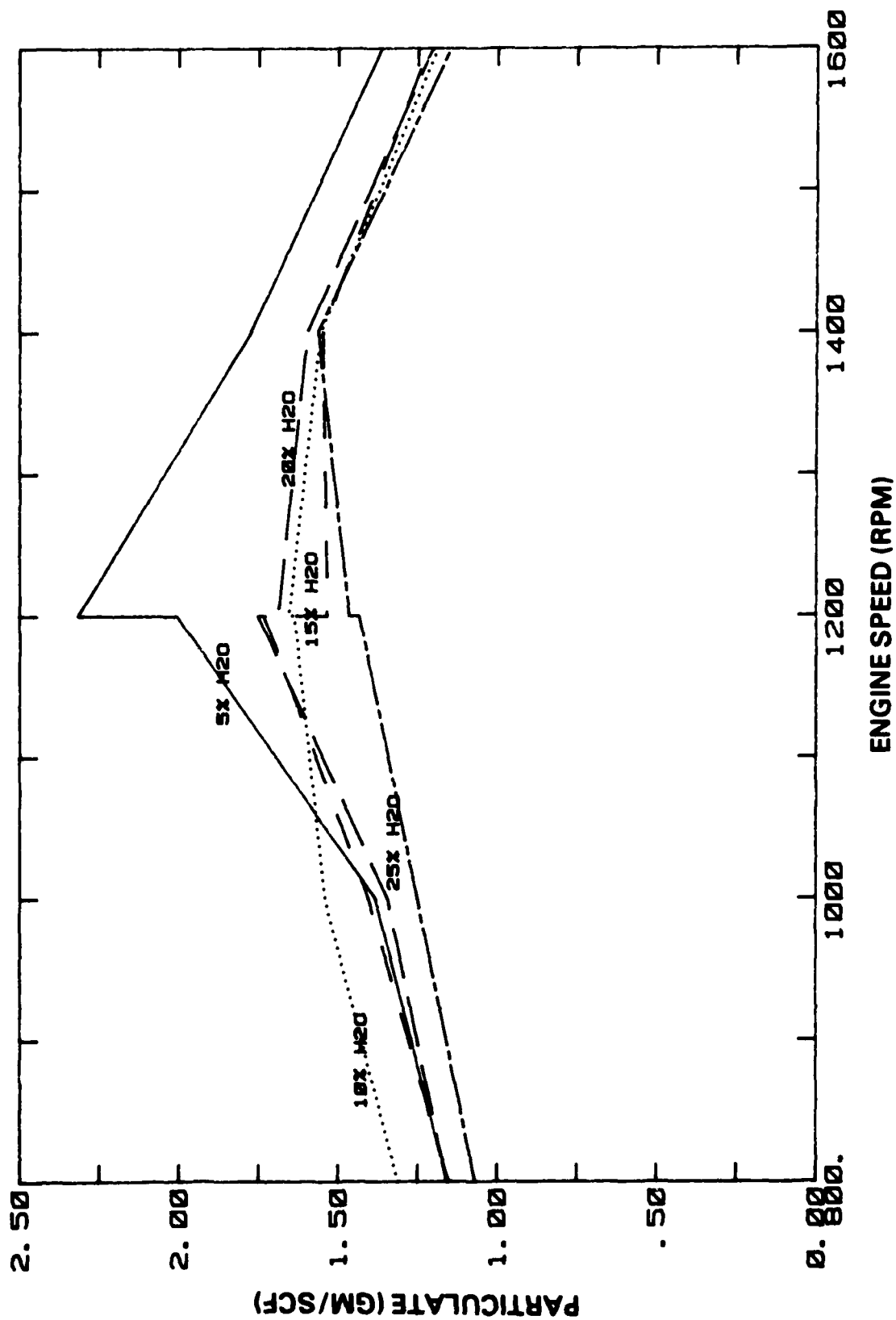


FIGURE 3-12. EXHAUST PARTICULATE EMISSIONS AS FUNCTION OF ENGINE SPEED, DETROIT DIESEL ENGINE

For the Cummins engine, the results of the testing program are summarized in Figure 3-13 for the 1800 rpm test point, and in Figure 3-14 for the 1200 rpm test point. Neither case allows the inference of a reduction in emissions of oxides of nitrogen as phrased in terms of nitric oxide concentrations. In fact, the results at 1800 rpm suggest that water addition did in fact increase the nitric oxide emissions. This result is due in part to a unique characteristic of the Cummins fuel injection system. The PT system utilized on the test engine provides for the end of fuel injection at a fixed crank angle location. In other words, the fuel injection event ends at the same point during each engine cycle regardless of the quantity of fuel supplied to the injector. An increase in liquid volume, such as that obtained by the addition of water to the fuel, results in an advance of the point at which injection begins. Thus, the injection event begins earlier in the engine cycle as water is added to the fuel. The effect of injection advance on emissions of oxides of nitrogen is well documented; in general, injection advance tends to increase the emissions of this substance. It is likely, therefore, that the effect of the injection advance offset the tendency toward NO reduction afforded by the presence of water, and the result was the observed constancy or slight increase of nitric oxide levels.

Some specific experiments were performed to assess the degree of injection advance associated with the addition of water to the fuel. Through the use of a strain-gauged component in the injection linkage, a signal was obtained that allowed display of the injection event on an oscilloscope. A series of tests was performed at the 1800 rpm test point; the results are shown in Figure 3-15. The injection event is defined by the point indicated. It may be observed that as the water concentration increases the point at which injection begins tends to advance with respect to the top dead center position. From evaluation of the oscilloscope photographs, it was determined that an injection advance of approximately one degree could be associated with the addition of each five percent water added to the fuel.

Emissions of oxides of nitrogen for the tests of the Detroit Diesel engine are summarized in Figure 3-16; the effect is similar to that observed for the

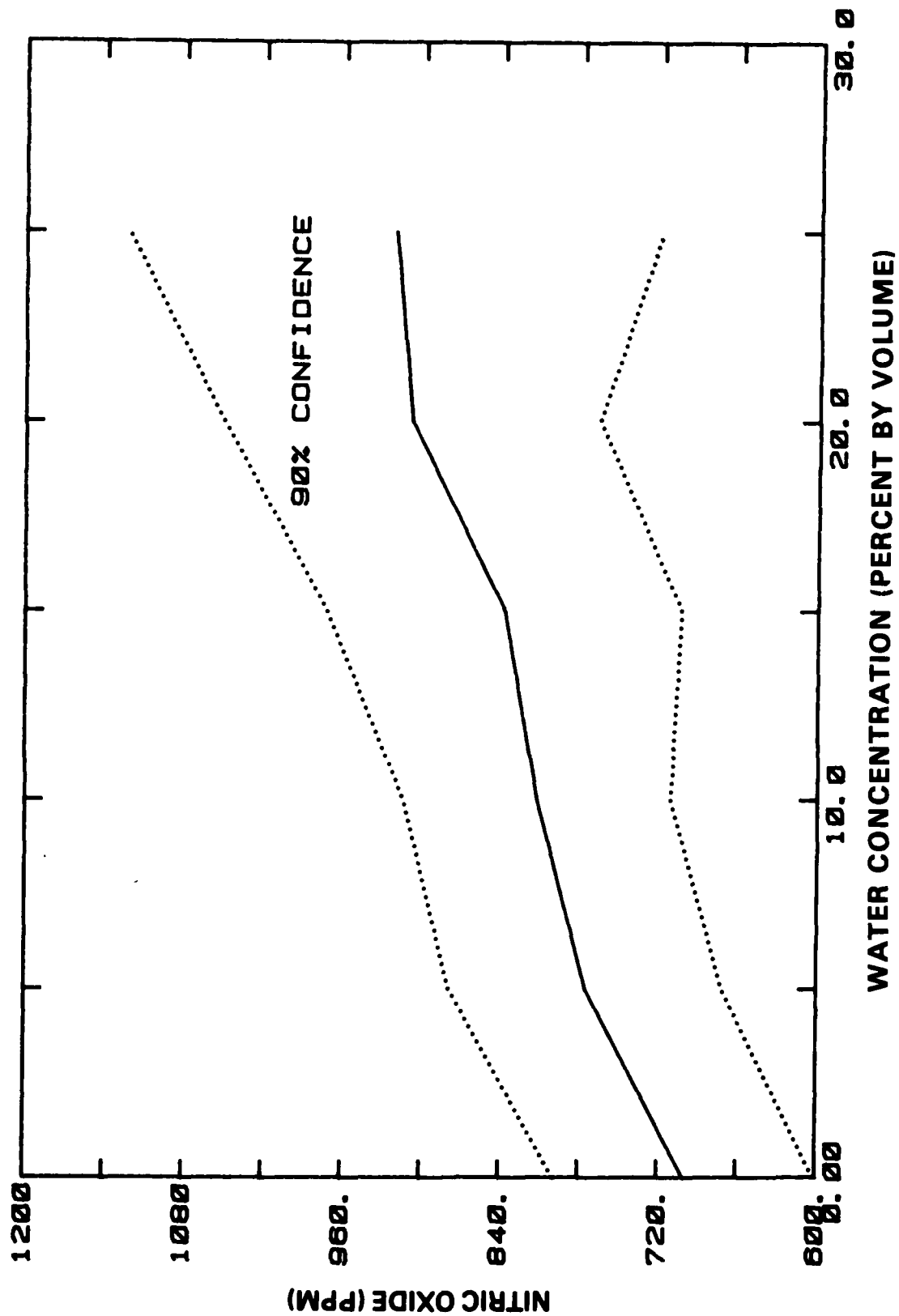


FIGURE 3-13. EMISSIONS OF NITRIC OXIDE, CUMMINS ENGINE, 1800 RPM

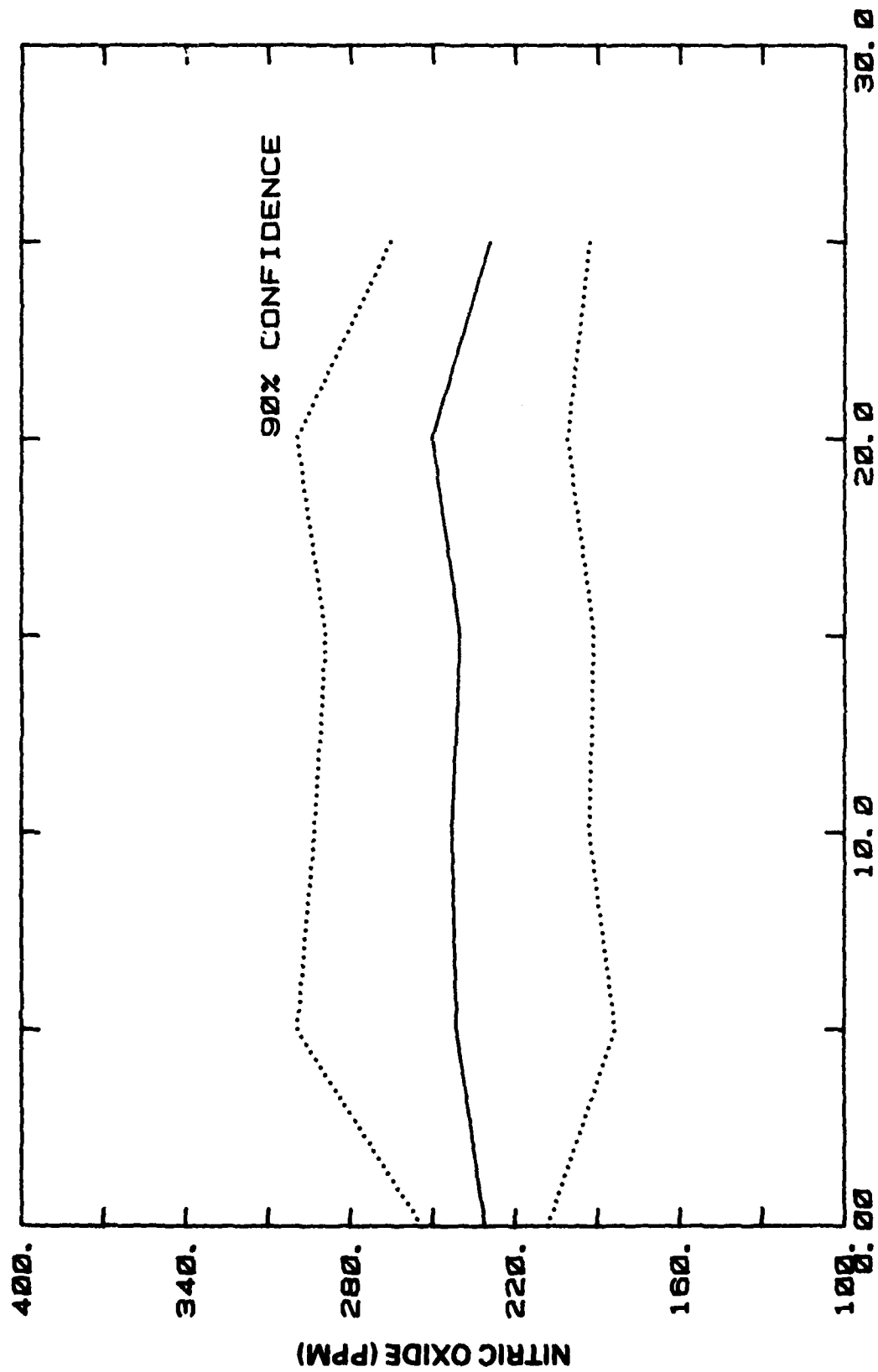
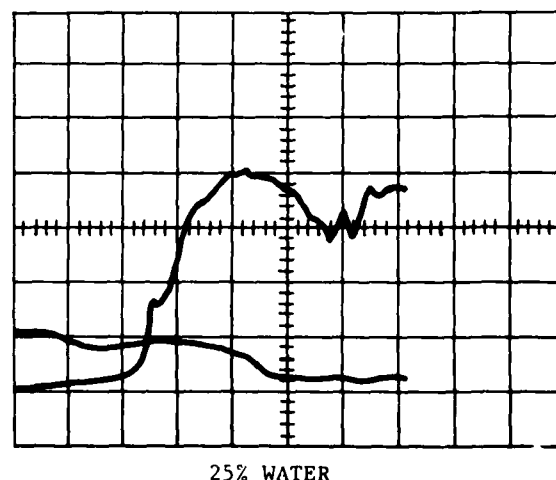
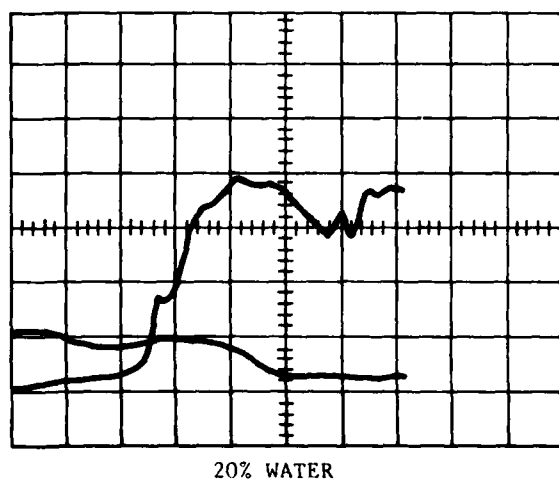
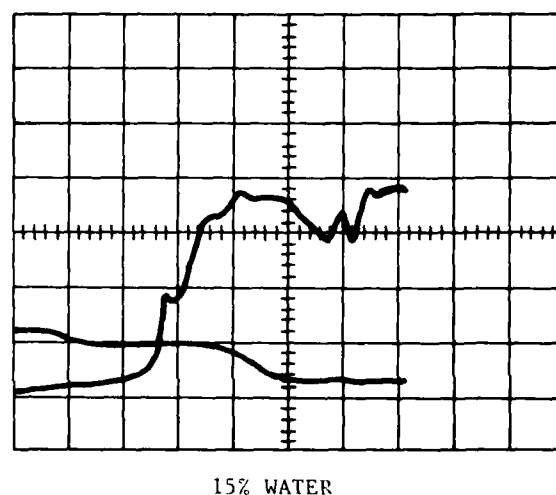
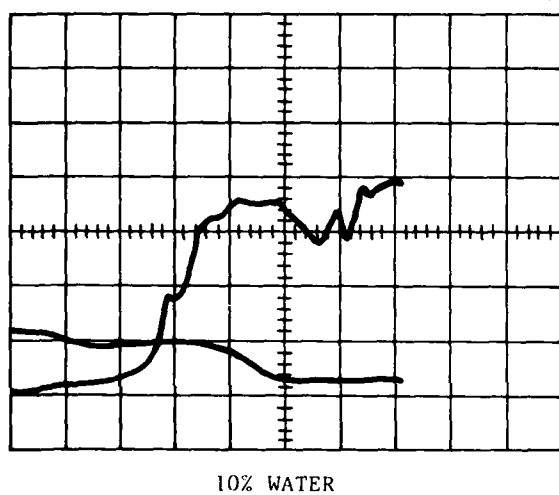
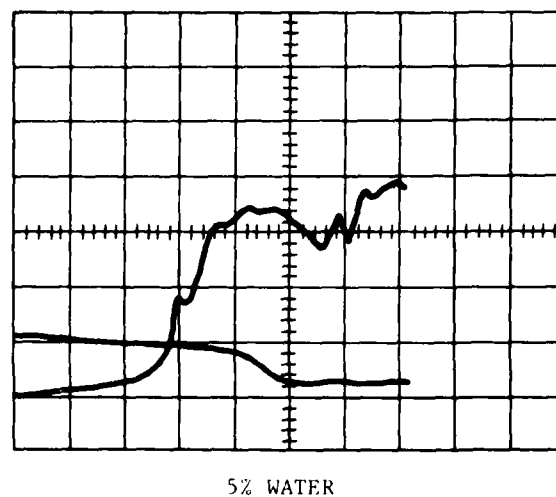
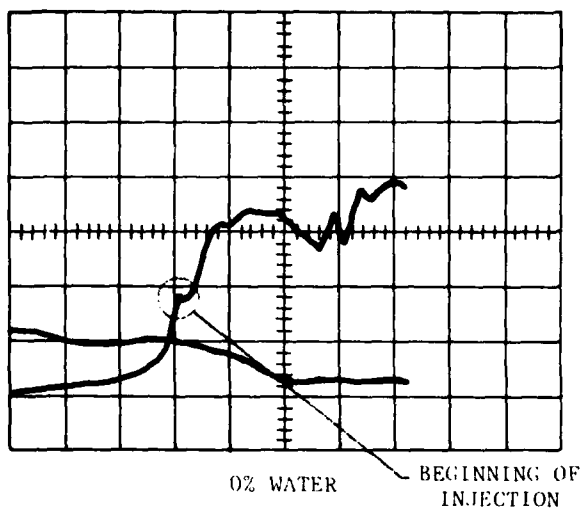


FIGURE 3-14. EMISSIONS OF NITRIC OXIDE, CUMMINS ENGINE, 1200 RPM



Note: Each major vertical division represents ten degrees.

FIGURE 3-15. TIMING OF THE BEGINNING OF FUEL INJECTION,
CUMMINS ENGINE

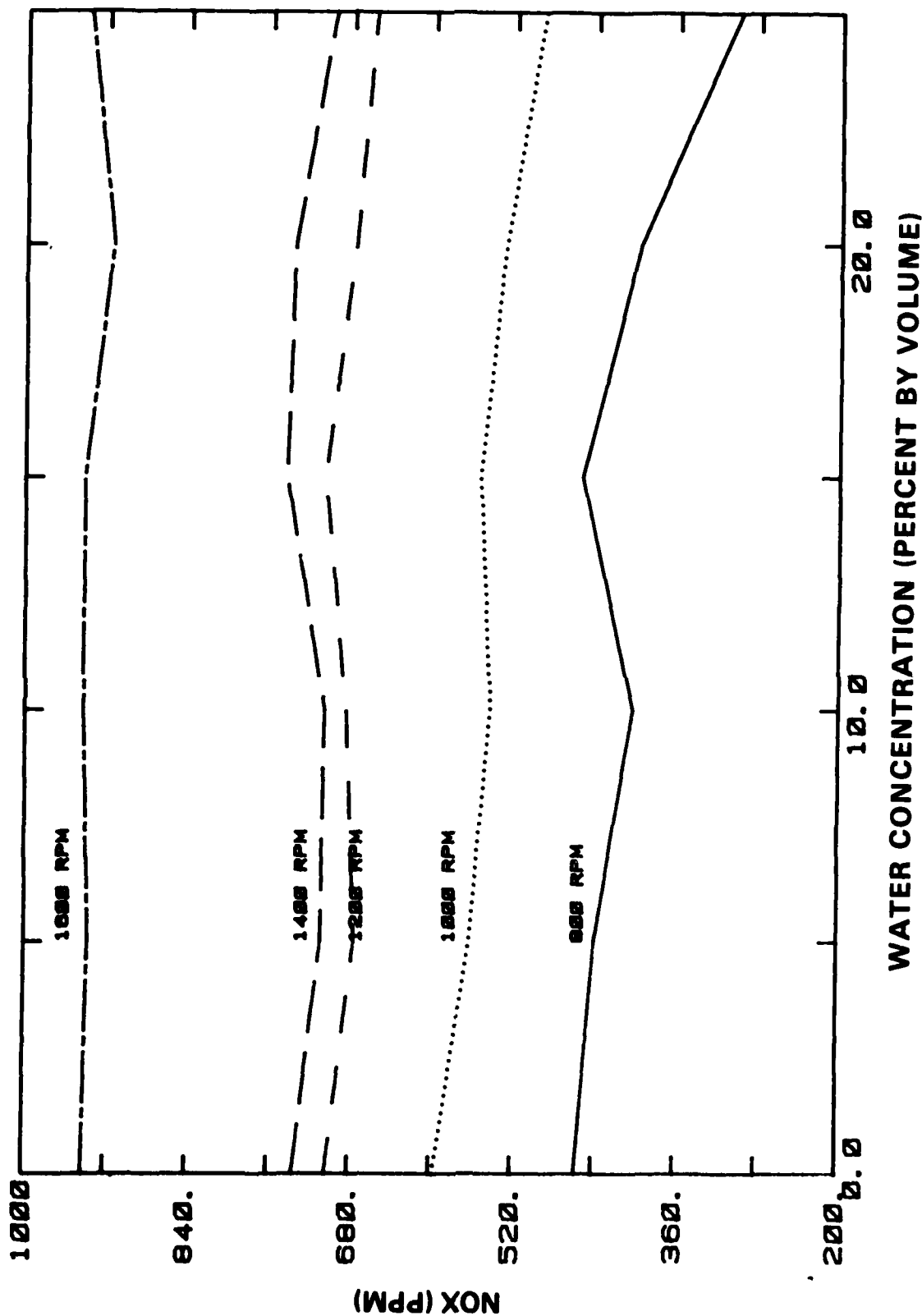


FIGURE 3-16. EMISSIONS OF OXIDES OF NITROGEN, DETROIT DIESEL ENGINE, FIVE SPEEDS

Cummins engine. The emissions increase as the load increases; this result is the usual consequence of increased cycle temperatures. Although some reductions seem to occur at low rpm (800 and 1000) and high water concentrations, in general, the addition of water does not appear to be effective for the reduction of emissions of oxides of nitrogen at any concentration examined during these tests. The explanation used for the lack of influence of water addition on emissions of oxides of nitrogen for the Cummins engine is not applicable in this case; increased liquid quantities do not affect the timing of the beginning of injection for the Detroit Diesel engine.

Two mechanisms may be postulated for the control of emissions of oxides of nitrogen through water addition. First, the water tends to absorb energy from the combustion process, and lower peak cycle temperatures might be attained. In addition, the presence of water tends to increase the ignition delay period; the net effect in this case would be a retarded combustion event. Since both cycle temperature reduction and retarded injection timing have previously been demonstrated as effective control techniques, it would appear that water addition should provide the desired results. However, the data obtained during this program indicate that, if the mechanisms described were operative, they were not sufficient in magnitude to provide effective control. In other words, at the water concentration levels employed and at the engine power levels utilized, the ignition delay increase and the cycle temperature decrease were not sufficient to cause an appreciable decrease in the emissions of oxides of nitrogen.

3.5 UNBURNED HYDROCARBONS

Unburned hydrocarbons are another exhaust contaminant of particular interest in engine exhaust streams. In general, it has been found that the presence of water in the fuel tends to increase the occurrence of unburned hydrocarbons in the exhaust due to a reduction in the cycle temperatures. The hydrocarbon results for the Cummins engine are shown in Figures 3-17 and 3-18 for the test points at 1800 rpm and 1200 rpm. The effect of water addition

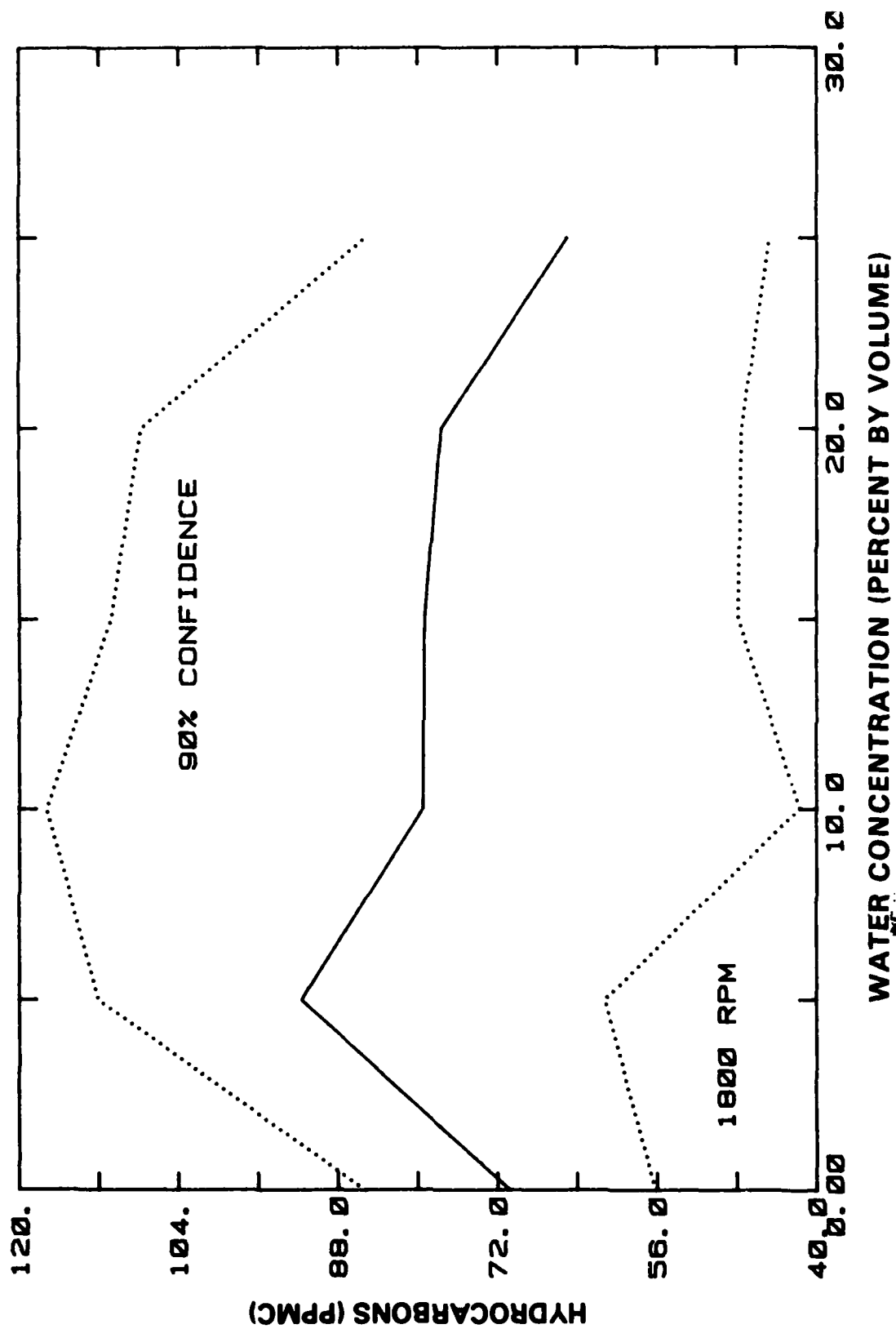
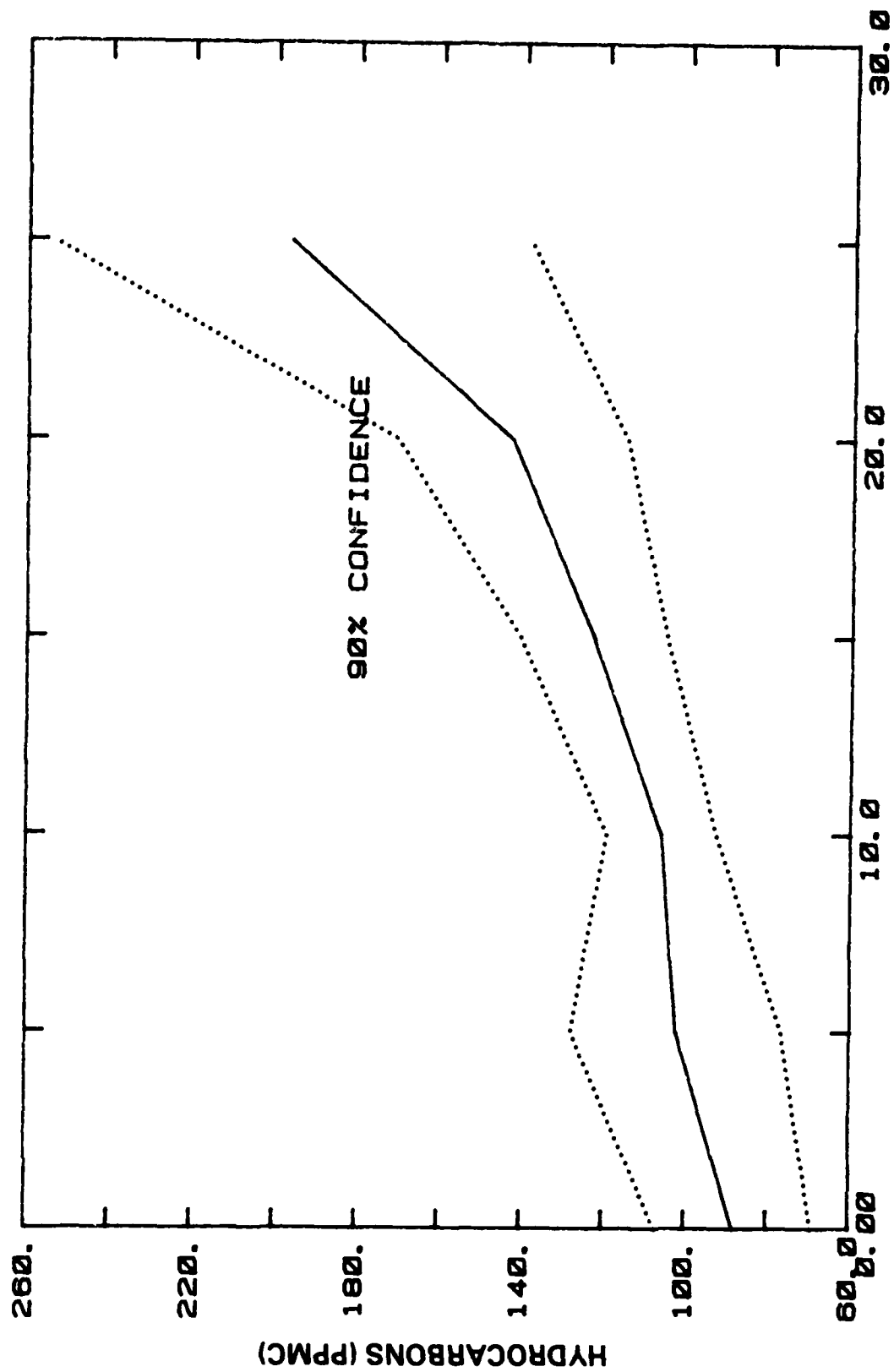


FIGURE 3-17. EMISSIONS OF UNBURNED HYDROCARBONS, CUMMINS ENGINE, 1800 RPM



WATER CONCENTRATION (PERCENT BY VOLUME)

FIGURE 3-18. EMISSIONS OF UNBURNED HYDROCARBONS, CUMMINS ENGINE, 1200 RPM

is largely inconclusive at 1800 rpm; at 1200 rpm an increase in hydrocarbons may be observed. Again, it is likely that the effect of injection advance counteracted the effect of the presence of water to some extent.

For the Detroit Diesel engine, the values of unburned hydrocarbon emissions are shown in Figure 3-19. The magnitudes of the emission levels are higher than those observed for the Cummins engine; this result is not unusual for comparisons between four-stroke cycle and two-stroke cycle engines. The presence of water in the fuel appears to yield an increase in hydrocarbon emissions; the levels associated with five percent water concentration are increased by about thirty percent compared to the baseline values. Water concentrations above five percent, however, had little additional effect on hydrocarbon emissions.

3.6 CARBON MONOXIDE

Carbon monoxide is a contaminant of the same character as unburned hydrocarbons in that both substances occur as a result of incomplete oxidation of the fuel. The situations that cause high hydrocarbon emissions typically cause high carbon monoxide emissions in addition. For the Cummins engine, it may be observed in Figures 3-20 and 3-21 that the character of the carbon monoxide emissions for these tests is similar to that for the emissions of unburned hydrocarbons. The results at 1800 rpm do not indicate a significant change in carbon monoxide emissions, and a moderate increase is apparent for the 1200 rpm test point at the high water concentration.

For the Detroit Diesel engine, the emissions of carbon monoxide are described in Figure 3-22. The results for 1200 rpm suggest a small influence of water concentration on carbon monoxide emissions. At speeds below 1200 rpm, an increasing tendency toward higher emissions may be observed, while an increasing tendency toward emission reduction can be associated with speeds above 1200 rpm. An explanation of this trend may be postulated in terms of the effect of water addition on the ignition delay of the fuel and on the mixing of fuel and air within the cylinder. At the low speeds, the effect of the

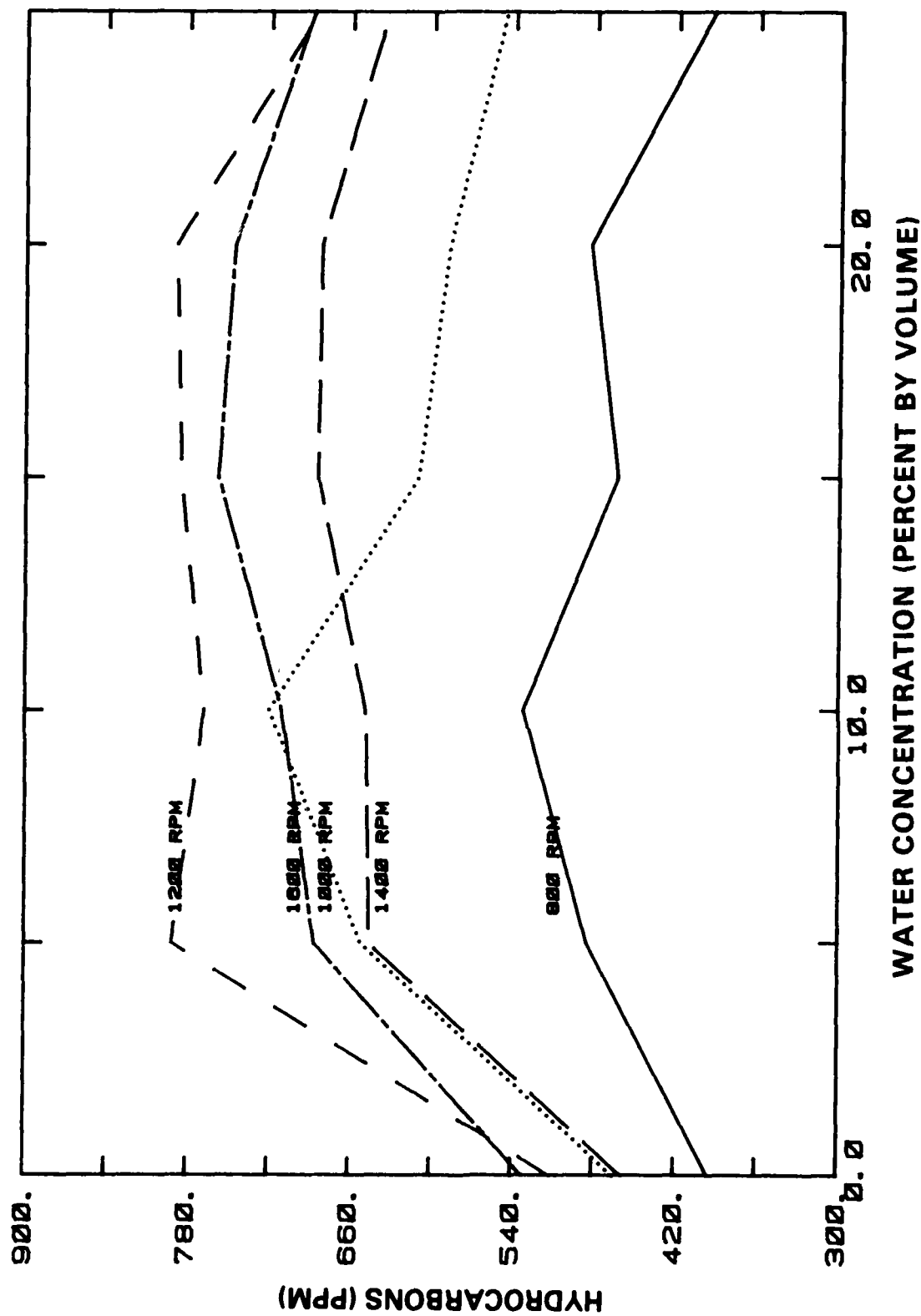
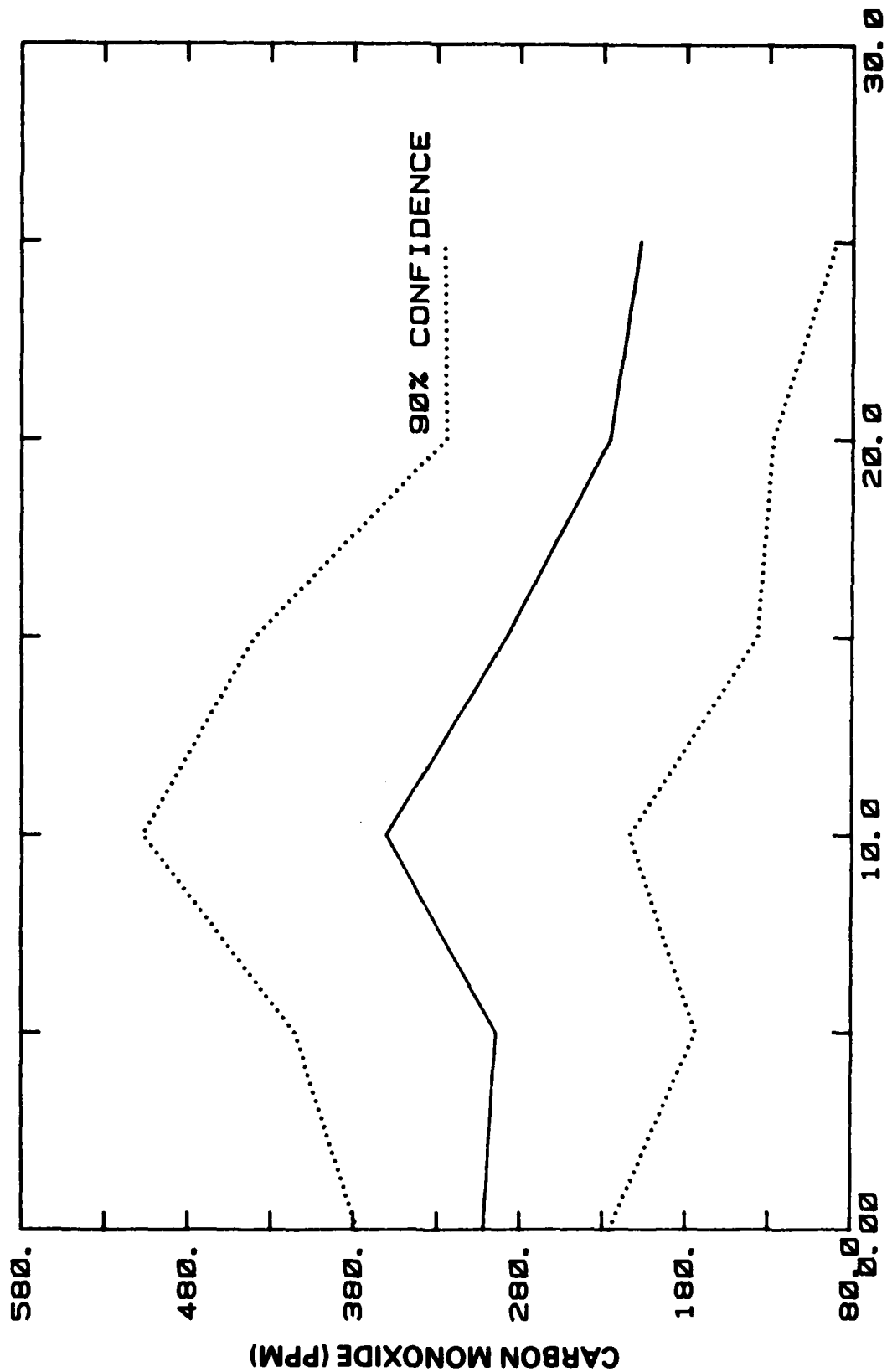


FIGURE 3-19. EMISSIONS OF UNBURNED HYDROCARBONS, DETROIT DIESEL ENGINE, FIVE SPEEDS



WATER CONCENTRATION (PERCENT BY VOLUME)

FIGURE 3-20. EMISSIONS OF CARBON MONOXIDE, CUMMINS ENGINE, 1800 RPM

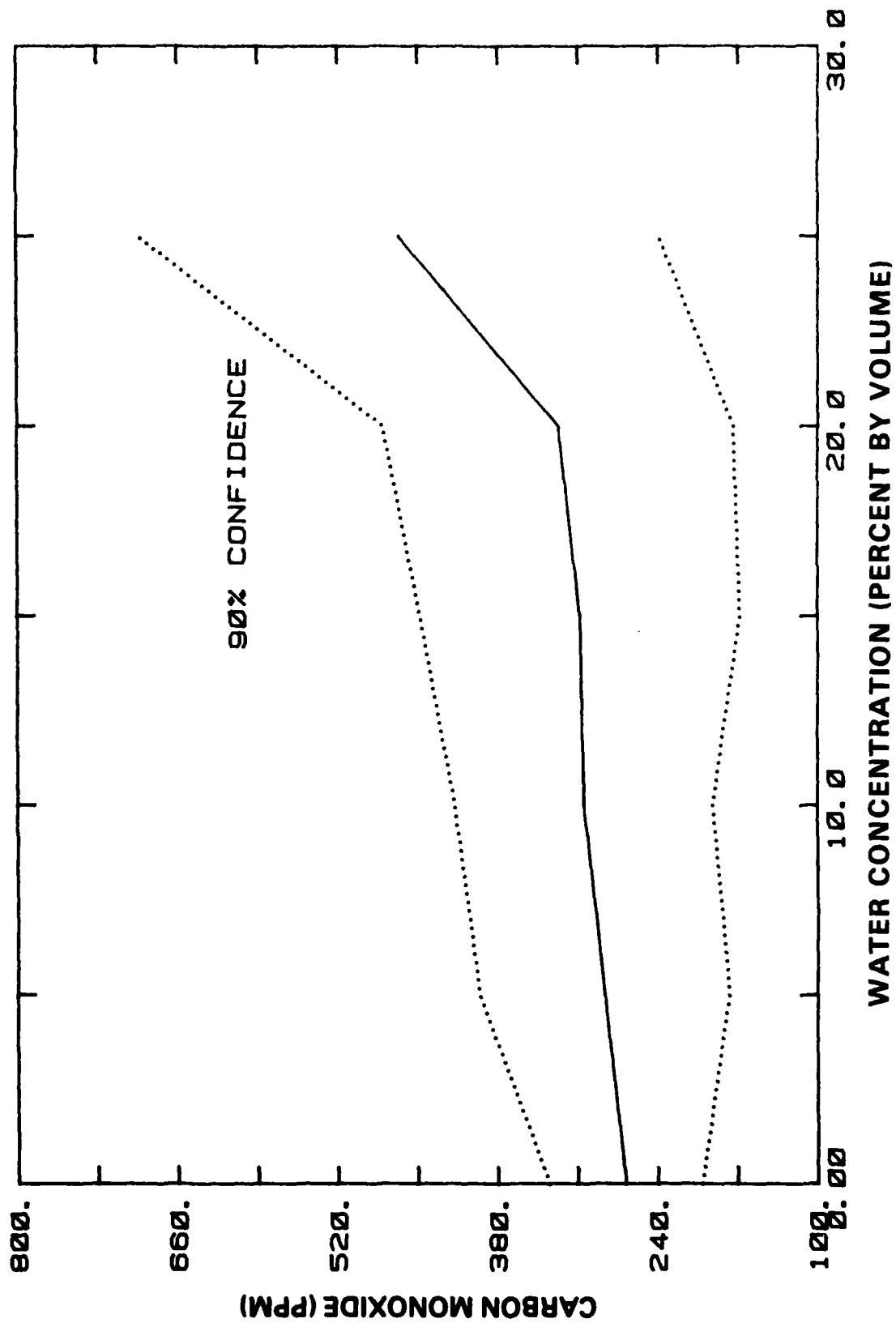
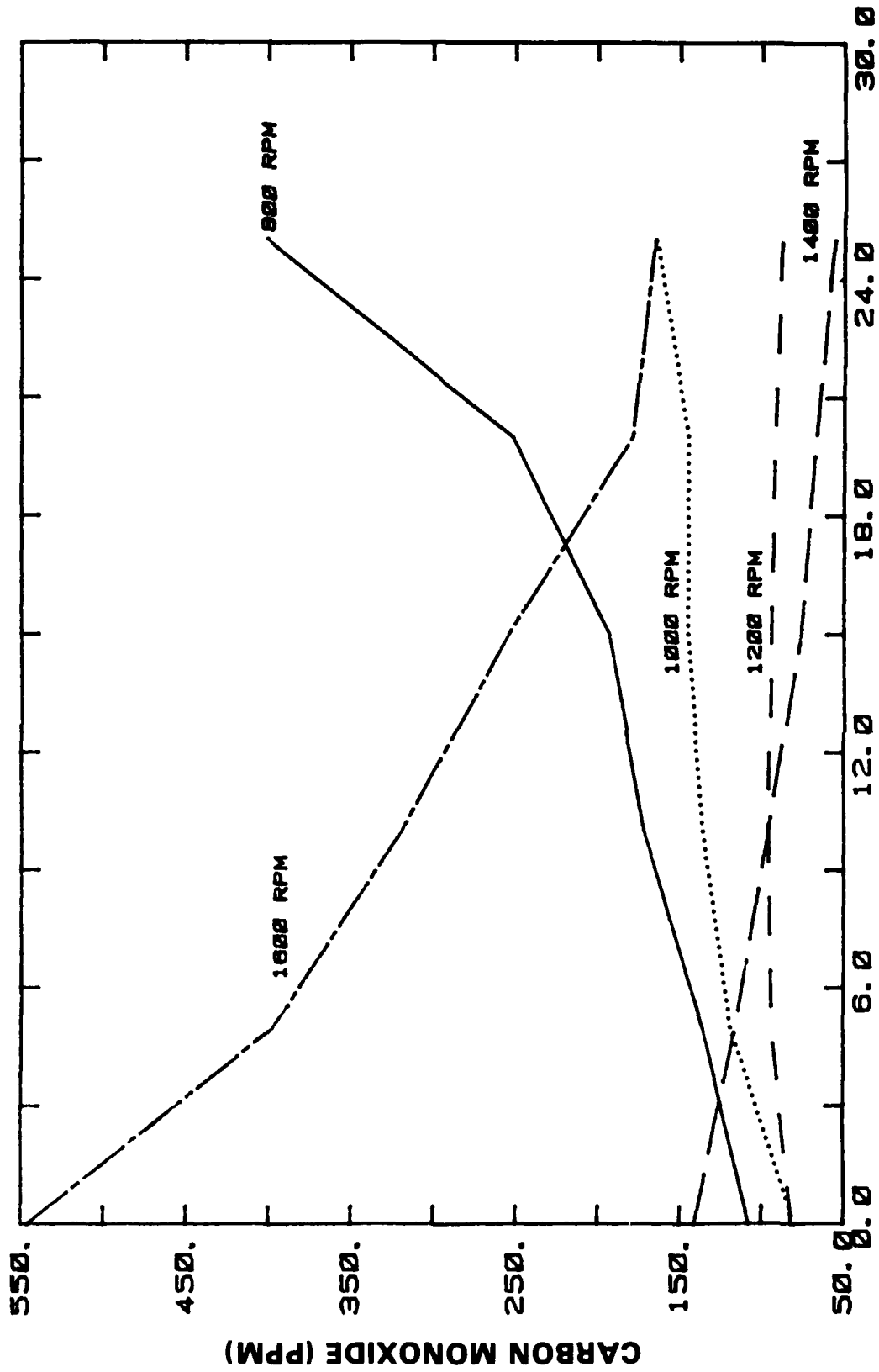


FIGURE 3-21. EMISSIONS OF CARBON MONOXIDE, CUMMINS ENGINE, 1200 RPM



WATER CONCENTRATION (PERCENT BY VOLUME)

FIGURE 3-22. EMISSIONS OF CARBON MONOXIDE, DETROIT DIESEL ENGINE, FIVE SPEEDS

addition of water on the ignition delay might be sufficient to cause increased emissions of carbon monoxide, although no effect on emissions of hydrocarbons and oxides of nitrogen was discernible.

It may be more appropriate to examine the carbon monoxide emissions from the Detroit Diesel engine in the context of mixing within the engine cylinder. During the 800 rpm tests, the fuel rate was quite small at the prop load condition. The addition of an inert component to the fuel stream would tend to diversify the jet of injected fuel with respect to the interior of the cylinder; the local fuel-air ratio in the vicinity of a fuel droplet would tend to become leaner. Since successful combustion depends upon ignition at points within the chamber and subsequent mixing of burning and unburned materials, it is possible that the addition of water allowed portions of the charge to escape complete inflammation. At the higher fuel rates, this effect of water addition would be reduced, and the effect of water addition on carbon monoxide emissions would be reduced. This argument does not explain the high carbon monoxide levels at the 1600 rpm test point; the baseline carbon monoxide emissions at that point seem uncharacteristically high. Since the fuel-air ratio at this point is well within customary limits for good combustion, poor mixing of air and fuel could be the cause of poor combustion. It is possible that the injection of an increased volume of liquid allowed improved penetration of the fuel injection jet, and increased mixing caused a reduction in carbon monoxide levels to values typical of lower speeds.

3.7 CARBON DIOXIDE AND OXYGEN

The emissions of carbon dioxide and oxygen are recorded in the test data shown in Appendix C. These substances, although not regulated contaminants, are of interest in the generalized context of engine testing. The carbon dioxide measurement is particularly important to carbon balance fuel-air ratio calculations, and results for these estimates have been presented in Figure 2-14.

4. SUMMARY AND CONCLUSIONS

During the testing program described by this document, Cummins and Detroit Diesel engines representative of USCG main propulsion units were operated under loading conditions typical of marine service using water-in-fuel emulsions having various concentrations. Measurements of engine performance and emissions were obtained in an effort to define optimum points for further exploitation of the benefits of emulsified fuels.

The engines were evaluated on a laboratory test bed that included a dynamometer capable of absorbing the maximum engine output. Instrumentation was provided to allow measurement of speed, load, and pertinent temperatures and pressures throughout the installation. Fuel was supplied through a system capable of blending water with diesel fuel in amounts up to 25 percent of the total volume of liquid supplied to the engine; fuel not used by the engine was cooled and recycled through the blending system. No surfactants or stabilizers were employed. A Gaulin "Hydroshear" emulsifier was used to accomplish the mixing of fuel and water, and visual observation of samples obtained from various points suggested that separation of fuel and water did not occur within the fuel system. The fuel consumption measurements were performed using a direct weight method.

Measurements of gaseous exhaust emissions were obtained for both engines using instruments appropriate to the type and level of the individual contaminant substances. In addition, a dilution tunnel was used to measure particulate emissions from the Detroit Diesel engine, and exhaust smoke measurements were obtained for the Cummins engine.

Data from cutter logs were used to define the prop load test points of particular interest for the Cummins engine, and tests were repeated several times for those points in order that a statistical basis for the results could be constructed. For the Detroit Diesel engine, tests were performed at more points along the prop load curve, but the repetition of tests was less extensive.

The fuel consumption tests for the Cummins engine suggested that diesel fuel savings averaging two to three percent could be obtained using emulsion concentrations of fifteen to twenty percent water. No significant fuel saving could be associated with the use of emulsions in the Detroit Diesel engine. Since the laboratory test conditions were generally more favorable than those that would prevail in actual marine use, it is necessary to conclude that the use of water-in-fuel emulsions would not be beneficial to USCG operations.

Measurements of exhaust smoke were performed for the Cummins engine, and particulate emissions were measured for the Detroit Diesel engine. Although dramatic reductions in exhaust plume opacity were observed, the smoke levels for engine operation without water addition were not excessive. Thus, although the data suggest that water-in-fuel emulsions could be used for smoke control, the observation of excessive smoke at any operating point other than full rated load is probably indicative of defective engine components or poor adjustment of engine systems, and smoke control should be effected through correction of those conditions. The addition of water to the fuel did not have a significant effect on the emission of exhaust particulates, although the Detroit Diesel engine was generally insensitive to the presence of water at all test points.

In terms of gaseous exhaust emissions, the expected effects of water addition were not generally observed. The addition of water to the fuel should yield an increase in the emissions of oxides of nitrogen. Although some trends toward these effects could be observed in the test results, no definitive conclusions can be drawn concerning the effect of water addition on emissions.

From a theoretical viewpoint, the addition of water to diesel fuel can result in a mixture which would exhibit unique properties at the onset of combustion. Specifically, it is believed that the vaporization of the water phase causes a "micro-explosion" that is capable of shattering a fuel droplet; the result of this process would be improved mixing of fuel and air and enhanced combustion quality. In addition to improving combustion in a diesel engine, the presence of water in the fuel should lower combustion temperatures, and

emissions of unburned hydrocarbons and carbon monoxide should increase. Also, the lower temperature and an increase in the ignition delay period should reduce the emissions of oxides of nitrogen. The micro-explosion phenomenon has been demonstrated for burning of single droplets, and the addition of water to fuel has been suggested for application to a wide range of combustion processes.^{2,3,4,5,6}

Several investigators have obtained encouraging test results using water-in-fuel emulsions in diesel engines;^{1,6,7,8} others have been less successful in demonstrating benefits associated with the emulsion use.^{9,10} The basic engine configuration apparently affects the results; four-stroke cycle engines have generally produced more noticeable effects.

During the present study, all of the observations were macroscopic in nature, and no attempt was made to observe the details of emulsion quality or the micro-explosion event. However, the tests were performed in such a way that the effects of emulsions on engine performance would be revealed.

For the four-stroke cycle (Cummins) engine, the observed reductions in fuel consumption and exhaust stream opacity are indicative of improved mixing between the fuel spray and the air charge within the combustion chamber. The results for unburned hydrocarbons and carbon monoxide were inconclusive, and the emissions of oxides of nitrogen were probably affected by the change in injection timing due to increased fuel quantity. Thus, some evidence can be associated with support of the micro-explosion theory, although the effects were not sufficiently large to be of practical interest.

In the case of the two-stroke cycle (Detroit Diesel) engine, no improvement in fuel consumption or particulate emissions could be observed. Some indication of mixing quality could be inferred from the data on carbon monoxide emissions, but the presumed micro-explosion effects could not be separated from alterations of the fuel spray due to increased injection quantity. In general, the two-stroke cycle engine was quite tolerant of, and insensitive to, the addition of water to the fuel. This result is consistent with the observations of other investigators; for example, some observers have found that water concentrations exceeding 40 percent were necessary to obtain

significant changes in engine performance.¹¹ Such water concentrations lie beyond the range of practical interest for USCG operations.

Both the data obtained during this study and the results reported by other investigators indicate that the effect of water-in-fuel emulsions on engine performance is dependent upon the engine system configuration. Although inferences can be drawn from the body of accumulated information, it is not possible, as yet, to predict the response of an untested engine to the addition of water to the fuel. Additional information must be obtained to define the specific mechanisms which are operative and the effect that these mechanisms exert on the combustion process.

It is possible that further investigation would reveal significant differences between techniques for the production of water-in-fuel emulsions, both in the microstructure of the emulsion product and in the effect on engine operation. Aside from the assurance of a stability sufficient for transit through the fuel system, this study did not address the details of emulsion production. An investigation of the effects of different production techniques, if attempted, should be closely coupled with a study designed to reveal the dominant mechanisms of combustion process control.

5. RECOMMENDATIONS

On the basis of the results obtained during this study, it is recommended that no future effort be directed toward the use of water-in-fuel emulsion in 85 foot and 95 foot WPB class cutters. Although a small fuel consumption benefit was observed for the Cummins engine in a laboratory environment, it is unlikely that a benefit of 2-3 percent could be translated to field use.

The use of water-in-fuel emulsions for smoke control is possible for the Cummins engine, but emulsion use should not be pursued as a control strategy. Excessive smoke at conditions other than engine rated speed and load is indicative of a hardware failure or poor control system adjustment, and correction of the defect is indicated in preference to an auxiliary control strategy.

The data obtained on the Cummins and Detroit Diesel engines do not preclude the successful use of emulsions in other USCG power units. If emulsions are candidates for application to, for example, larger medium-speed diesel engines, then specific tests should be conducted to determine the response of those engines to the presence of water in the fuel system.

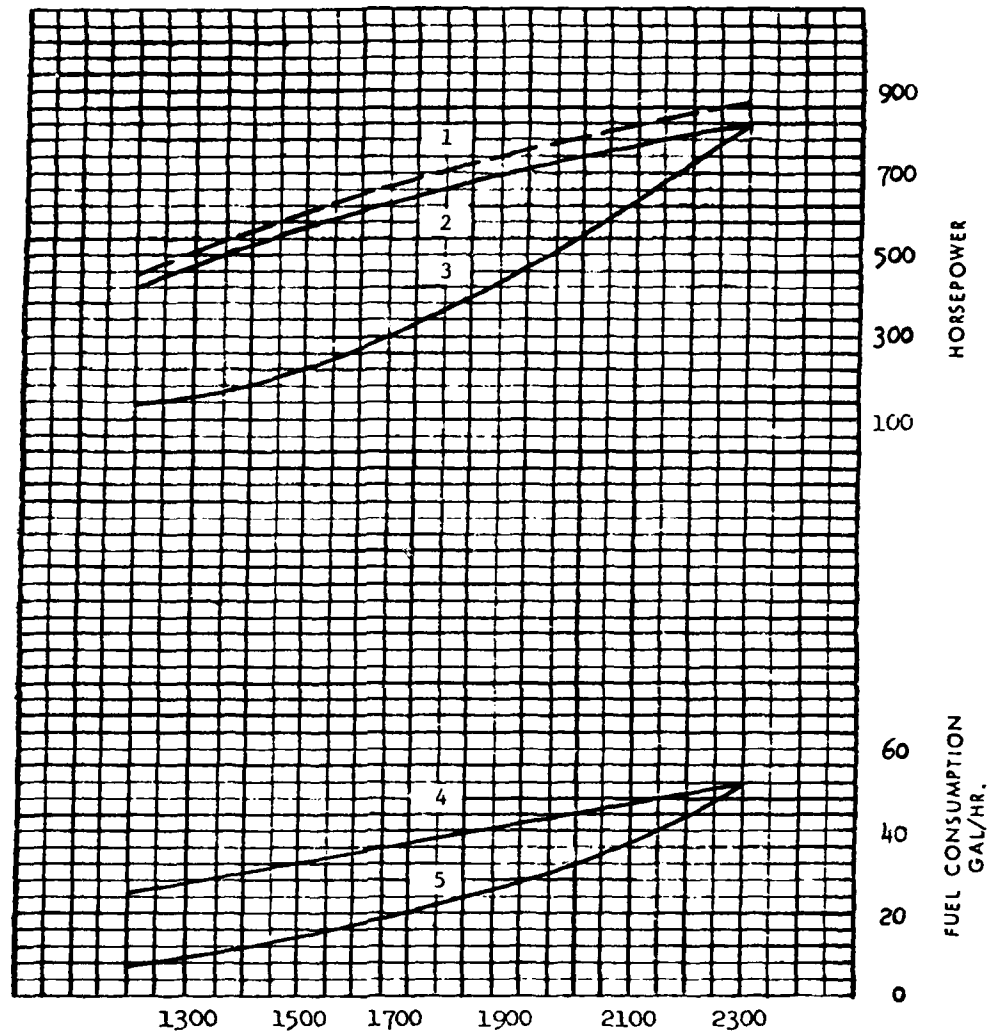
Additional basic work will be required in order to formulate general statements concerning the necessary properties of emulsions and the effect of those emulsions on engine performance. While the execution of this basic work is beyond the scope of USCG interests, it is recommended that performance of the basic research efforts be encouraged. Until the general results for emulsion use are understood and documented, tests of specific engine-emulsification system combinations will be necessary for the assessment of practicality.

APPENDIX A
FUEL PROPERTIES AND ENGINE DATA

TABLE A-1. FUEL ANALYSIS DATA

PROPERTY	CUMMINS TESTS RUNS 171-282	DETROIT DIESEL TESTS RUNS 1-106	DETROIT DIESEL TESTS RUNS 107-150
Heat of Combustion (BTU/LB)	20,038	20,050	19,400
Hydrogen (% by Weight)	12.83	12.92	13.52
Carbon (% by Weight)	85.75	84.71	84.31
Oxygen (% by Weight)	2.37	1.60	0.96
Nitrogen (% by Weight)	0.68	0.77	0.48
Sulfur (% by Weight)	0.18	0.12	0.075
API Gravity at 60°F	35.3	33.9	35.1
Reid Vapor Pressure	1.78	2.60	0.31
Cetane Number (Calc.)	47.5	49.7	50.6
Flash Point (°F)	147	163	162
Viscosity (centistokes)			
50°F	4.91	7.30	5.51
100°F	2.59	3.55	3.14
150°F	1.61	2.18	1.95
210°F	1.07	1.35	1.26
Distillation			
IBP (°F)	360	387	385
10% (°F)	420	463	446
20% (°F)	446	489	473
30% (°F)	464	505	482
40% (°F)	481	520	507
50% (°F)	499	534	522
60% (°F)	514	549	536
70% (°F)	533	568	554
80% (°F)	552	595	579
90% (°F)	581	640	621
95% (°F)	606	682	657
EP (°F)	630	714	700
Recovery (%)	98.5	96.75	98
Residue (%)	1.5	1.25	2
Loss (%)	0.0	2.00	0.0

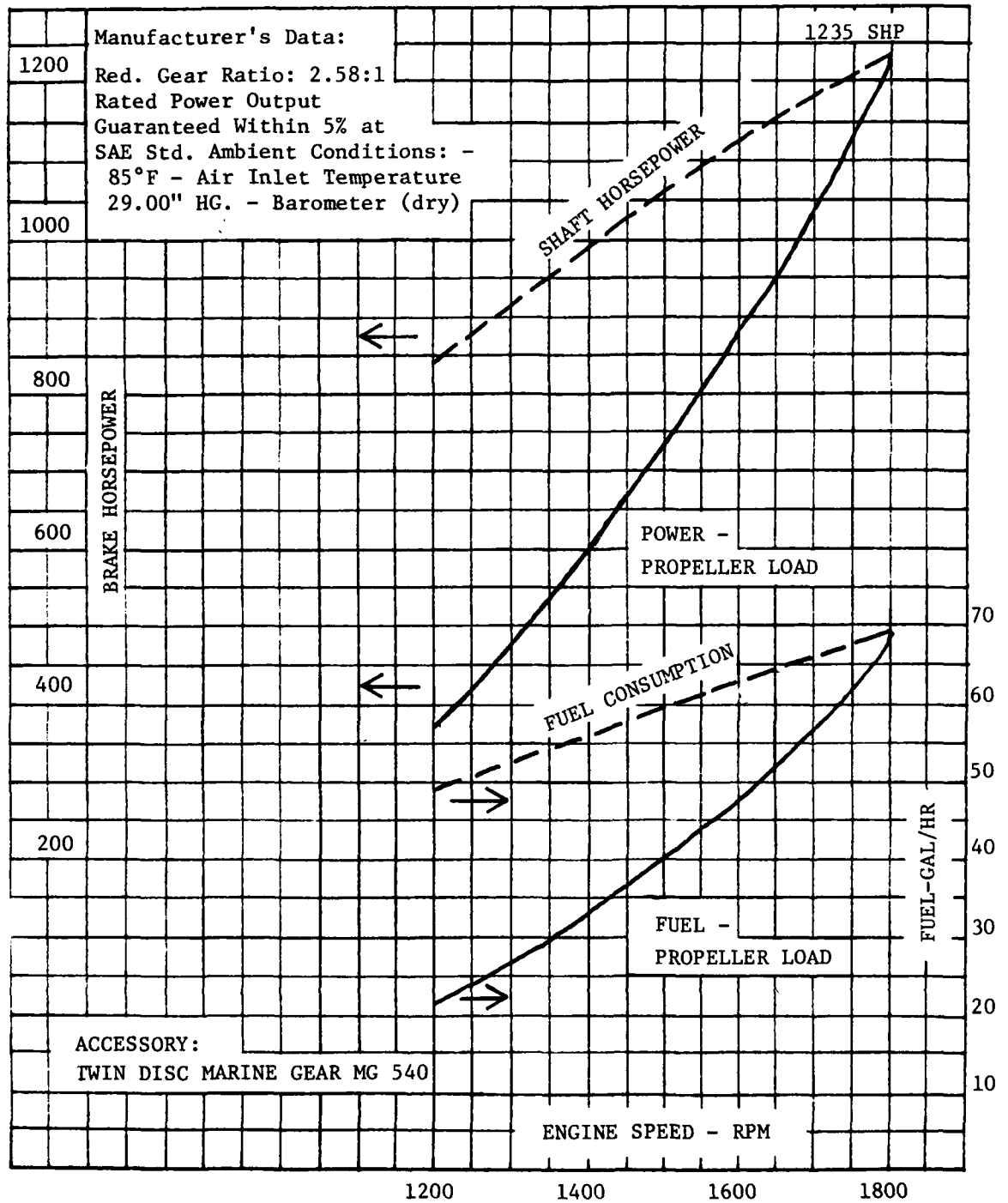
TABLE A-2. MARINE ENGINE PERFORMANCE CURVE



1. GROSS BRAKE HORSEPOWER.
2. NET HORSEPOWER WITH REVERSE REDUCTION GEAR, GENERATOR AND RAW WATER PUMP.
3. HYPOTHETICAL PROPELLER POWER CURVE (3.0 EXPONENT).
4. FUEL CONSUMPTION FOR NET SHAFT HORSEPOWER.
5. FUEL CONSUMPTION FOR HYPOTHETICAL PROPELLER.

The above curves are based on 500 ft. altitude (29.38" HG.) and 85°F intake air temperature; fuel consumption curves are based on fuel weight of 7.0 lb/US gal. Manufacturer's data for Model VT12-900M engine (turbocharged-aftercooled, 12 cylinders, 1710 cu. in. displacement, with 5-1/2 in. bore and 6 in. stroke, military version).

TABLE A-3. ESTIMATED PERFORMANCE SERIES V-149TI MARINE 16V-149TI
CREW BOAT, JACKET WATER INTERCOOLER, 150 INJECTORS



APPENDIX B
SAMPLE CALCULATIONS

During each individual test run, engine data were entered on a permanent record sheet. The data items that were recorded are listed in Table B-1 along with the numerical values associated with run number 235 for the Cummins engine; the sample calculations which follow will be based upon the numerical values shown.

The differences between the data items recorded for the Cummins and Detroit Diesel engines were minor. The Detroit Diesel engine was equipped with four turbochargers; therefore, the number of turbocharger-related temperatures and pressures was doubled by comparison with the Cummins engine. Also, air box pressure, rather than fuel rail pressure, was recorded for the Detroit Diesel engine.

Recorded engine test data were entered into a computer program, and several calculation routines were executed. The following discussion describes the details of the calculation procedure, and the numerical values for Cummins run number 235 are presented as an example.

Humidity Calculations

The air supplied to the engine contained some moisture, and the further addition of water to the fuel affected the exhaust moisture. The following equation was used for the calculation of the saturation vapor pressure of water:¹²

$$P_B = \exp \left[B \ln T + \sum_{i=0}^9 F_i T^{i-2} \right], \quad (1)$$

where P_B = saturation vapor pressure, pascals
 T = temperature, °K
 B = -12.150799
 F_0 = -8.49922×10^3
 F_1 = -7.4231865×10^3
 F_2 = 96.1635147

TABLE B-1. TEST DATA

Date: 24 July 1979		Value for Cummins Run 235
Data Item	Units	
Dynamometer Constant	-	3000
Nominal Water Concentration	Percent	20
Barometric Pressure	Inches - Hg	29.03
Wet Bulb Temperature	°F	77
Dry Bulb Temperature	°F	87
Engine Hour Meter	Hours	5222.3
Engine Speed	RPM	1800
Beam Load	Pounds	718
Coolant Inlet Temperature	°F	175
Coolant Outlet Temperature	°F	186
Oil Sump Temperature	°F	219
Fuel Temperature at Emulsifier	°F	112
Diesel Fuel Inlet Temperature	°F	95
Return Fuel Temperature	°F	151
Return Fuel Temperature After Cooler	°F	113
Intake Air Temperature	°F	90
Exhaust Stack Temperature (Left)	°F	762
Exhaust Stack Temperature (Right)	°F	777
Turbine Inlet Temperature (Left)	°F	905
Turbine Inlet Temperature (Right)	°F	917
Compressor Outlet Temperature (Left)	°F	224
Compressor Outlet Temperature (Right)	°F	222
Charge Air Temperature (Left)	°F	189
Charge Air Temperature (Right)	°F	189
Tap Water Inlet Temperature	°F	101
Cell Air Temperature	°F	91
Engine Oil Pressure	psi	76
Fuel Rail Pressure	psi	96

TABLE B-1. TEST DATA, continued

Data Item	Units	Value For Cummins Run 235
Boost Pressure (Right)	psi	9.9
Boost Pressure (Left)	psi	10.0
Turbine Inlet Pressure (Left)	psi	9.0
Turbine Inlet Pressure (Right)	psi	10.0
Inlet Vacuum	In. H ₂ O	13.9
Exhaust Pressure (Right)	Inches - Hg	0.2
Exhaust Pressure (Left)	Inches - Hg	0.5
Pressure Drop, LFE Filter	In. H ₂ O	5.40
Pressure Drop, Laminar Flow Element	In. H ₂ O	4.25
Exhaust Temperature, Cylinder 1R	°F	905
Exhaust Temperature, Cylinder 2R	°F	890
Exhaust Temperature, Cylinder 3R	°F	897
Exhaust Temperature, Cylinder 4R	°F	873
Exhaust Temperature, Cylinder 5R	°F	890
Exhaust Temperature, Cylinder 6R	°F	898
Exhaust Temperature, Cylinder 1L	°F	939
Exhaust Temperature, Cylinder 2L	°F	913
Exhaust Temperature, Cylinder 3L	°F	880
Exhaust Temperature, Cylinder 4L	°F	882
Exhaust Temperature, Cylinder 5L	°F	892
Exhaust Temperature, Cylinder 6L	°F	904
Water Flowmeter 1, Glass Float	mm	150+
Water Flowmeter 2, SS Float	mm	115
Water Flowmeter 3, SS Float	mm	0
Fuel Pressure, Tank	psi	20
Pressure, Emulsifier Inlet	psi	100
Pressure, Fuel at Engine	psi	1.6
Water Supply Pressure	psi	65
Emission Concentrations		
Hydrocarbons	ppmc	56
Carbon Monoxide	ppm	148

TABLE B-1. TEST DATA, continued

Data Item	Units	Value For Cummins Run 235
Nitric Oxide	ppm	773
Oxides of Nitrogen	ppm	770
Carbon Dioxide	Percent	7.8
Oxygen	Percent	12.8
Smoke	Percent	3.3
Fuel Flow Measurements	Pounds	5.0
Times: 1	sec	102.3
2	sec	102.6
3	sec	102.4
4	sec	102.7

$$\begin{aligned}
F_3 &= 2.4917646 \times 10^{-2} \\
F_4 &= -1.3160119 \times 10^{-5} \\
F_5 &= -1.1460454 \times 10^{-8} \\
F_6 &= 2.1701289 \times 10^{-11} \\
F_7 &= -3.610258 \times 10^{-15} \\
F_8 &= 3.8504519 \times 10^{-18} \\
F_9 &= -1.4317 \times 10^{-21}.
\end{aligned}$$

Application of this equation to the dry and wet bulb temperatures for run 235 yields the following:

$$\begin{aligned}
P_{WB} &= 3168.62 \text{ pascals (at } 298.15^\circ\text{K)} \\
P_{DB} &= 4382.41 \text{ pascals (at } 303.71^\circ\text{K)}.
\end{aligned}$$

The vapor pressure at the wet bulb temperature was obtained from "Ferrels equation",

$$P_V = P_{WB} - 0.000660 (T_{DB} - T_{WB}) P_{BARO} \left[1 + 0.0015 (T_{WB} - 273.15) \right], \quad (2)$$

$$\begin{aligned}
\text{where } P_V &= \text{vapor pressure, pascals} \\
T_{DB} &= \text{dry bulb temperature, } ^\circ\text{K} \\
T_{WB} &= \text{wet bulb temperature, } ^\circ\text{K} \\
P_{BARO} &= \text{barometric pressure, 98307.2 pascals.}
\end{aligned}$$

Using this relationship, the vapor pressure was found to be

$$P_V = 2797.50 \text{ pascals.}$$

The relative humidity, by definition, was calculated as:

$$RH = \frac{P_V}{P_{DB}} \times 100 = 63.8\%, \quad (3)$$

and the specific humidity was calculated from:

$$H = \frac{(K)(P_V)}{P_{BARO} - P_V}, \quad (4)$$

where H = specific humidity, gm H₂O/gm dry air

K = 0.6220 gm H₂O/gm dry air,

for the test case,

$$H = 0.0182 \text{ gm H}_2\text{O/gm dry air}$$

(or pounds moisture/pound dry air).

The volume concentration of the water vapor was calculated on a dry basis as:

$$Y = \frac{(H)(M_{AIR})}{M_{H_2O}} = 0.0293, \quad (5)$$

where Y = water vapor volume concentration

M_{AIR} = molecular weight of air = 28.9645

M_{H₂O} = molecular weight of water = 18.01534/

Water Flow Rate Calculations

Although a nominal water concentration was associated with each test run, the actual flow to the engine fuel system was measured using variable area flowmeters. The flowmeters were calibrated with water prior to the initiation of testing, and a fifth order curve was fitted to the calibration data. Two flowmeters were utilized, and one of the two units contained two floats; thus three calibrated flow ranges were available. The matrix of flowmeter constants is shown in Table B-2. The water flow determination was based upon the flow range most applicable to the particular test run; the procedure was

$$WFR = W_1 + W_2(X) + W_3(X^2) + W_4(X^3) + W_5(X^4) + W_6(X^5), \quad (6)$$

where WFR = water flow rate, cc/min

TABLE B-2. WATER FLOWMETER CURVE COEFFICIENTS

	<u>Meter 1 Glass Float</u>	<u>Meter 1 Stainless Steel Float</u>	<u>Meter 2 Stainless Steel Float</u>
W ₁	0.1124503×10^2	-0.3398302×10^1	0.1701297×10^1
W ₂	-0.1180202×10^1	0.8969192	0.7123502
W ₃	0.6830435×10^{-1}	0.7994353×10^{-1}	0.1005951
W ₄	$-0.7587800 \times 10^{-3}$	$-0.1017442 \times 10^{-2}$	$-0.1434834 \times 10^{-2}$
W ₅	0.3808533×10^{-5}	0.5968658×10^{-5}	0.8912745×10^{-5}
W ₆	$-0.6943106 \times 10^{-8}$	$-0.1340098 \times 10^{-7}$	$-0.2025536 \times 10^{-7}$

- W = calibration coefficient, Table B-2
 X = flowmeter scale reading, mm.

The calculated water flow rate was utilized in subsequent calculations for the measured water concentration and the corrected exhaust humidity. For the example situation (run 235), the water flow rate was:

$$\text{WFR} = 384 \text{ cc/min.}$$

Engine Performance Calculations

The observed brake horsepower was calculated from the engine speed and load:

$$\text{BHP} = \frac{(N)(L)}{K}, \quad (7)$$

- where BHP = brake horsepower
 N = engine speed, rpm
 L = dynamometer beam load, pounds
 K = dynamometer constant
 = 3000 for Cummins tests
 = 2000 for DDAD runs 1 - 106
 = 3000 for DDAD runs 107 - 150.

For the case of Cummins run 235,

$$\text{BHP} = \frac{(1800)(718)}{3000} = 431.$$

The observed torque was obtained from

$$T = \frac{(5252)(L)}{K} = 1257 \text{ lb. ft.}, \quad (8)$$

- where T = torque, lb. ft.
 L = beam load, lb.

K = dynamometer constant.

Correction factors for the observed engine performance were developed on the basis of atmospheric conditions.¹³ The dry barometric pressure was calculated from

$$P_{B, DRY} = P_{BARO} - \frac{P_V}{K_p} = 28.20 \text{ in. Hg}, \quad (9)$$

where $P_{B, DRY}$ = dry barometric pressure, in. Hg
 K_p = 3386.4 pascal/in. Hg.

the value of the correction factor was then obtained

$$C_D = \left(\frac{29.00}{P_{B, DRY}} \right) \left(\frac{T_{test}}{545} \right)^{0.7}, \quad (10)$$

where C_D = correction factor
 T_{test} = intake air absolute temperature, °R.

For the specific test case,

$$C_D = \left(\frac{29.00}{28.20} \right) \left(\frac{90 + 460}{545} \right)^{0.7} = 1.035,$$

therefore, the corrected horsepower was

$$CBHP = (431)(1.035) = 446.$$

The mean effective pressure is a useful parameter that describes engine output per unit area of piston surface. In the calculation routine, values were obtained from the relationship

$$bmep = \frac{K_m (CBHP)}{(D)(N)} = 115, \quad (11)$$

where bmep = brake mean effective pressure, psi
 K_m = constant, 792,000 for 4-stroke cycle
 396,000 for 2-stroke cycle
 D = engine displacement, cubic inches
 = 1710 for Cummins engine
 = 1788 for Detroit Diesel engine
 N = engine speed, rpm.

Air Flow Calculations

During the Cummins engine tests, the air flow to the engine was measured using a Meriam Laminar Flow Element. During test runs, the pressure drop across the element, the pressure drop across the filter, and the temperature of the incoming air were recorded. The volume flow rate was obtained from a curve fitted to the flow element calibration curve by means of the following relationship:

$$CFM = AC + BC (dp) + CC (dp)^2 + DC (dp)^3, \quad (12)$$

where CFM = volume flow, cubic feet per minute
 dp = pressure drop across element, inches of water
 AC = 0.0
 BC = 298.825
 CC = 5.88898
 DC = 0.19913.

For the example calculation, it may be observed that

$$CFM = 1179.$$

Two correction factors were used to adjust the volume flow rate to the calibration basis of standard cubic feet per minute. The pressure correction was

$$PCF = \frac{P_{BARO} - (dp \text{ filter})(0.07355)}{29.92} = 0.957, \quad (13)$$

where PCF = pressure correction factor
 dp filter = pressure drop across filter, inches of water.

The correction for temperature was obtained from a curve fitted to data supplied with the instrument (Table B-3).¹⁴

$$TCF = X_1 + X_2(T_1) + X_3(T_1)^2 + X_4(T_1)^3 = 0.937, \quad (14)$$

where TCF = temperature correction factor
 T_1 = inlet air temperature, °F
 X_1 = 1.28345
 X_2 = -0.0048289
 X_3 = 1.227782×10^{-5}
 X_4 = -1.618912×10^{-8} .

The air mass flow rate was then established in terms of air density at the calibration condition (70°F) as:

$$AMF = (CFM)(PCF)(TCF)(\rho_s) = 79.2, \quad (15)$$

where AMF = air mass flow, pounds per minute
 ρ_s = density of air at 70°F and 29.92 inches of mercury, pounds per cubic foot.

The air flow rate was adjusted using the previously calculated moisture concentration:

$$DAMF = AMF (1.0 - H), \quad (16)$$

where DAMF = mass flow rate of dry air, pounds per minute
 H = moisture, pounds water per pound dry air.

For the example calculation,

$$DAMF = 79.2 (1.0 - 0.0182) = 77.8.$$

TABLE B-3. AIR TEMPERATURE CORRECTION FACTORS

AIR TEMPERATURE CORRECTION FACTORS FOR SCFM
AIR BASE TEMPERATURE 70°F, VISCOSITY 181.87 MICROPOISE
REFERENCE NBS CIRCULAR 564

$$\text{CORRECTION FACTOR} = \frac{529.67}{459.67 + ^\circ\text{F}} \times \frac{181.87}{\mu\text{g}^*}$$

μg^* Viscosity of Air at flowing temperature

TEMP °F	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9
50	1.0707	1.0670	1.0633	1.0596	1.0559	1.0523	1.0487	1.0451	1.0415	1.0379
60	1.0344	1.0303	1.0273	1.0238	1.0204	1.0169	1.0135	1.0101	1.0067	1.0033
70	1.0000	.9966	.9933	.9900	.9867	.9834	.9802	.9770	.9737	.9705
80	.9674	.9642	.9611	.9579	.9548	.9517	.9486	.9456	.9425	.9395
90	.9365	.9335	.9305	.9275	.9246	.9216	.9187	.9158	.9129	.9100
100	.9072	.9043	.9015	.8987	.8959	.8931	.8903	.8875	.8848	.8820
110	.8793	.8766	.8739	.8712	.8686	.8659	.8633	.8606	.8580	.8554
120	.8528	.8503	.8477	.8452	.8426	.8401	.8376	.8351	.8326	.8301
130	.8276	.8252	.8227	.8203	.8179	.8155	.8131	.8107	.8083	.8060
140	.8036	.8013	.7990	.7966	.7943	.7920	.7898	.7875	.7852	.7830
150	.7807	.7785	.7763	.7741	.7719	.7697	.7675	.7653	.7632	.7610

Fuel Flow Calculations

During each test run, several measurements of the mass flow rate of diesel fuel were performed. The determinations were made by observing the time required for consumption of a known mass of fuel from a container on a scale; the fuel masses were varied to permit time measurements on the order of two minutes. Each fuel mass flow rate was calculated, and an average was obtained. For the case of Cummins run 235, the following data apply:

Observation	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
Fuel mass, pounds	5.0	5.0	5.0	5.0
Time, seconds	102.3	102.6	102.4	102.7
Fuel rate, pounds per hour	175.95	175.44	175.78	175.27

Average Fuel Rate = F = 175.61 pounds per hour.

The brake specific fuel consumption was calculated from the average fuel rate and the corrected brake horsepower:

$$\text{BSFC} = \frac{F}{\text{CBHP}} = 0.3939 \text{ pounds fuel per brake horsepower hour.} \quad (17)$$

As a consequence of the fuel and air flow determinations, the observed fuel-air ratio was calculated:

$$\left(\frac{F}{A} \right)_{\text{MEAS}} = \frac{F}{(\text{DAMF})(60)} = 0.0376. \quad (18)$$

In order to obtain the fuel volume flow rate, a hydrometer measurement of the API gravity of the fuel was obtained and corrected to 60°F through the use of ASTM IP Table 5.¹⁵ The value at 60°F was then used in the context of ASTM IP Table 3¹⁵ to determine the specific gravity of the fuel; for the test case, the specific gravity of the fuel at 60°F compared to water at 60°F was:

$$\text{SG}_{60/60} = 0.8483,$$

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MULTICYLINDER DIESEL ENGINE TESTS WITH UNSTABILIZED WATER-IN-FU--ETC(U)

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the fuel density was then calculated as

$$\rho_{\text{fuel}} = (\rho_{\text{water}})(SG_{60/60}) \left(\frac{\text{ft}^3}{1728 \text{ in}^3} \right) \left(\frac{231 \text{ in}^3}{\text{gallon}} \right) = 7.074, \quad (19)$$

where ρ_{fuel} = fuel density, pounds per gallon

ρ_{water} = density of water at 60°F

= 62.38 pounds per cubic foot

A temperature correction for the difference between the 60°F standard and the observed fuel temperature was established from ASTM IP Table 6¹⁵ and using the 60°F value of the API gravity. Values of the volume reduction factor were selected from the table for the temperature range 60°F - 120°F, and a curve was fitted to the data. The temperature correction was:

$$TF = Z_1 + Z_2(T_f) + Z_3(T_f)^2 + Z_4(T_f)^3, \quad (20)$$

where TF = temperature correction factor for fuel volume

T_f = fuel temperature, °F

$Z_1 = 0.102678 \times 10$

$Z_2 = -0.446429 \times 10^{-3}$

$Z_3 = -0.14715 \times 10^{-12}$

$Z_4 = 0.10462 \times 10^{-14},$

for the example case of run 235,

$$TF = 0.9844.$$

The fuel density at the test condition was, therefore,

$$\rho_{ft} = (7.074)(TF) = 6.963 \text{ pounds per gallon},$$

and the fuel volume flow rate was

$$V_F = \frac{(F)(A)}{(\rho_{Ft})(B)} = 1591, \quad (21)$$

where V_F = fuel volume flow rate, cc per minute
 A = conversion factor, 3785 cc per gallon
 B = conversion factor, 60 minutes per hour.

As a result of the fuel volume flow determination, the water concentration in the fuel mixture was calculated:

$$W = \frac{WFR}{WFR + V_F} \times 100 = 19.4\%, \quad (22)$$

where W = water concentration, percent
 WFR = water flow rate, cc per minute
 V_F = fuel flow rate, cc per minute.

In order to facilitate subsequent calculations, the water content of the exhaust was modified to include the water introduced with the fuel along with the water entrained in the inlet air. Assuming a density of one gram per cubic centimeter for water,

$$WF = \frac{WFR}{453.6} = 0.8466, \quad (23)$$

where WF = water flow rate, pounds per minute
 WFR = water flow rate, cc per minute,

then,

$$PR = \frac{WF}{DAMF} = 0.0109, \quad (24)$$

where PR = moisture added with fuel, pounds water per pound dry air

and

$$H' = H + PR = 0.0217, \quad (25)$$

where H' = specific humidity of exhaust, pounds water per pound dry air.

The corrected volume concentration was

$$Y' = \frac{(H')(M_{AIR})}{M_{H_2O}} = 0.0349. \quad (26)$$

Exhaust Calculations

From the fuel analysis data shown in Appendix A, the hydrogen/carbon ratio of the fuel was calculated as follows:

$$HCR = \left(\frac{HD}{CA} \right) \left(\frac{M_C}{M_H} \right) = 1.78, \quad (27)$$

where HCR = fuel hydrogen/carbon ratio

HD = 12.83 = hydrogen content, percent by weight

CA = 85.75 = carbon content, percent by weight

M_C = 12.001 = molecular weight of carbon

M_H = 1.008 = molecular weight of hydrogen.

The concentrations of various exhaust constituents were measured using instruments appropriate to the type of gas and the level present in the exhaust stream. Each relevant range of each instrument was calibrated monthly using at least four gas mixtures within the range, and both zero and span gases were applied to each relevant range before and after testing on each test day. During each test run, scale readings from the instruments were compared to curves developed from the monthly calibrations, and concentrations were reported in parts per million (ppm) or percent. Three gas species, unburned hydrocarbons, carbon monoxide, and carbon dioxide, were of particular importance for the calculation of an air-fuel ratio. The hydrocarbon measurements were made on a wet basis, and the concentrations were corrected to a dry basis during the calculation procedure.

The air-fuel ratio was calculated from exhaust constituent levels using relationships described in the Federal Register.¹² The initial

calculation was for the stoichiometric fuel-air ratio:

$$\left(\frac{F}{A} \right)_{\text{STOICH}} = \frac{M_C + (HCR) \frac{M_H}{4}}{138.18 \left(1 + \frac{HCR}{4} \right)} = 0.0691. \quad (28)$$

The equivalence ratio was then calculated from

$$\phi = \frac{\left(\frac{F}{A} \right)_{\text{MEAS}}}{\left(\frac{F}{A} \right)_{\text{STOICH}}} = 0.544. \quad (29)$$

For convenience, the following ratios were calculated:

$$R_1 = \frac{HCC}{10^6}$$

$$R_2 = \frac{CO}{10^6}$$

$$R_3 = \frac{CO_2}{10^2},$$

where HCC = measured hydrocarbon concentration, parts per million carbon

CO = measured carbon monoxide concentration, parts per million

CO₂ = measured carbon dioxide concentration, percent.

The wet-to-dry correction factor was then obtained from:

$$K_w = \frac{1}{1 + \frac{HCR(R_2 + R_3) + \frac{2Y'}{\phi} (R_1 + R_2 + R_3) \left(1 + \frac{HCR}{4} \right)}{2 \left(1 + \frac{R_2}{(R_3)(K)} \right)}} = 0.929, \quad (30)$$

where K_w = wet-to-dry correction factor
 K = water-gas equilibrium constant = 3.5 .

then the hydrocarbon concentration that would exist in a dry stream was calculated:

$$HCD = \frac{HCC}{K_w} = 60 , \quad (31)$$

and

$$R_4 = \frac{HCD}{10^6} . \quad (32)$$

It was convenient to define the parameter

$$\bar{X} = R_2 + R_3 + R_4 , \quad (33)$$

for use in subsequent calculations

The exhaust fuel-air ratio was obtained from the relationship

$$\left(\frac{F}{A}\right)_{\text{calc}} = \frac{\frac{1}{\bar{X}} - \left(\frac{R_2}{2\bar{X}}\right) - \left(\frac{R_4}{\bar{X}}\right) + \left(\frac{HCR}{4}\right) \left(1 - \frac{R_4}{\bar{X}}\right) - \frac{4.77 \left(1 + \frac{HCR}{4}\right) \left(\frac{F}{A}\right)_{\text{STOICH}}}{(0.75)(HCR)}}{\left(\frac{K}{\left(\frac{R_2}{\bar{X}}\right)}\right) + \left(\frac{1 - K}{1 - \frac{R_4}{\bar{X}}}\right)} . \quad (34)$$

For the data representing Cummins run 235, the calculated fuel-air ratio was

$$\left(\frac{F}{A}\right)_{\text{calc}} = 0.0358 .$$

The difference between the calculated and measured values of the fuel-air ratio was obtained from

$$D = \frac{\left(\frac{F}{A}\right)_{\text{calc}} - \left(\frac{F}{A}\right)_{\text{meas}}}{\left(\frac{F}{A}\right)_{\text{meas}}} (100) = -4.9, \quad (35)$$

where D = percentage difference between measured and calculated fuel-air ratios.

According to reference (12), the absolute value of D should be less than 10 for most engine operating conditions.

The measured concentrations of nitric oxide were corrected for humidity using relationships described in reference (12). The calculation of the correction factor depends upon inlet air temperature, exhaust stream humidity, and the measured dry fuel-air ratio:

$$K_{\text{NO}_x} = \frac{1}{1 + A(G - 75) + B(T - 85)} = 1.19, \quad (36)$$

$$\text{where } A = 0.044 \left(\frac{F}{A}\right)_{\text{meas}} - 0.0038$$

$$B = -0.116 \left(\frac{F}{A}\right)_{\text{meas}} + 0.0053$$

$$G = \text{humidity in grains per pound dry air} \\ = (7000)(H')$$

$$T = \text{inlet air temperature, } ^\circ\text{F},$$

then

$$\text{DNO} = (\text{NO})(K_{\text{NO}_x}), \quad (37)$$

where DNO = corrected nitric oxide concentration

NO = measured dry nitric oxide concentration.

The above correction is based upon the use of a water-ice bath for condensation of the water vapor present in the exhaust stream. The specific instrument used for this program employed a methanol-dry ice bath for this purpose; the bath temperature was about -150°F . Thus, an additional correction for moisture removal was used:

$$DKNO = \frac{DNO}{1.00678} \quad (38)$$

The dry values of the exhaust constituent concentrations were used for the calculation of mass emissions. Again, several ratios were defined for convenience:

$$R_5 = \frac{HCD}{10^4}$$

$$R_6 = \frac{CO}{10^4}$$

$$R_7 = R_6 + CO_2 + R_5$$

$$R_8 = \frac{DKNO}{10^4}$$

The mass emissions, in grams per hour, were obtained from the following relationships:

$$W_{HC} = \frac{(R_5)(W_F)}{R_7} = 61 \quad (39)$$

$$W_{CO} = \frac{(M_{CO})(R_6)(W_F)}{(M_C + (HCR)(M_H))(R_7)} = 306 \quad (40)$$

$$W_{NO_x} = \frac{(M_{NO_2})(R_8)(W_F)}{(M_C + (HCR)(M_H))(R_7)} = 2940, \quad (41)$$

where W_{HC} , W_{CO} , W_{NO_x} = mass emissions of exhaust constituent, grams per hour

W_F = mass flow rate of diesel fuel, grams per hour
 = $(453.6)(F)$

M_{CO} = molecular weight of CO = 28.0

M_{NO_x} = molecular weight of NO_2 = 46.0
 M_C = molecular weight of carbon
 M_H = molecular weight of hydrogen.

The specific emissions were calculated on the basis of the corrected brake horsepower:

$$S_{HC} = \frac{W_{HC}}{CBHP} = 0.14 \quad (42)$$

$$S_{CO} = \frac{W_{CO}}{CBHP} + 0.69 \quad (43)$$

$$S_{NO_x} = \frac{W_{NO_x}}{CBHP} = 6.59, \quad (44)$$

where S_{HC} , S_{CO} , S_{NO_x} = specific emissions, grams per brake horsepower hour.

Statistical Calculations

During the Cummins engine tests, statistical procedures were used to evaluate the confidence in certain measured results and to assess the probable effect of the addition of water to the fuel. The performance of the statistical tests required that test procedures be repeated several times under the same conditions in order to provide suitable samples.

As an example of the statistical techniques, two sets of test data will be considered. Table B-4 contains a list of all of the diesel fuel consumption rates observed for the Cummins engine with no water addition and with 20 percent water addition. Sample 1, for no water addition, was regarded as a sample of the entire population of test runs that could be performed at the specified engine setting without water addition. Similarly, Sample 2 was considered to be representative of all of the test runs that might be conducted at the specified engine condition with 20 percent water addition.

The mean of each sample was calculated according to the relationship

$$\bar{X} = \frac{1}{n} \sum_{i=1}^n X, \quad (45)$$

TABLE B-4. POPULATION SAMPLES

Diesel Fuel Flow Rates at 1200 RPM
Cummins Engine Tests

Sample 1		Sample 2	
0% Water		20% Water	
<u>Run</u>	<u>Fuel Rate</u>	<u>Run</u>	<u>Fuel Rate</u>
178	54.72	182	53.71
188	55.30	192	53.04
194	54.43	228	53.92
224	54.84	242	53.80
230	55.04	<u>256</u>	<u>54.77</u>
238	54.94	Mean	53.85
244	55.58	S	0.6184
252	56.01	90% band	53.85 $\pm$ 0.5896
<u>258</u>	<u>55.94</u>		
Mean	55.20		
S	0.5482		
90% band	55.20 $\pm$ 0.340		

where $\bar{X}$ = sample mean
 n = number of items in sample
 X = value of each fuel rate in the sample.

The calculated mean value for each sample is shown in Table B-4.

The standard deviation for each sample was calculated according to:

$$S = \sqrt{\frac{\sum X^2 - \frac{(\sum X)^2}{n}}{n - 1}}, \quad (46)$$

where the individual terms are defined above. The standard deviation for each sample is also shown in Table B-4.

One statistical test was applied to each sample as an individual entity. The Student's t-distribution was used to attach a confidence band to each sample mean. Values of the t-distribution are shown in Table B-5.¹⁶ For a desired confidence level, say 90 percent, it can be argued that the true population mean lies within the band defined by

$$\bar{X} \pm t_{0.95} (n-1) \sqrt{\frac{S}{n}}, \quad (47)$$

where the values of t are obtained from Table B-5. For the example data, the values of the upper and lower limits of the 90 percent confidence band are shown in Table B-4. Thus, it is possible to state with 90 percent confidence that the fuel rate for an additional test at 1200 rpm without water addition would lie between 54.86 and 55.54 pounds per hour.

Since the effect of water addition is desired, it is also desirable to employ a test that compares the two samples. It is possible that the two samples selected are a part of the same population; in that case no definite statement could be made concerning the effect of water addition. The goal of the second statistical procedure is a confidence level for the statement that the means of the two populations (without and with water addition) are different.

As a first step, it was assumed that the two population means were equal. The pooled standard deviation was calculated:

TABLE B-5. CUMULATIVE DISTRIBUTION

v	0.75	0.80	0.85	0.90	0.95	0.975	0.995	0.9995
1	1.0005	1.376	1.963	3.078	6.314	12.706	63.657	636.619
2	0.816	1.061	1.386	1.886	2.920	4.303	8.925	31.598
3	0.765	0.978	1.250	1.638	2.353	3.182	5.841	12.941
4	0.741	0.941	1.190	1.533	2.132	2.776	4.604	8.610
5	0.727	0.920	1.156	1.476	2.015	2.571	4.032	6.859
6	0.718	0.906	1.134	1.440	1.943	2.447	3.707	5.959
7	0.711	0.896	1.119	1.415	1.895	2.365	3.499	5.405
8	0.706	0.889	1.108	1.397	1.860	2.306	3.355	5.041
9	0.703	0.883	1.100	1.383	1.833	2.262	3.250	4.781
10	0.700	0.879	1.093	1.372	1.812	2.228	3.169	4.587
11	0.697	0.876	1.088	1.363	1.796	2.201	3.106	4.437
12	0.695	0.873	1.083	1.356	1.782	2.179	3.055	4.318
13	0.694	0.870	1.079	1.350	1.771	2.160	3.012	4.221
14	0.692	0.868	1.076	1.345	1.761	2.145	2.977	4.140
15	0.691	0.866	1.074	1.341	1.753	2.131	2.947	4.073
16	0.690	0.866	1.071	1.337	1.746	2.120	2.921	4.015
17	0.689	0.863	1.069	1.333	1.740	2.110	2.898	3.965
18	0.688	0.862	1.067	1.330	1.734	2.101	2.878	3.922
19	0.688	0.861	1.066	1.328	1.729	2.093	2.861	3.883
20	0.687	0.860	1.064	1.325	1.725	2.086	2.845	3.850
21	0.686	0.859	1.063	1.323	1.721	2.080	2.831	3.819
22	0.686	0.858	1.061	1.321	1.717	2.074	2.819	3.792
23	0.685	0.858	1.060	1.319	1.714	2.069	2.807	3.767
24	0.685	0.857	1.059	1.318	1.711	2.064	2.797	3.745
25	0.684	0.856	1.058	1.316	1.708	2.060	2.787	3.725
26	0.684	0.856	1.058	1.315	1.706	2.056	2.779	3.707
27	0.684	0.855	1.057	1.314	1.703	2.052	2.771	3.690
28	0.683	0.855	1.056	1.313	1.701	2.048	2.763	3.674
29	0.683	0.854	1.055	1.311	1.699	2.045	2.756	3.659
30	0.683	0.854	1.055	1.310	1.697	2.042	2.750	3.646
35	0.682	0.852	1.052	1.306	1.690	2.030	2.724	3.591
40	0.681	0.851	1.050	1.303	1.684	2.021	2.704	3.551
45	0.680	1.048	1.048	1.301	1.680	2.014	2.690	3.520
50	0.680	0.849	1.047	1.299	1.676	2.008	2.678	3.496
55	0.679	0.849	1.047	1.297	1.673	2.004	2.669	3.476
60	0.679	0.848	1.046	1.296	1.671	2.000	2.660	3.460
70	0.678	0.847	1.045	1.294	1.667	1.994	2.648	3.435
80	0.678	0.847	1.044	1.293	1.665	1.990	2.638	3.416
90	0.678	0.846	1.043	1.291	1.662	1.987	2.632	3.402
100	0.677	0.846	1.042	1.290	1.661	1.984	2.626	3.390
200	0.676	0.844	1.039	1.286	1.653	1.972	2.601	3.340
300	0.676	0.843	1.038	1.285	1.650	1.968	2.592	3.323
400	0.676	0.843	1.038	1.284	1.649	1.966	2.588	3.315
500	0.676	0.843	1.037	1.284	1.684	1.965	2.586	3.310
1000	0.675	0.842	1.037	1.283	1.647	1.962	2.581	3.301
∞	0.67449	0.84162	1.03643	1.28155	1.64485	1.95996	2.57582	3.29053

$$S = \frac{(\eta_1 - 1) S_1^2 + (\eta_2 - 1) S_2^2}{\eta_1 + \eta_2 - 2} = 0.3278, \quad (48)$$

where η = sample size

S = sample standard deviation,

then

$$S_{\bar{X}_1 - \bar{X}_2} = \sqrt{\frac{S^2}{\eta_1} + \frac{S^2}{\eta_2}} = 0.3194, \quad (49)$$

and

$$T = \frac{\bar{X}_1 - \bar{X}_2}{S_{\bar{X}_1 - \bar{X}_2}} = 4.2272, \quad (50)$$

now, if

$$T \leq -t_{(1 - \frac{\alpha}{2})}(\eta_1 + \eta_2 - 2), \quad (51)$$

or

$$T \geq t_{(1 - \frac{\alpha}{2})}(\eta_1 + \eta_2 - 2), \quad (52)$$

where α is the probability of rejecting a true hypothesis, then the hypothesis of equal sample means can be rejected. For the present case, using Table B-5,

$$T > t_{(.995)}(12),$$

and

$$1 - \frac{\alpha}{2} = 0.995,$$

imply that $\alpha = 0.01$.

Thus, it is possible to state with 99 percent confidence that the two samples represent different populations and that significance can be attached to the difference between the means.

APPENDIX C
TEST RESULTS

TABLE C-1. ENGINE TEST RESULTS, CUMMINS ENGINE,
900 RPM, BASELINE

DYNAMOMETER CONSTANT: 3000		API GRAVITY OF DIESEL FUEL: 35.3 AT 60F						
H/C RATIO: 1.78								
RUN NUMBER		259.	262.	268.	269.	275.	276.	282.
NOM. WATER PCT.		0.	0.	0.	0.	0.	0.	0.
ENGINE SPEED	RPM	900.	900.	900.	900.	900.	900.	900.
OBS. TORQUE	LB-FT	257.	257.	257.	257.	257.	257.	257.
BAR. PRESS.	IN-HG	28.95	29.14	29.12	29.32	29.25	29.30	29.21
DRY BULB	DEG F	83.	77.	87.	78.	91.	77.	89.
WET BULB	DEG F	69.	66.	66.	66.	68.	61.	65.
REL. HUMIDITY	PCT	49.	56.	32.	53.	30.	39.	26.
CORR. BHP	HP	44.9	44.1	44.8	43.9	44.8	43.6	44.6
CORR. BMEP	PSI	23.1	22.7	23.1	22.6	23.0	22.5	23.0
FUEL FLOW	LB/HR	25.12	25.11	24.73	25.52	25.24	24.70	24.85
WATER FLOW	CC/MIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CALC. VOL. %	PCT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BSFC	LB/BHP-HR	5590	5692	5516	5817	5635	5662	5570
AIR FLOW	LB/MIN	26.1	26.5	26.0	26.3	26.1	26.6	26.1
COOLANT IN	DEG F	183.	174.	179.	179.	181.	178.	176.
COOLANT OUT	DEG F	188.	184.	185.	185.	186.	184.	183.
OIL SUMP	DEG F	194.	188.	193.	192.	193.	189.	191.
FUEL IN	DEG F	90.	90.	93.	89.	95.	92.	92.
FUEL RETURN	DEG F	137.	135.	151.	143.	150.	142.	145.
FUEL SUPPLY	DEG F	111.	106.	108.	104.	107.	104.	107.
FUEL COOLER	DEG F	87.	91.	91.	88.	95.	95.	90.
INTAKE AIR	DEG F	83.	75.	90.	76.	92.	75.	90.
TURB. INLET (L)	DEG F	457.	450.	467.	448.	464.	447.	464.
TURB. INLET (R)	DEG F	480.	471.	482.	468.	482.	464.	478.
COMP. OUT (L)	DEG F	101.	92.	107.	93.	110.	92.	107.
COMP. OUT (R)	DEG F	104.	97.	112.	93.	110.	95.	107.
CHARGE AIR (L)	DEG F	174.	168.	174.	172.	176.	170.	172.
CHARGE AIR (R)	DEG F	177.	170.	176.	174.	177.	173.	174.
EXH. STACK (R)	DEG F	444.	435.	446.	433.	445.	430.	441.
EXH. STACK (L)	DEG F	425.	419.	434.	416.	431.	415.	430.
WATER INLET	DEG F	91.	84.	93.	83.	97.	80.	97.
CELL AIR	DEG F	80.	77.	90.	80.	92.	78.	90.
EXHAUST 1R	DEG F	559.	553.	561.	555.	560.	551.	557.
EXHAUST 2R	DEG F	433.	429.	442.	434.	445.	426.	431.
EXHAUST 3R	DEG F	439.	421.	438.	427.	427.	419.	422.
EXHAUST 4R	DEG F	513.	566.	509.	508.	511.	502.	510.
EXHAUST 5R	DEG F	486.	480.	489.	483.	491.	479.	497.
EXHAUST 6R	DEG F	534.	527.	545.	532.	541.	538.	540.
EXHAUST 1L	DEG F	458.	450.	465.	457.	460.	457.	463.
EXHAUST 2L	DEG F	529.	534.	540.	530.	529.	535.	537.
EXHAUST 3L	DEG F	435.	427.	443.	427.	439.	429.	438.
EXHAUST 4L	DEG F	440.	426.	439.	428.	443.	432.	439.
EXHAUST 5L	DEG F	551.	550.	566.	551.	549.	546.	558.
EXHAUST 6L	DEG F	472.	466.	490.	471.	486.	479.	488.
OIL PRESSURE	PSI	48.	50.	48.	48.	48.	50.	49.
RAIL PRESSURE	PSI	5.0	6.0	6.0	6.0	6.0	6.0	6.0
BOOST (R)	PSI	1.5	1.5	1.5	1.5	1.5	1.5	1.5
BOOST (L)	PSI	1.0	1.0	1.0	1.0	1.0	1.0	1.0
INLET VAC (R)	IN-H2O	2.2	2.2	2.2	2.1	1.0	2.1	2.2
EXH. PRESS. (R)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EXH. PRESS. (L)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TURB. IN. (R)	IN-HG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TURB. IN. (L)	IN-HG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FULL PRESS	PSI	20.	20.	20.	20.	20.	20.	20.
EMULSION PRESS.	PSI	100.	100.	100.	100.	100.	100.	100.
FUEL SUPPLY	PSI	3.	3.	3.	2.	3.	3.	3.
WATER PRESS.	PSI	0.	0.	0.	0.	0.	0.	0.

TABLE C-2. ENGINE TEST RESULTS, CUMMINS ENGINE,
900 RPM, 5% WATER

DYNAMOMETER CONSTANT: 3000
H/C RATIO: 1.28

API GRAVITY OF DIESEL FUEL: 35.3 AT 60F

KUN NUMBER		260	263	270	277
NOM. WATER PCT		5	5	5	5
ENGINE SPEED	RPM	900	900	900	900
OBS. TORQUE	LB-FT	257	257	257	257
BAR. PRESS.	IN-HG	28.90	29.15	29.34	29.31
DRY BULB	DEG F	85	77	78	77
WET BULB	DEG F	70	66	66	61
REL. HUMIDITY	PCT	47	56	53	39
CORR. BHP	HP	45.3	44.3	44.1	43.8
CORR. BMEP	PSI	23.3	22.8	22.7	22.5
FUEL FLOW	LB/HR	24.82	25.06	24.89	24.73
WATER FLOW	CC/MIN	11.5	10.5	11.1	10.5
CALC. VOL. %	PCT	4.9	4.4	4.7	4.5
BSFC	LB/BHP-HR	548.3	565.2	564.6	561.7
AIR FLOW	LB/MIN	25.6	26.2	26.4	26.4
COOLANT IN	DEG F	182	179	179	177
COOLANT OUT	DEG F	187	185	184	184
OIL SUMP	DEG F	194	191	192	190
FUEL IN	DEG F	99	99	92	92
FUEL RETURN	DEG F	151	147	146	145
FUEL SUPPLY	DEG F	114	109	107	107
FUEL COOLER	DEG F	96	90	91	90
INTAKE AIR	DEG F	87	79	80	78
TURB. INLET (L)	DEG F	448	458	448	448
TURB. INLET (R)	DEG F	467	476	469	466
COMP. OUT (L)	DEG F	104	96	97	95
COMP. OUT (R)	DEG F	107	98	97	95
CHARGE AIR (L)	DEG F	174	172	173	171
CHARGE AIR (R)	DEG F	177	175	175	174
EXH. STACK (R)	DEG F	434	440	434	433
EXH. STACK (L)	DEG F	419	425	416	417
WATER INLET	DEG F	94	85	84	84
CELL AIR	DEG F	86	80	81	79
EXHAUST 1R	DEG F	563	560	548	549
EXHAUST 2R	DEG F	435	433	430	424
EXHAUST 3R	DEG F	430	429	426	419
EXHAUST 4R	DEG F	497	499	491	495
EXHAUST 5R	DEG F	471	484	470	477
EXHAUST 6R	DEG F	540	530	526	527
EXHAUST 1L	DEG F	464	466	454	451
EXHAUST 2L	DEG F	533	535	525	528
EXHAUST 3L	DEG F	432	436	430	433
EXHAUST 4L	DEG F	425	431	425	426
EXHAUST 5L	DEG F	545	533	536	533
EXHAUST 6L	DEG F	475	473	471	468
OIL PRESSURE	PSI	48	48	48	49
RAIL PRESSURE	PSI	6.0	6.0	6.0	6.0
BOOST (R)	PSI	1.2	1.0	1.5	1.5
BOOST (L)	PSI	1.2	1.0	1.5	1.5
INLET VAC (R)	IN-H2O	2.2	2.2	2.2	2.2
EXH. PRESS. (R)	PSI	0.0	0.0	0.0	0.0
EXH. PRESS. (L)	PSI	0.0	0.0	0.0	0.0
TURB. IN. (R)	IN-HG	0.0	0.0	0.0	0.0
TURB. IN. (L)	IN-HG	0.0	0.0	0.0	0.0
FUEL PRESS.	PSI	20	20	20	20
EMULSION PRESS.	PSI	100	100	100	100
FUEL SUPPLY	PSI	2	3	3	3
WATER PRESS.	PSI	60	60	60	60

TABLE C-3. ENGINE TEST RESULTS, CUMMINS ENGINE,
900 RPM, 10% WATER

DYNAMOMETER CONSTANT: 3000
H/C RATIO: 1.78

API GRAVITY OF DIESEL FUEL: 35.3 AT 60F

RUN NUMBER		261.	264.	271.	278.
NOM. WATER PCT.		10.	10.	10.	10.
ENGINE SPEED	RPM	900.	900.	900.	900.
OBS. TORQUE	LB-FT	257.	257.	257.	257.
BAR. PRESS.	IN-HG	28.89	29.15	29.35	29.32
DRY BULB	DEG F	85.	82.	82.	80.
WET BULB	DEG F	70.	66.	67.	64.
REL. HUMIDITY	PCT	48.	43.	46.	41.
CORR. BHP	HP	45.4	44.5	44.2	44.0
CORR. BMEP	PSI	23.4	22.9	22.7	22.6
FUEL FLOW	LB/HR	24.87	25.03	25.31	24.89
WATER FLOW	CC/MIN	17.3	19.7	19.7	19.7
CALC. VOL. %	PCT	7.1	8.0	7.9	8.1
BSFC	LB/BHP-HR	5479	5627	5731	5660
AIR FLOW	LB/MIN	25.6	26.2	26.2	26.6
COOLANT IN	DEG F	184.	178.	179.	174.
COOLANT OUT	DEG F	189.	184.	184.	180.
OIL SUMP	DEG F	195.	191.	192.	187.
FUEL IN	DEG F	102.	92.	94.	93.
FUEL RETURN	DEG F	155.	111.	148.	146.
FUEL SUPPLY	DEG F	114.	147.	111.	109.
FUEL COOLER	DEG F	101.	90.	92.	92.
INTAKE AIR	DEG F	89.	83.	82.	80.
TURB. INLET (L)	DEG F	442.	445.	440.	439.
TURB. INLET (R)	DEG F	467.	463.	461.	457.
COMP. OUT (L)	DEG F	106.	99.	99.	96.
COMP. OUT (R)	DEG F	110.	104.	99.	96.
CHARGE AIR (L)	DEG F	176.	172.	173.	168.
CHARGE AIR (R)	DEG F	178.	174.	175.	171.
EXH. STACK (R)	DEG F	433.	430.	427.	424.
EXH. STACK (L)	DEG F	412.	415.	409.	408.
WATER INLET	DEG F	92.	86.	84.	82.
CELL AIR	DEG F	88.	81.	83.	80.
EXHAUST 1R	DEG F	551.	550.	544.	538.
EXHAUST 2R	DEG F	438.	434.	427.	425.
EXHAUST 3R	DEG F	417.	423.	421.	413.
EXHAUST 4R	DEG F	494.	496.	492.	489.
EXHAUST 5R	DEG F	475.	470.	465.	474.
EXHAUST 6R	DEG F	527.	523.	521.	516.
EXHAUST 1L	DEG F	466.	464.	460.	454.
EXHAUST 2L	DEG F	515.	524.	519.	519.
EXHAUST 3L	DEG F	425.	432.	426.	420.
EXHAUST 4L	DEG F	414.	429.	421.	418.
EXHAUST 5L	DEG F	535.	531.	528.	530.
EXHAUST 6L	DEG F	470.	462.	464.	463.
OIL PRESSURE	PSI	47.	49.	48.	50.
RAIL PRESSURE	PSI	7.5	7.5	7.5	7.5
BOOST (R)	PSI	1.2	1.0	1.5	1.5
BOOST (L)	PSI	2.3	2.2	2.2	2.2
INLET VAC. (R)	IN-H2O	0.0	0.0	0.0	0.0
EXH. PRESS. (R)	PSI	0.0	0.0	0.0	0.0
EXH. PRESS. (L)	PSI	0.0	0.0	0.0	0.0
TURB. IN. (R)	IN-HG	0.0	0.0	0.0	0.0
TURB. IN. (L)	IN-HG	0.0	0.0	0.0	0.0
FUEL PRESS	PSI	20.	20.	20.	20.
EMULSION PRESS.	PSI	100.	100.	100.	100.
FUEL SUPPLY	PSI	2.	3.	3.	3.
WATER PRESS.	PSI	50.	60.	60.	60.

TABLE C-4. ENGINE TEST RESULTS, CUMMINS ENGINE,
900 RPM, 15% WATER

DYNAMOMETER CONSTANT: 3000
H/C RATIO: 1.78

API GRAVITY OF DIESEL FUEL: 35.3 AT 60F

RUN NUMBER		265.	272.	279.
NOM. WATER PCT.		15.	15.	15.
ENGINE SPEED	RPM	900.	900.	900.
OBS. TORQUE	LB-FT	257.	257.	257.
BAR. PRESS.	IN-HG	29.15	29.34	29.30
DRY BULB	DEG F	83.	87.	84.
WET BULB	DEG F	67.	68.	66.
REL. HUMIDITY	PCT	43.	37.	38.
CORR. BHP	HP	44.6	44.4	44.3
CORR. BMEP	PSI	22.9	22.8	22.8
FUEL FLOW	LB/HR	24.50	24.29	24.46
WATER FLOW	CC/MIN	33.8	33.8	33.8
CALC. VOL. %	PCT	13.2	13.3	13.2
BSFC	LB/BHP-HR	5498	5474	5526
AIR FLOW	LB/MIN	26.1	26.3	26.3
COOLANT IN	DEG F	179.	180.	178.
COOLANT OUT	DEG F	185.	185.	184.
OIL SUMP	DEG F	192.	192.	190.
FUEL IN	DEG F	92.	97.	99.
FUEL RETURN	DEG F	112.	150.	152.
FUEL SUPPLY	DEG F	149.	112.	109.
FUEL COOLER	DEG F	90.	95.	97.
INTAKE AIR	DEG F	84.	86.	84.
TURB. INLET (L)	DEG F	440.	435.	435.
TURB. INLET (R)	DEG F	459.	457.	455.
COMP. OUT (L)	DEG F	100.	102.	100.
COMP. OUT (R)	DEG F	105.	102.	100.
CHARGE AIR (L)	DEG F	174.	174.	173.
CHARGE AIR (R)	DEG F	176.	176.	175.
EXH. STACK (R)	DEG F	425.	424.	423.
EXH. STACK (L)	DEG F	409.	406.	406.
WATER INLET	DEG F	88.	89.	86.
CELL AIR	DEG F	83.	86.	85.
EXHAUST 1R	DEG F	540.	538.	537.
EXHAUST 2R	DEG F	429.	427.	427.
EXHAUST 3R	DEG F	420.	416.	415.
EXHAUST 4R	DEG F	491.	489.	488.
EXHAUST 5R	DEG F	467.	471.	470.
EXHAUST 6R	DEG F	514.	519.	517.
EXHAUST 1L	DEG F	463.	458.	457.
EXHAUST 2L	DEG F	511.	508.	510.
EXHAUST 3L	DEG F	419.	417.	420.
EXHAUST 4L	DEG F	425.	421.	423.
EXHAUST 5L	DEG F	530.	526.	529.
EXHAUST 6L	DEG F	455.	461.	464.
OIL PRESSURE	PSI	48.	48.	49.
RAIL PRESSURE	PSI	7.0	7.0	7.0
BOOST (R)	PSI	1.5	1.5	1.5
BOOST (L)	PSI	2.2	2.2	2.2
INLET VAC. (R)	IN-H2O	0.0	0.0	0.0
EXH. PRESS. (R)	PSI	0.0	0.0	0.0
EXH. PRESS. (L)	PSI	0.0	0.0	0.0
TURB. IN. (R)	IN-HG	0.0	0.0	0.0
TURB. IN. (L)	IN-HG	0.0	0.0	0.0
FUEL PRESS.	PSI	20.	20.	20.
EMULSION PRESS.	PSI	100.	100.	100.
FUEL SUPPLY	PSI	3.	3.	3.
WATER PRESS.	PSI	60.	60.	60.

TABLE C-5. ENGINE TEST RESULTS, CUMMINS ENGINE,
900 RPM, 20% WATER

DYNAMOMETER CONSTANT: 3000
H/C RATIO: 1.78

API GRAVITY OF DIESEL FUEL: 35.3 AT 60F

RUN NUMBER		266.	273.	280.
NOM. WATER PCT.		20.	20.	20.
ENGINE SPEED	RPM	900.	900.	900.
OBS. TORQUE	LB-FT	257.	257.	257.
BAR. PRESS.	IN-HG	29.14	29.32	29.28
DRY BULB	DEG F	83.	87.	84.
WET BULB	DEG F	87.	88.	86.
REL. HUMIDITY	PCT	43.	37.	38.
CORR. BHP	HP	44.7	44.5	44.4
CORR. BMEP	PSI	23.0	22.9	22.8
FUEL FLOW	LB/HR	24.45	24.81	24.68
WATER FLOW	CC/MIN	49.8	49.8	49.8
CALC. VOL. %	PCT	18.4	18.1	18.2
BSFC	LB/BHP-HR	5469	5573	5565
AIR FLOW	LB/MIN	25.7	26.2	26.2
COOLANT IN	DEG F	179.	180.	176.
COOLANT OUT	DEG F	184.	186.	183.
OIL SUMP	DEG F	192.	192.	190.
FUEL IN	DEG F	94.	99.	95.
FUEL RETURN	DEG F	151.	152.	152.
FUEL SUPPLY	DEG F	115.	122.	115.
FUEL COOLER	DEG F	92.	98.	93.
INTAKE AIR	DEG F	86.	88.	85.
TURB. INLET (L)	DEG F	432.	426.	424.
TURB. INLET (R)	DEG F	448.	448.	443.
COMP. OUT (L)	DEG F	102.	104.	102.
COMP. OUT (R)	DEG F	107.	104.	102.
CHARGE AIR (L)	DEG F	174.	175.	172.
CHARGE AIR (R)	DEG F	176.	177.	174.
EXH. STACK (R)	DEG F	415.	415.	412.
EXH. STACK (L)	DEG F	402.	397.	396.
WATER INLET	DEG F	90.	89.	88.
CELL AIR	DEG F	85.	89.	87.
EXHAUST 1R	DEG F	520.	518.	516.
EXHAUST 2R	DEG F	411.	404.	409.
EXHAUST 3R	DEG F	412.	409.	406.
EXHAUST 4R	DEG F	483.	482.	477.
EXHAUST 5R	DEG F	457.	460.	463.
EXHAUST 6R	DEG F	502.	505.	501.
EXHAUST 1L	DEG F	455.	452.	450.
EXHAUST 2L	DEG F	488.	484.	486.
EXHAUST 3L	DEG F	408.	407.	405.
EXHAUST 4L	DEG F	414.	409.	411.
EXHAUST 5L	DEG F	515.	509.	507.
EXHAUST 6L	DEG F	440.	441.	432.
OIL PRESSURE	PSI	48.	48.	49.
RAIL PRESSURE	PSI	7.5	8.0	8.0
BOOST (R)	PSI	1.5	1.5	1.5
BOOST (L)	PSI	1.5	1.5	1.5
INLET VAC. (R)	IN-H2O	2.2	2.2	2.2
EXH. PRESS. (R)	PSI	0.0	0.0	0.0
EXH. PRESS. (L)	PSI	0.0	0.0	0.0
TURB. IN. (R)	IN-HG	0.0	0.0	0.0
TURB. IN. (L)	IN-HG	0.0	0.0	0.0
FUEL PRESS.	PSI	20.	20.	20.
EMULSION PRESS.	PSI	100.	100.	100.
FUEL SUPPLY	PSI	3.	3.	3.
WATER PRESS.	PSI	60.	60.	60.

TABLE C-6. ENGINE TEST RESULTS, CUMMINS ENGINE,
900 RPM, 25% WATER

DYNAMOMETER CONSTANT: 3000
H/C RATIO: 1.78

API GRAVITY OF DIESEL FUEL: 35.3 AT 60F

RUN NUMBER		267.	274.	281.
NOM. WATER PCT.		25.	25.	25.
ENGINE SPEED	RPM	900.	900.	900.
ORS. TORQUE	LB-FT	257.	257.	257.
BAR. PRESS	IN-HG	29.13	29.29	29.25
DRY BULB	DEG F	87.	90.	88.
WET BULB	DEG F	66.	69.	65.
REL. HUMIDITY	PCT	32.	34.	28.
CORR. BHP	HP	44.7	44.7	44.5
CORR. BMEP	PSI	23.0	23.0	22.9
FUEL FLOW	LB/HR	25.16	24.84	24.73
WATER FLOW	CC/MIN	66.4	66.4	66.4
CALC. VOL. %	PCT	22.6	22.7	22.9
BSFC	LB/BHP-HR	5628	5560	5562
AIR FLOW	LB/MIN	26.0	26.2	26.1
COOLANT IN	DEG F	183.	181.	176.
COOLANT OUT	DEG F	188.	187.	182.
OIL SUMP	DEG F	194.	193.	189.
FUEL IN	DEG F	95.	100.	95.
FUEL RETURN	DEG F	154.	155.	151.
FUEL SUPPLY	DEG F	112.	114.	113.
FUEL COOLER	DEG F	93.	100.	94.
INTAKE AIR	DEG F	88.	90.	88.
TURB. INLET (L)	DEG F	428.	426.	421.
TURB. INLET (R)	DEG F	443.	445.	440.
COMP. OUT (L)	DEG F	105.	107.	104.
COMP. OUT (R)	DEG F	110.	107.	104.
CHARGE AIR (L)	DEG F	176.	176.	172.
CHARGE AIR (R)	DEG F	178.	178.	174.
EXH. STACK (R)	DEG F	411.	412.	407.
EXH. STACK (L)	DEG F	400.	398.	393.
WATER INLET	DEG F	89.	90.	88.
CELL AIR	DEG F	88.	90.	88.
EXHAUST 1R	DEG F	507.	510.	509.
EXHAUST 2R	DEG F	406.	403.	396.
EXHAUST 3R	DEG F	412.	411.	406.
EXHAUST 4R	DEG F	473.	481.	473.
EXHAUST 5R	DEG F	450.	461.	460.
EXHAUST 6R	DEG F	495.	499.	492.
EXHAUST 1L	DEG F	450.	450.	446.
EXHAUST 2L	DEG F	483.	481.	477.
EXHAUST 3L	DEG F	411.	412.	410.
EXHAUST 4L	DEG F	411.	413.	409.
EXHAUST 5L	DEG F	496.	503.	491.
EXHAUST 6L	DEG F	432.	439.	432.
OIL PRESSURE	PSI	48.	48.	50.
RAIL PRESSURE	PSI	8.0	9.0	8.0
BOOST (R)	PSI	5.9	5.5	5.5
BOOST (L)	PSI	5.9	5.5	5.5
INLET VAC. (R)	IN-H2O	2.2	2.2	2.2
EXH. PRESS. (R)	PSI	0.0	0.0	0.0
EXH. PRESS. (L)	PSI	0.0	0.0	0.0
TURB. IN. (R)	IN-HG	0.0	0.0	0.0
TURB. IN. (L)	IN-HG	0.0	0.0	0.0
FUEL PRESS	PSI	20.	20.	20.
EMULSION PRESS	PSI	100.	100.	0.
FUEL SUPPLY	PSI	3.	3.	3.
WATER PRESS.	PSI	60.	60.	60.

TABLE C-7. ENGINE TEST RESULTS, CUMMINS ENGINE,
1200 RPM, BASELINE

DYNAMOMETER CONSTANT: 3000 M/C RATIO: 1 78		API GRAVITY OF DIESEL FUEL: 35.3 AT 60F								
RUN NUMBER		178	188	194	224	230	238	244	252	258
NOM WATER PCT		0	0	0	0	0	0	0	0	0
ENGINE SPEED	RPM	1200	1200	1200	1200	1200	1200	1200	1200	1200
OBS. TORQUE	LB-FT	508	508	508	508	508	508	508	508	508
BAR. PRESS.	IN-HG	29.33	29.11	29.17	29.03	29.03	28.95	28.92	29.01	29.10
DRY BULB	DEG F	78	73	81	82	89	86	100	82	81
WET BULB	DEG F	63	68	72	76	76	76	78	77	74
REL HUMIDITY	PCT	43	78	65	76	55	63	38	80	72
CORR. BHP	HP	115.4	116.2	117.5	118.9	119.9	119.8	121.6	119.4	117.8
CORR. BMEP	PSI	44.6	44.8	45.4	45.9	46.3	46.2	46.9	46.1	45.5
FUEL FLOW	LB/HR	54.72	55.30	54.43	54.84	55.04	54.94	55.58	56.01	55.94
WATER FLOW	CC/MIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CALC VOL. %	PCT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BSFC	LB/BHP-HR	4740	4761	4631	4613	4589	4586	4570	4689	4748
AIR FLOW	LB/MIN	38.4	38.0	37.3	36.5	36.8	37.3	36.7	36.9	37.3
STOICH. F/A		0.691	0.691	0.691	0.691	0.691	0.691	0.691	0.691	0.691
MEAS. F/A		0.237	0.242	0.243	0.250	0.249	0.245	0.252	0.253	0.250
CALC. F/A		0.256	0.248	0.250	0.246	0.245	0.250	0.255	0.235	0.252
% DIFF.	PCT	8.07	2.37	2.74	-1.67	-1.80	2.07	-1.18	-7.14	6.1
COOLANT IN	DEG F	169	172	173	176	177	174	170	176	177
COOLANT OUT	DEG F	180	181	182	185	185	183	180	184	185
OIL SUMP	DEG F	194	194	197	198	200	195	195	198	199
FUEL IN	DEG F	93	92	95	100	103	99	103	102	96
FUEL RETURN	DEG F	147	149	152	149	152	149	150	149	150
FUEL SUPPLY	DEG F	91	94	102	102	109	104	109	103	95
FUEL COOLER	DEG F	90	90	91	96	96	96	98	99	94
INTAKE AIR	DEG F	79	72	81	82	91	87	100	84	79
TURB. INLET (L)	DEG F	649	629	637	663	658	658	677	664	657
TURB. INLET (R)	DEG F	639	657	660	653	684	658	657	659	682
COMP. OUT (L)	DEG F	112	106	112	113	123	118	131	114	111
COMP. OUT (R)	DEG F	111	105	112	112	122	118	131	114	111
CHARGE AIR (L)	DEG F	167	168	169	170	172	169	169	170	171
CHARGE AIR (R)	DEG F	168	169	170	172	174	170	170	171	173
EXH. STACK (R)	DEG F	584	599	601	598	622	600	604	603	620
EXH. STACK (L)	DEG F	594	574	579	605	599	599	621	605	600
WATER INLET	DEG F	81	75	86	86	94	87	103	85	86
CELL AIR	DEG F	78	76	80	85	92	90	101	87	80
EXHAUST 1R	DEG F	662	713	701	711	715	709	698	706	714
EXHAUST 2R	DEG F	509	598	568	583	581	568	563	585	595
EXHAUST 3R	DEG F	607	600	621	588	627	614	618	608	610
EXHAUST 4R	DEG F	677	669	680	682	690	680	679	704	692
EXHAUST 5R	DEG F	642	654	661	653	671	643	633	657	653
EXHAUST 6R	DEG F	698	711	715	709	735	704	692	703	711
EXHAUST 1L	DEG F	663	655	632	670	653	670	689	674	657
EXHAUST 2L	DEG F	715	678	655	692	666	712	697	706	701
EXHAUST 3L	DEG F	613	601	623	621	642	616	643	630	628
EXHAUST 4L	DEG F	627	618	626	640	633	626	644	645	628
EXHAUST 5L	DEG F	714	639	670	709	680	714	720	706	716
EXHAUST 6L	DEG F	680	679	690	683	702	689	701	694	0
OIL PRESSURE	PSI	65	66	64	64	64	66	66	65	64
RAIL PRESSURE	PSI	14.9	149.0	15	15.0	15.0	15.0	15.0	15.0	15.0
BOOST (R)	PSI	1.8	1	1	1	1	1	1	1	1
BOOST (L)	PSI	2.6	2	2	2	2	2	2	2	2
INLET VAC. (R)	IN-H2O	3.6	3	3	4	4	4	4	4	4
EXH. PRESS. (R)	PSI	1	1	1	1	1	1	1	1	1
EXH. PRESS. (L)	PSI	1	1	1	1	1	1	1	1	1
TURB. IN. (R)	IN-HG	2.5	2	2	2	2	2	2	2	2
TURB. IN. (L)	IN-HG	1.4	1.4	1.5	1.5	1.5	1.5	1.5	1.5	1.5
FUEL PRESS.	PSI	18	21	20	20	20	20	20	20	20
EMULSION PRESS.	PSI	100	100	100	100	100	100	100	100	100
FUEL SUPPLY	PSI	2	2	2	2	2	2	2	2	2
WATER PRESS.	PSI	0	0	0	0	0	0	0	0	0
HYDROCARBONS	PPMC	96	54	84	77	124	120	117	70	59
CARBON MONOXIDE	PPM	488	212	508	281	199	233	239	239	233
NITRIC OXIDE	PPM	340	289	263	213	229	217	239	174	225
NITROGEN OXIDES	PPM	355	313	288	234	251	230	258	198	240
CARBON DIOXIDE	PCT	5.4	5.3	5.3	5.3	5.2	5.3	5.5	5.6	5.4
OXYGEN	PCT	14.3	15.8	15.8	11.6	9.9	13.9	19.6	13.6	15.2
SMOKE OPACITY	PCT	7.5	8.6	8.7	9.6	12.5	10.2	10.5	9.5	10.5
HC MASS	GM-HR	45.656	26.649	40.645	37.936	62.058	58.433	56.697	37.212	29.219
CO MASS	GM-HR	446.11	283.80	475.89	268.15	192.15	218.68	223.13	244.86	223.67
NOX MASS	GM-HR	521.28	535.94	484.32	431.38	441.64	484.88	419.61	383.03	427.36
BSHC	GM/BHP-HR	3.955	2.294	3.499	3.191	5.174	4.879	4.678	3.116	2.480
BSOC	GM/BHP-HR	3.8642	1.7475	4.0426	2.2588	1.6823	1.8259	1.8348	0.9011	1.0811
BSNO	GM/BHP-HR	4.5146	4.6137	4.1211	3.6298	3.6818	3.3749	3.4504	3.2069	3.6272

TABLE C-8. ENGINE TEST RESULTS, CUMMINS ENGINE,
1200 RPM, 5% WATER

DYNAMOMETER CONSTANT: 3000		API GRAVITY OF DIESEL FUEL: 35.3 AT 60F				
H/C RATIO: 1.78						
RUN NUMBER		179	189	225	239	253
NOM. WATER PCT.		5	5	5	5	5
ENGINE SPEED	RPM	1200	1200	1200	1200	1200
OBS. TORQUE	LB-FT	508	508	508	508	508
BAR. PRESS.	IN-HG	29.32	29.14	29.04	28.97	29.02
DRY BULB	DEG F	78	73	82	86	82
WET BULB	DEG F	63	68	76	76	77
REL. HUMIDITY	PCT	43	78	76	63	80
CURR. BHP	HP	115.6	116.2	118.7	120.0	119.5
CORR. BMEP	PSI	44.6	44.8	45.8	46.3	46.1
FUEL FLOW	LB/HR	54.66	54.55	54.86	54.48	55.53
WATER FLOW	CC/MIN	23.7	23.7	25.0	23.7	18.5
CALC. VOL. %	PCT	4.6	4.6	4.8	4.6	3.5
BSFC	LB/BHP-HR	4727	4694	4622	4539	4645
AIR FLOW	LB/MIN	38.4	38.0	35.7	37.1	36.9
STOICH. F/A		.0691	.0691	.0691	.0691	.0691
MEAS. F/A		.0237	.0240	.0256	.0245	.0251
CALC. F/A		.0252	.0246	.0244	.0250	.0245
% DIFF.	PCT	6.05	2.61	-4.78	2.34	-2.35
COOLANT IN	DEG F	168	173	176	171	176
COOLANT OUT	DEG F	179	182	185	181	184
OIL SUMP	DEG F	195	196	195	196	198
FUEL IN	DEG F	95	95	100	100	99
FUEL RETURN	DEG F	148	150	149	149	149
FUEL SUPPLY	DEG F	93	95	103	106	102
FUEL COOLER	DEG F	92	92	97	96	95
INTAKE AIR	DEG F	80	73	81	89	85
TURB. INLET (L)	DEG F	646	619	643	657	653
TURB. INLET (R)	DEG F	628	649	658	647	652
COMP. OUT (L)	DEG F	112	105	112	120	116
COMP. OUT (R)	DEG F	112	105	112	121	117
CHARGE AIR (L)	DEG F	166	168	171	170	170
CHARGE AIR (R)	DEG F	168	169	172	171	172
EXH. STACK (R)	DEG F	574	591	597	590	596
EXH. STACK (L)	DEG F	591	564	585	600	597
WATER INLET	DEG F	83	75	84	93	85
CELL AIR	DEG F	78	75	84	93	86
EXHAUST 1R	DEG F	673	704	711	696	697
EXHAUST 2R	DEG F	549	587	595	572	587
EXHAUST 3R	DEG F	602	606	601	600	605
EXHAUST 4R	DEG F	650	659	666	662	655
EXHAUST 5R	DEG F	623	621	636	634	644
EXHAUST 6R	DEG F	677	687	708	703	702
EXHAUST 1L	DEG F	655	628	647	677	666
EXHAUST 2L	DEG F	688	639	654	704	692
EXHAUST 3L	DEG F	627	609	624	629	632
EXHAUST 4L	DEG F	630	614	624	629	632
EXHAUST 5L	DEG F	687	659	697	709	692
EXHAUST 6L	DEG F	681	672	677	693	680
OIL PRESSURE	PSI	66	65	64	65	65
KAIL PRESSURE	PSI	15.0	15.0	15.0	15.0	15.0
BOOST (R)	PSI	1.8	1.8	1.8	1.8	1.8
BOOST (L)	PSI	2.6	2.5	2.5	2.5	2.5
INLET VAC. (R)	IN-H2O	3.7	3.8	4.2	4.6	3.3
EXH. PRESS. (R)	PSI	1	1.0	0.0	0.0	1.1
EXH. PRESS. (L)	PSI	1	1.0	1	1.0	1.2
TURB. IN. (R)	IN-HG	2.5	2.5	2.5	2.5	2.5
TURB. IN. (L)	IN-HG	1.3	1.4	1.5	1.5	1.4
FUEL PRESS.	PSI	18	22	20	20	20
EMULSION PRESS.	PSI	100	100	100	100	100
FUEL SUPPLY	PSI	2	2	2	2	2
WATER PRESS.	PSI	60	50	60	60	60
HYDROCARBONS	PPMC	105	70	107	142	38
CARBON MONOXIDE	PPM	239	488	267	219	219
NITRIC OXIDE	PPM	320	275	210	214	178
NITROGEN OXIDES	PPM	320	300	231	235	198
CARBON DIOXIDE	PCT	5.4	5.2	5.2	5.3	5.2
OXYGEN	PCT	13.7	16.0	11.6	14.0	13.6
SMOKE OPACITY	PCT	5.5	5.6	6.0	8.0	6.5
HC MASS	GM-HR	50.691	34.560	54.561	68.819	44.503
CO MASS	GM-HR	222.69	464.32	257.26	284.27	213.32
NOX MASS	GM-HR	537.09	527.31	444.20	423.10	390.81
BSHC	GM/BHP-HR	4384	2974	4597	574	3723
BSCO	GM/BHP-HR	1.9258	3.9961	2.1678	1.7020	1.7844
BSNO	GM/BHP-HR	4.6447	4.5434	3.7430	3.5254	3.2623

TABLE C-9. ENGINE TEST RESULTS, CUMMINS ENGINE,
1200 RPM, 10% WATER

DYNAMOMETER CONSTANT: 3800		API GRAVITY OF DIESEL FUEL: 35.3 AT 60F				
H/C RATIO: 1.78						
RUN NUMBER		180.	190.	226.	240.	254.
NOM. WATER PCT.		10.	10.	10.	10.	10.
ENGINE SPEED	RPM	1200.	1200.	1200.	1200.	1200.
OBS. TORQUE	LB-FT	508.	508.	508.	508.	508.
BAR. PRESS.	IN-HG	29.31	29.14	29.85	28.96	29.04
DRY BULB	DEG F	80.	74.	82.	92.	86.
WET BULB	DEG F	65.	68.	75.	78.	79.
REL. HUMIDITY	PCT	44.	74.	72.	54.	74.
CORR. BHP	HP	116.1	116.1	118.5	120.6	119.6
CORR. BMEP	PSI	44.8	44.8	45.7	46.5	46.2
FUEL FLOW	LB/HR	53.63	53.71	54.38	53.90	55.02
WATER FLOW	CC/MIN	49.8	49.8	49.8	49.8	49.8
CALC. VOL. X	PCT	9.3	9.3	9.2	9.2	9.1
BSEC	LB/BHP-HR	4617	4624	4591	4470	4599
AIR FLOW	LB/MIN	37.2	37.9	37.1	36.5	36.7
STOICH. F/A		0.691	0.691	0.691	0.691	0.691
MEAS. F/A		0.240	0.236	0.240	0.246	0.250
CALC. F/A		0.249	0.242	0.240	0.252	0.235
X DIFF.	PCT	3.57	2.52	-2.03	2.37	-6.06
COOLANT IN	DEG F	170.	173.	177.	172.	176.
COOLANT OUT	DEG F	181.	181.	185.	182.	184.
OIL BUMP	DEG F	196.	196.	199.	196.	198.
FUEL IN	DEG F	97.	96.	100.	103.	100.
FUEL RETURN	DEG F	150.	150.	148.	149.	148.
FUEL SUPPLY	DEG F	96.	97.	104.	109.	102.
FUEL COOLER	DEG F	96.	93.	94.	98.	96.
INTAKE AIR	DEG F	82.	73.	81.	92.	85.
TURB. INLET (L)	DEG F	633.	611.	628.	639.	632.
TURB. INLET (R)	DEG F	621.	630.	645.	628.	639.
COMP. OUT (L)	DEG F	114.	104.	112.	122.	115.
COMP. OUT (R)	DEG F	113.	104.	112.	123.	117.
CHARGE AIR (L)	DEG F	168.	168.	170.	179.	170.
CHARGE AIR (R)	DEG F	169.	169.	172.	171.	172.
EXH. STACK (R)	DEG F	648.	625.	627.	671.	658.
EXH. STACK (L)	DEG F	578.	557.	572.	585.	578.
WATER INLET	DEG F	85.	79.	85.	95.	86.
CELL AIR	DEG F	81.	74.	84.	93.	86.
EXHAUST 1R	DEG F	661.	674.	684.	670.	670.
EXHAUST 2R	DEG F	551.	568.	572.	557.	588.
EXHAUST 3R	DEG F	592.	603.	601.	591.	598.
EXHAUST 4R	DEG F	638.	650.	663.	650.	640.
EXHAUST 5R	DEG F	618.	620.	642.	627.	640.
EXHAUST 6R	DEG F	615.	688.	698.	679.	692.
EXHAUST 1L	DEG F	641.	625.	634.	688.	659.
EXHAUST 2L	DEG F	673.	637.	638.	683.	680.
EXHAUST 3L	DEG F	609.	603.	611.	614.	608.
EXHAUST 4L	DEG F	613.	602.	608.	615.	612.
EXHAUST 5L	DEG F	671.	651.	690.	686.	678.
EXHAUST 6L	DEG F	667.	652.	670.	671.	665.
OIL PRESSURE	PSI	65.	65.	64.	63.	65.
RAIL PRESSURE	PSI	15.	15.	17.	15.	16.
BOOST (R)	PSI	1.82	1.82	1.77	1.77	1.86
BOOST (L)	PSI	2.3	2.3	2.25	2.5	2.3
INLET VAC. (R)	IN-H2O	3.7	3.8	4.2	4.6	3.4
EXH. PRESS. (R)	PSI	1.	1.	0.	0.	1.
EXH. PRESS. (L)	PSI	1.7	1.5	1.6	1.6	1.7
TURB. IN. (R)	IN-HG	1.2	1.4	1.3	1.4	1.1
TURB. IN. (L)	IN-HG	1.2	1.4	1.3	1.4	1.1
FUEL PRESS.	PSI	18.	22.	20.	20.	20.
EMULSION PRESS.	PSI	100.	100.	100.	100.	100.
FUEL SUPPLY	PSI	2.	24.	2.	2.	2.
WATER PRESS.	PSI	60.	50.	60.	60.	60.
HYDROCARBONS	PPMC	99.	93.	119.	123.	96.
CARBON MONOXIDE	PPH	298.	508.	444.	452.	225.
NITRIC OXIDE	PPH	320.	275.	200.	205.	215.
NITROGEN OXIDES	PPH	350.	275.	228.	230.	240.
CARBON DIOXIDE	PCT	5.3	5.1	5.1	5.4	5.0
OXYGEN	PCT	13.5	16.1	11.6	15.8	15.1
SMOKE OPACITY	PCT	4.2	4.2	4.5	4.4	3.5
HC MASS	GM-HR	47.349	45.610	60.147	58.619	58.255
CO MASS	GM-HR	275.89	483.12	498.19	494.88	523.87
NOX MASS	GM-HR	557.82	496.47	498.12	419.09	523.87
BSEC	GM/BHP-HR	4.077	3.927	5.077	4.861	4.200
BSCO	GM/BHP-HR	2.3754	4.1595	2.2513	1.6923	1.8683
BENO	GM/BHP-HR	4.8082	4.2736	3.7997	3.4753	4.3130

TABLE C-10. ENGINE TEST RESULTS, CUMMINS ENGINE,
1200 RPM, 15% WATER

DYNAMOMETER CONSTANT: 3000 H/C RATIO: 1.78		API GRAVITY OF DIESEL FUEL: 35.3 AT 60F				
RUN NUMBER		181	191	227	241	255
NDM. WATER PCT.		15	15	15	15	15
ENGINE SPEED	RPM	1200	1200	1200	1200	1200
OBS. TORQUE	LB-FT	508	508	508	508	508
BAR. PRESS.	IN-HG	29.29	29.15	29.05	28.96	29.06
DRY BULB	DEG F	81	74	84	93	85
WET BULB	DEG F	64	68	76	74	77
REL. HUMIDITY	PCT	39	74	70	54	70
CURR. BHP	HP	116.2	116.4	118.7	121.0	119.1
CORR. BMEP	PSI	44.8	44.9	45.8	46.7	46.0
FUEL FLOW	LB/HR	54.19	53.25	53.70	53.06	53.38
WATER FLOW	CC/MIN	79.6	82.8	82.8	81.2	82.8
CALC. VOL. %	PCT	13.9	14.6	14.5	14.4	14.6
BSFC	LB/BHP-HR	4664	4575	4524	4384	4483
AIR FLOW	LB/MIN	37.7	37.6	36.9	36.3	36.6
STOICH. F/A		.0691	.0691	.0691	.0691	.0691
MEAS. F/A		.0240	.0236	.0242	.0244	.0243
CALC. F/A		.0249	.0240	.0242	.0251	.0250
% DIFF.	PCT	3.74	1.55	- .26	2.80	2.66
COOLANT IN	DEG F	170	173	176	174	178
COOLANT OUT	DEG F	180	182	184	182	185
OIL SUMP	DEG F	195	196	198	197	199
FUEL IN	DEG F	100	97	100	103	100
FUEL RETURN	DEG F	150	149	147	149	148
FUEL SUPPLY	DEG F	96	99	102	109	102
FUEL COOLER	DEG F	98	95	95	99	97
INTAKE AIR	DEG F	83	75	82	94	84
TURB. INLET (L)	DEG F	617	598	606	625	615
TURB. INLET (R)	DEG F	612	617	633	618	628
COMP. OUT (L)	DEG F	114	105	112	123	117
COMP. OUT (R)	DEG F	114	105	112	123	117
CHARGE AIR (L)	DEG F	148	168	170	171	172
CHARGE AIR (R)	DEG F	169	169	171	172	173
EXH. STACK (R)	DEG F	561	564	577	565	574
EXH. STACK (L)	DEG F	565	547	553	571	566
WATER INLET	DEG F	86	82	87	95	86
CELL AIR	DEG F	83	76	86	95	86
EXHAUST 1R	DEG F	623	628	681	663	672
EXHAUST 2R	DEG F	623	628	678	661	672
EXHAUST 3R	DEG F	584	590	601	589	592
EXHAUST 4R	DEG F	629	637	651	639	633
EXHAUST 5R	DEG F	611	610	629	606	634
EXHAUST 6R	DEG F	672	663	690	665	676
EXHAUST 1L	DEG F	632	613	630	654	641
EXHAUST 2L	DEG F	659	617	636	661	651
EXHAUST 3L	DEG F	594	587	603	604	591
EXHAUST 4L	DEG F	605	587	595	602	596
EXHAUST 5L	DEG F	655	634	659	677	660
EXHAUST 6L	DEG F	646	627	647	653	640
OIL PRESSURE	PSI	65	65	64	65	64
RAIL PRESSURE	PSI	150	150	170	170	180
BOOST (R)	PSI	2.0	2.0	2.0	2.0	2.0
BOOST (L)	PSI	2.0	2.0	2.0	2.0	2.0
INLET VAC. (R)	IN-H2O	1.1	1.1	1.1	1.1	1.1
EXH. PRESS. (R)	PSI	1.1	1.1	1.1	1.1	1.1
EXH. PRESS. (L)	PSI	1.1	1.1	1.1	1.1	1.1
TURB. IN. (R)	IN-HG	2	2	2	2	2
TURB. IN. (L)	IN-HG	2	2	2	2	2
FUEL PRESS.	PSI	19	22	20	20	20
EMULSION PRESS.	PSI	100	100	100	100	100
FUEL SUPPLY	PSI	60	50	60	60	60
WATER PRESS.	PSI	60	50	60	60	60
HYDROCARBONS	PPMC	125	108	124	152	105
CARBON MONOXIDE	PPM	246	571	246	239	239
NITRIC OXIDE	PPM	320	263	255	239	239
NITROGEN OXIDES	PPM	355	300	234	239	239
CARBON DIOXIDE	PCT	15.4	15.1	15.1	15.3	15.3
OXYGEN	PCT	15.4	15.1	15.1	15.3	15.3
SMOKE OPACITY	PCT	3.4	3.9	4.0	4.6	2.2
HC MASS	GM-HR	60.609	53.197	61.402	71.818	50.092
CO MASS	GM-HR	230.08	544.39	234.59	217.14	219.86
NOX MASS	GM-HR	579.26	568.46	476.79	444.33	467.86
BSHC	GM/BHP-HR	1.3216	4.470	5.173	5.934	1.4206
BSCO	GM/BHP-HR	1.9800	4.6764	1.9764	1.7944	1.8417
BSNO	GM/BHP-HR	4.9849	4.8832	4.8167	3.6735	3.9233

TABLE C-11. ENGINE TEST RESULTS, CUMMINS ENGINE,
1200 RPM, 20% WATER

DYNAMOMETER CONSTANT: 3000		API GRAVITY OF DIESEL FUEL: 35.3 AT 60F				
H/C RATIO: 1.78						
RUN NUMBER		182.	192.	228.	242.	256.
NOM. WATER PCT.		20.	20.	20.	20.	20.
ENGINE SPEED	RPM	1200.	1200.	1200.	1200.	1200.
OBS. TORQUE	LB-FT	508.	508.	508.	508.	508.
BAR. PRESS.	IN-HG	29.28	29.16	29.06	28.96	29.12
DRY BULB	DEG F	81.	77.	84.	93.	82.
WET BULB	DEG F	64.	70.	76.	79.	75.
REL. HUMIDITY	PCT	39.	71.	70.	54.	72.
CORR. BHP	HP	116.5	116.7	119.3	121.2	118.2
CORR. BMHP	PSI	45.0	45.0	46.0	46.8	45.6
FUEL FLOW	LB/HR	53.71	53.04	53.92	53.80	54.77
WATER FLOW	CC/MIN	114.0	111.0	114.0	114.0	111.0
CALC. VOL. %	PCT	18.9	18.7	18.9	18.9	18.3
BSFC	LB/BHP-HR	4609	4546	4521	4439	4635
AIR FLOW	LB/MIN	37.5	37.4	36.7	36.2	36.7
STOICH. F/A		.0691	.0691	.0691	.0691	.0691
MEAS. F/A		.0239	.0236	.0245	.0248	.0249
CALC. F/A		.0249	.0243	.0250	.0250	.0250
% DIFF.	PCT	4.36	2.82	1.76	.82	.35
COOLANT IN	DEG F	170.	177.	177.	174.	178.
COOLANT OUT	DEG F	180.	185.	185.	182.	185.
OIL SUMP	DEG F	195.	198.	199.	197.	198.
FUEL IN	DEG F	101.	98.	101.	105.	99.
FUEL RETURN	DEG F	150.	151.	148.	149.	147.
FUEL SUPPLY	DEG F	96.	98.	106.	111.	101.
FUEL COOLER	DEG F	95.	97.	96.	100.	95.
INTAKE AIR	DEG F	85.	76.	86.	91.	81.
TURB. INLET (L)	DEG F	601.	588.	596.	608.	593.
TURB. INLET (R)	DEG F	603.	611.	625.	606.	611.
COMP. OUT (L)	DEG F	114.	107.	115.	123.	110.
COMP. OUT (R)	DEG F	114.	107.	115.	124.	114.
CHARGE AIR (L)	DEG F	168.	171.	172.	172.	171.
CHARGE AIR (R)	DEG F	169.	172.	173.	173.	172.
EXH. STACK (R)	DEG F	552.	558.	571.	555.	555.
EXH. STACK (L)	DEG F	551.	558.	546.	557.	558.
WATER INLET	DEG F	84.	87.	86.	96.	83.
CELL AIR	DEG F	84.	87.	86.	96.	83.
EXHAUST 1R	DEG F	634.	644.	655.	648.	655.
EXHAUST 2R	DEG F	542.	555.	567.	557.	573.
EXHAUST 3R	DEG F	580.	588.	597.	584.	583.
EXHAUST 4R	DEG F	612.	622.	636.	619.	617.
EXHAUST 5R	DEG F	601.	602.	632.	599.	622.
EXHAUST 6R	DEG F	655.	647.	609.	648.	656.
EXHAUST 1L	DEG F	644.	649.	649.	625.	645.
EXHAUST 2L	DEG F	637.	648.	649.	625.	645.
EXHAUST 3L	DEG F	577.	572.	585.	586.	570.
EXHAUST 4L	DEG F	586.	581.	589.	588.	588.
EXHAUST 5L	DEG F	564.	613.	634.	656.	639.
EXHAUST 6L	DEG F	615.	604.	620.	628.	615.
OIL PRESSURE	PSI	65.	64.	64.	65.	64.
RAIL PRESSURE	PSI	15.	15.	20.	18.	19.
BOOST (R)	PSI	2.	2.	2.	2.	2.
BOOST (L)	PSI	2.	2.	2.	2.	2.
INLET VAC. (R) IN-H2O		3.7	3.7	4.0	4.0	3.7
EXH. PRESS. (R) PSI		1.	1.	0.	0.	1.
EXH. PRESS. (L) PSI		1.	1.	0.	0.	1.
TURB. IN. (R) IN-HG		2.	2.	2.	2.	2.
TURB. IN. (L) IN-HG		2.	2.	2.	2.	2.
FUEL PRESS.	PSI	100.	100.	100.	100.	100.
EMULSION PRESS.	PSI	100.	100.	100.	100.	100.
FUEL SUPPLY	PSI	60.	50.	60.	60.	60.
WATER PRESS.	PSI	60.	50.	60.	60.	60.
HYDROCARBONS	PPM	175.	149.	149.	146.	95.
CARBON MONOXIDE	PPM	263.	613.	229.	261.	205.
NITRIC OXIDE	PPM	330.	273.	211.	215.	205.
NITROGEN OXIDES	PPM	360.	313.	248.	249.	205.
CARBON DIOXIDE	PCT	15.3	5.1	5.3	5.3	15.3
OXYGEN	PCT	15.3	15.0	9.3	15.3	15.3
SMOKE OPACITY	PCT	2.7	3.6	4.0	3.9	1.5
HC MASS	GM-HR	84.052	72.323	71.784	70.145	46.490
CO MASS	GM-HR	243.65	574.23	212.34	242.9	250.74
NOX MASS	GM-HR	607.14	611.99	514.94	509.43	520.74
BSHC	GM/BHP-HR	2.0912	4.9214	1.5819	2.5788	3.3916
BSCO	GM/BHP-HR	2.0912	4.9214	1.5819	2.5788	3.3916
BEMO	GM/BHP-HR	5.2097	5.2405	4.3176	4.2035	4.4818

TABLE C-12. ENGINE TEST RESULTS, CUMMINS ENGINE,
1200 RPM, 25% WATER

DYNAMOMETER CONSTANT: 3000 API GRAVITY OF DIESEL FUEL: 35.3 AT 60F
H/C RATIO: 1.78

RUN NUMBER	193	229	243	257
NOM. WATER PCT.	25	25	25	25

ENGINE SPEED	RPM	1200	1200	1200	1200
OBS. TORQUE	LB-FT	508	508	508	508

BAR. PRESS.	IN-HG	29.17	29.04	28.95	29.11
DRY BULB	DEG F	77	88	94	82
WET BULB	DEG F	70	76	80	73
REL. HUMIDITY	PCT	71	58	55	65
CORR. BHP	HP	117.1	119.5	121.5	117.9
CORR. BMEP	PSI	45.2	46.1	46.9	45.5

FUEL FLOW	LB/HR	53.33	53.66	53.75	53.57
WATER FLOW	CC/MIN	143.8	159.0	159.0	159.0
CALC. VOL. %	PCT	22.9	24.6	24.5	24.6
BSFC	LB/BHP-HR	4555	4491	4423	4544
AIR FLOW	LB/MIN	37.2	36.5	36.0	36.5

STOICH. F/A	0.0691	0.0691	0.0691	0.0691	
MEAS. F/A	0.0239	0.0245	0.0249	0.0244	
CALC. F/A	0.0248	0.0240	0.0252	0.0236	
% DIFF.	PCT	3.84	-1.99	1.18	-3.42

COOLANT IN	DEG F	178	177	176	178
COOLANT OUT	DEG F	185	185	184	186
OIL SUMP	DEG F	198	198	197	190
FUEL IN	DEG F	97	102	105	100
FUEL RETURN	DEG F	149	147	149	147
FUEL SUPPLY	DEG F	100	107	112	102
FUEL COOLER	DEG F	94	98	102	96
INTAKE AIR	DEG F	79	88	96	81
TURB. INLET (L)	DEG F	582	578	595	583
TURB. INLET (R)	DEG F	605	612	598	603
COMP. OUT (L)	DEG F	109	117	124	110
COMP. OUT (R)	DEG F	110	116	125	117
CHARGE AIR (L)	DEG F	171	172	172	171
CHARGE AIR (R)	DEG F	172	173	173	173
EXH. STACK (R)	DEG F	552	559	549	552
EXH. STACK (L)	DEG F	532	531	547	536
WATER INLET	DEG F	84	89	95	88
CELL AIR	DEG F	78	90	98	82
EXHAUST 1R	DEG F	630	645	634	637
EXHAUST 2R	DEG F	552	558	548	563
EXHAUST 3R	DEG F	582	591	580	578
EXHAUST 4R	DEG F	604	611	602	600
EXHAUST 5R	DEG F	593	615	593	607
EXHAUST 6R	DEG F	626	650	630	631
EXHAUST 1L	DEG F	594	582	603	594
EXHAUST 2L	DEG F	605	603	634	622
EXHAUST 3L	DEG F	563	571	576	568
EXHAUST 4L	DEG F	571	571	576	566
EXHAUST 5L	DEG F	570	610	632	615
EXHAUST 6L	DEG F	578	561	602	590

OIL PRESSURE	PSI	64	64	65	64
RAIL PRESSURE <th>PSI</th> <td>20.0</td> <td>20.0</td> <td>20.0</td> <td>20.0</td>	PSI	20.0	20.0	20.0	20.0
BOOST (R) <th>PSI</th> <td>1.6</td> <td>1.5</td> <td>1.5</td> <td>1.5</td>	PSI	1.6	1.5	1.5	1.5
BOOST (L) <th>PSI</th> <td>2.0</td> <td>2.0</td> <td>2.4</td> <td>2.2</td>	PSI	2.0	2.0	2.4	2.2
INLET VAC (R) <th>IN-H2O</th> <td>3.6</td> <td>0.0</td> <td>0.0</td> <td>1.2</td>	IN-H2O	3.6	0.0	0.0	1.2
EXH. PRESS (R) <th>PSI</th> <td>1.1</td> <td>0.0</td> <td>0.0</td> <td>1.3</td>	PSI	1.1	0.0	0.0	1.3
EXH. PRESS (L) <th>PSI</th> <td>1.1</td> <td>1.1</td> <td>1.1</td> <td>1.3</td>	PSI	1.1	1.1	1.1	1.3
TURB. IN. (R) <th>IN-HG</th> <td>2.5</td> <td>2.4</td> <td>2.5</td> <td>2.5</td>	IN-HG	2.5	2.4	2.5	2.5
TURB. IN. (L) <th>IN-HG</th> <td>1.2</td> <td>1.2</td> <td>1.2</td> <td>1.1</td>	IN-HG	1.2	1.2	1.2	1.1
FUEL PRESS <th>PSI</th> <td>22</td> <td>20</td> <td>20</td> <td>20</td>	PSI	22	20	20	20
EMULSION PRESS <th>PSI</th> <td>100</td> <td>100</td> <td>100</td> <td>100</td>	PSI	100	100	100	100
FUEL SUPPLY <th>PSI</th> <td>2</td> <td>2</td> <td>2</td> <td>2</td>	PSI	2	2	2	2
WATER PRESS <th>PSI</th> <td>50</td> <td>60</td> <td>60</td> <td>60</td>	PSI	50	60	60	60

HYDROCARBONS	PPM	250	193	211	132
CARBON MONOXIDE <th>PPM</th> <td>749</td> <td>316</td> <td>417</td> <td>383</td>	PPM	749	316	417	383
NITRIC OXIDE <th>PPM</th> <td>275</td> <td>216</td> <td>210</td> <td>215</td>	PPM	275	216	210	215
NITROGEN OXIDES <th>PPM</th> <td>325</td> <td>250</td> <td>250</td> <td>250</td>	PPM	325	250	250	250
CARBON DIOXIDE <th>PCT</th> <td>5.2</td> <td>5.1</td> <td>5.3</td> <td>5.0</td>	PCT	5.2	5.1	5.3	5.0
OXYGEN <th>PCT</th> <td>16.0</td> <td>9.5</td> <td>15.9</td> <td>15.5</td>	PCT	16.0	9.5	15.9	15.5
SMOKE OPACITY <th>PCT</th> <td>2.9</td> <td>3.1</td> <td>3.5</td> <td>1.0</td>	PCT	2.9	3.1	3.5	1.0

HC MASS	GM-HR	120.00	96.372	100.63	66.775
CO MASS <th>GM-HR</th> <td>690.83</td> <td>303.46</td> <td>381.53</td> <td>272.81</td>	GM-HR	690.83	303.46	381.53	272.81
NOX MASS <th>GM-HR</th> <td>657.90</td> <td>555.93</td> <td>556.28</td> <td>557.48</td>	GM-HR	657.90	555.93	556.28	557.48
BSHC <th>GM/BHP-HR</th> <td>1.0248</td> <td>8067</td> <td>8281</td> <td>5666</td>	GM/BHP-HR	1.0248	8067	8281	5666
BSCO <th>GM/BHP-HR</th> <td>5.8998</td> <td>2.5400</td> <td>3.1394</td> <td>3.1626</td>	GM/BHP-HR	5.8998	2.5400	3.1394	3.1626
BSNO <th>GM/BHP-HR</th> <td>5.6186</td> <td>4.6525</td> <td>4.5773</td> <td>4.7291</td>	GM/BHP-HR	5.6186	4.6525	4.5773	4.7291

TABLE C-13. ENGINE TEST RESULTS, CUMMINS ENGINE,
1800 RPM, BASELINE

DYNAMOMETER CONSTANT: 3000		API GRAVITY OF DIESEL FUEL: 35.3 AT 60F						
H/C RATIO: 1.78								
RUN NUMBER		171	177	183	188	195	201	216
NOM. WATER PCT.		0	0	0	0	0	0	0
ENGINE SPEED	RPM	1800	1800	1800	1200	1800	1800	1800
OBS. TORQUE	LB-FT	1257	1257	1257	508	1257	1257	1257
BAR. PRESS.	IN-HG	29.29	29.16	28.96	29.11	29.22	29.26	29.10
DRY BULB	DEG F	82	91	81	73	79	78	89
WET BULB	DEG F	73	73	76	68	74	72	76
REL. HUMIDITY	PCT	65	42	80	78	79	75	55
CORR. BHP	HP	436.2	441.7	443.9	116.2	436.1	433.9	444.3
CORR. BMEP	PSI	112.2	113.7	114.2	44.8	112.2	111.6	114.3
FUEL FLOW	LB/HR	181.93	179.14	180.80	55.30	179.19	180.09	177.08
WATER FLOW	CC/MIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CALC. VOL. %	PCT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BSFC	LB/BHP-HR	417.1	405.6	407.3	476.1	410.9	415.1	398.6
AIR FLOW	LB/MIN	83.5	82.6	83.7	38.0	85.0	84.5	81.4
STOICH. F/A		0.691	0.691	0.691	0.691	0.691	0.691	0.691
MEAS. F/A		0.363	0.361	0.360	0.242	0.351	0.355	0.363
CALC. F/A		0.335	0.324	0.341	0.248	0.347	0.348	0.342
% DIFF.	PCT	-7.63	-10.37	-5.24	2.37	-1.15	-1.88	-5.58
COOLANT IN	DEG F	177	178	176	172	173	177	173
COOLANT OUT	DEG F	188	189	186	181	184	186	186
OIL SUMP	DEG F	221	222	218	194	217	219	217
FUEL IN	DEG F	105	104	107	92	105	103	110
FUEL RETURN	DEG F	153	154	155	149	152	152	153
FUEL SUPPLY	DEG F	89	92	92	94	90	89	96
FUEL COOLER	DEG F	106	105	109	90	105	105	109
INTAKE AIR	DEG F	83	95	84	72	79	78	91
TURB. INLET (L)	DEG F	965	977	949	629	937	942	959
TURB. INLET (R)	DEG F	927	977	960	657	953	951	965
COMP. OUT (L)	DEG F	231	240	232	106	225	224	234
COMP. OUT (R)	DEG F	228	238	230	105	224	223	232
CHARGE AIR (L)	DEG F	194	197	192	168	189	191	192
CHARGE AIR (R)	DEG F	194	197	194	169	190	192	192
EXH. STACK (R)	DEG F	816	824	805	599	800	800	813
EXH. STACK (L)	DEG F	806	813	792	574	780	787	801
WATER INLET	DEG F	88	100	89	75	82	88	95
CELL AIR	DEG F	86	95	84	76	80	80	92
EXHAUST 1R	DEG F	956	965	945	713	935	936	949
EXHAUST 2R	DEG F	928	936	931	598	908	911	924
EXHAUST 3R	DEG F	938	947	919	600	925	921	935
EXHAUST 4R	DEG F	914	925	904	669	900	898	911
EXHAUST 5R	DEG F	935	943	926	654	915	915	929
EXHAUST 6R	DEG F	958	963	951	711	943	937	955
EXHAUST 1L	DEG F	1005	1019	994	655	980	981	993
EXHAUST 2L	DEG F	961	973	955	678	940	940	958
EXHAUST 3L	DEG F	916	929	907	601	898	901	917
EXHAUST 4L	DEG F	929	942	921	618	911	908	928
EXHAUST 5L	DEG F	932	944	920	639	912	915	923
EXHAUST 6L	DEG F	955	959	933	679	926	925	951
OIL PRESSURE	PSI	76	76	76	66	76	76	76
RAIL PRESSURE	PSI	75.0	75.0	75.0	149.0	75.0	75.0	74.0
BOOST (R)	PSI	11.0	10.9	11.2	1	11.2	11.1	10.9
BOOST (L)	PSI	10.5	12.7	13.0	2	10.8	11.5	10
INLET VAC. (R)	IN-H2O	12.3	12.7	13.0	3.8	13.6	13.9	13.7
EXH. PRESS. (R)	PSI	3	3	3	1	1	1	2.5
EXH. PRESS. (L)	PSI	6	6	5	1.5	1.5	1.5	1.5
TURB. IN (R)	IN-HG	11.0	11.0	11.0	2.5	11.2	11.1	11.0
TURB. IN (L)	IN-HG	10.0	10.0	10.0	1.4	10.0	10.0	0.0
FULL PRESS.	PSI	22	20	20	21	20	20	20
EMULSION PRESS.	PSI	100	100	100	100	100	100	100
FUEL SUPPLY	PSI	2	2	2	2	2	2	2
WATER PRESS.	PSI	0	0	0	0	0	0	0
HYDROCARBONS	PPMC	100	40	130	54	78	70	82
CARBON MONOXIDE	PPM	306	163	635	212	281	550	125
NITRIC OXIDE	PPM	900	950	870	288	850	850	288
NITROGEN OXIDES	PPM	86.4	950	880	313	838	850	730
CARBON DIOXIDE	PCT	7.2	7.0	7.3	5.3	7.5	7.5	7.4
OXYGEN	PCT	10.5	10.3	11.5	15.8	12.2	12.3	15.0
SMOKE DENSITY	PCT	0.0	0.0	6.9	8.6	5.4	5.9	6.0
HC MASS	GM-HR	121.64	49.507	154.76	26.649	89.849	81.249	95.154
CO MASS	GM-HR	704.86	384.81	1431.4	203.00	615.43	1206.3	274.58
NOX MASS	GM-HR	3527.4	3789.1	3719.8	535.94	3371.8	3339.2	2949.6
BSHC	GM/BHP-HR	2789	1121	3486	2294	2060	1873	2142
BSOC	GM/BHP-HR	1.6161	8712	3.2248	1.7475	1.4113	2.7802	6.181
BSNO	GM/BHP-HR	8.0876	8.5787	8.3803	4.6137	7.7323	7.6960	6.6393

TABLE C-13. ENGINE TEST RESULTS, CUMMINS ENGINE,
1800 RPM, BASELINE (CONT'D)

DYNAMOMETER CONSTANT: 3000		API GRAVITY OF DIESEL FUEL: 35.3 AT 60F					
H/C RATIO: 1.78							
RUN NUMBER		217	223	231	237	245	251
NOM. WATER PCT.		0	0	0	0	0	0
ENGINE SPEED	RPM	1800	1800	1800	1800	1800	1800
OBS. TORQUE	LB-FT	1257	1257	1257	1257	1257	1257
BAR. PRESS.	IN-HG	29.19	29.24	28.95	29.00	28.94	28.91
DRY BULB	DEG F	80	89	83	92	88	90
WET BULB	DEG F	73	76	75	80	76	78
REL. HUMIDITY	PCT	72	55	69	60	58	59
CURR. BHP	HP	436.3	440.9	442.5	448.6	445.3	447.3
CURR. BMEP	PSI	112.3	113.5	113.9	115.4	114.6	115.1
FUEL FLOW	LB/HR	179.60	179.37	180.41	180.68	182.23	181.73
WATER FLOW	CC/MIN	0.0	0.0	0.0	0.0	0.0	0.0
CALC. VOL %	PCT	0.0	0.0	0.0	0.0	0.0	0.0
BSCC	LB/BHP-HR	4116	4068	4077	4078	4093	4063
AIR FLOW	LB/MIN	83.7	83.1	81.9	81.2	82.1	80.6
STOICH. F/A		0.691	0.691	0.691	0.691	0.691	0.691
MEAS. F/A		0.358	0.360	0.367	0.371	0.376	0.376
CALC. F/A		0.343	0.350	0.336	0.354	0.358	0.347
% DIFF.	PCT	-4.12	-2.85	-8.79	-4.51	-3.19	-7.62
COOLANT IN	DEG F	161	161	175	174	172	170
COOLANT OUT	DEG F	181	180	187	185	184	184
OIL SUMP	DEG F	214	216	219	218	220	218
FUEL IN	DEG F	106	110	109	109	110	109
FUEL RETURN	DEG F	148	152	153	155	154	154
FUEL SUPPLY	DEG F	90	102	92	96	95	96
FUEL COOLER	DEG F	106	109	110	110	111	110
INTAKE AIR	DEG F	80	89	83	92	88	90
TURB. INLET (L)	DEG F	941	958	961	966	968	968
TURB. INLET (R)	DEG F	949	963	964	975	977	977
COMP. OUT (L)	DEG F	225	234	229	238	235	234
COMP. OUT (R)	DEG F	223	232	227	235	232	232
CHARGE AIR (L)	DEG F	185	188	191	193	191	190
CHARGE AIR (R)	DEG F	186	188	192	193	191	191
EXH. STACK (R)	DEG F	776	812	808	822	822	823
EXH. STACK (L)	DEG F	784	802	800	810	810	812
WATER INLET	DEG F	84	99	87	97	93	102
CELL AIR	DEG F	81	90	86	95	89	92
EXHAUST 1R	DEG F	936	953	941	958	955	958
EXHAUST 2R	DEG F	912	926	920	935	928	930
EXHAUST 3R	DEG F	920	931	931	944	943	940
EXHAUST 4R	DEG F	894	910	911	921	918	921
EXHAUST 5R	DEG F	908	925	924	934	937	932
EXHAUST 6R	DEG F	937	958	952	961	964	957
EXHAUST 1L	DEG F	973	994	981	999	996	1002
EXHAUST 2L	DEG F	944	955	952	966	963	963
EXHAUST 3L	DEG F	905	920	920	927	927	927
EXHAUST 4L	DEG F	913	921	926	931	935	928
EXHAUST 5L	DEG F	906	920	919	930	930	928
EXHAUST 6L	DEG F	923	949	945	956	953	956
OIL PRESSURE	PSI	78	77	76	76	76	77
RAIL PRESSURE	PSI	75.0	75.0	75.0	75.0	75.0	75.0
BOOST (R)	PSI	11	10	10	10	10	10
BOOST (L)	PSI	10	10	10	10	10	10
INLET VAC. (R) IN-H2O		14.1	14	14.7	14.9	15.9	16.5
EXH. PRESS. (R) PSI		2.2	2.2	1.5	2.2	1.6	2.2
EXH. PRESS. (L) PSI		6	6	5	6	6	5
TURB. IN. (R) IN-HG		11.0	11	11.0	11.0	10.0	11.9
TURB. IN. (L) IN-HG		10.0	10	10	9.8	10.0	10.8
FUEL PRESS.	PSI	20	20	20	20	20	20
EMULSION PRESS.	PSI	100	100	100	100	100	100
FUEL SUPPLY	PSI	3	2	2	2	2	2
WATER PRESS.	PSI	0	0	0	0	0	0
HYDROCARBONS	PPM	61	55	50	60	94	29
CARBON MONOXIDE	PPM	246	253	246	281	250	284
NITRIC OXIDE	PPM	650	625	603	675	673	660
NITROGEN DIOXIDE	PPM	738	638	623	678	599	560
CARBON DIOXIDE	PCT	7.4	7.6	7.3	7.6	7.7	7.5
OXYGEN	PCT	14.0	11.9	12.7	12.8	10.3	12.3
SMOKE OPACITY	PCT	5.0	7.2	4.7	8.2	6.0	5.7
HC MASS	GM-HR	71.606	63.377	60.193	69.172	107.48	34.118
CO MASS	GM-HR	547.33	551.08	561.61	607.75	538.52	632.34
NOX MASS	GM-HR	2949.4	2483.7	2588.0	2842.1	2322.1	2373.3
MSHL	GM/BHP-HR	1.643	1.437	1.360	1.541	1.414	0.763
BSCC	GM/BHP-HR	1.2544	1.2498	1.2622	1.3547	1.2094	1.4137
BSNO	GM/BHP-HR	6.7594	5.6311	5.8488	6.3354	5.2151	5.3042

TABLE C-14. ENGINE TEST RESULTS, CUMMINS ENGINE,
1800 RPM, 5% WATER

DYNAMOMETER CONSTANT: 3000 H/C RATIO: 1.78		API GRAVITY OF DIESEL FUEL: 35.3 AT 60F					
RUN NUMBER		172	184	196	218	232	246
NOM. WATER PCT.		5	5	5	5	5	5
ENGINE SPEED	RPM	1800	1800	1800	1800	1800	1800
OBS. TORQUE	LB-FT	1257	1257	1257	1257	1257	1257
BAR. PRESS.	IN-HG	29.27	28.95	29.23	29.21	28.96	28.95
DRY BULB	DEG F	82	82	79	80	81	89
WET BULB	DEG F	73	82	74	73	75	76
REL. HUMIDITY	PCT	65	60	79	72	69	55
CORR. BHP	HP	437.6	453.4	437.0	437.2	442.9	446.6
CORR. BMEP	PSI	112.6	116.7	112.5	112.5	114.0	114.9
FUEL FLOW	LB/HR	179.89	168.98	178.13	178.26	179.46	181.31
WATER FLOW	CC/MIN	82.8	82.8	82.8	82.8	82.8	82.8
CALC. VOL. X	PCT	4.8	4.9	4.9	4.9	4.9	4.8
BSFC	LB/BHP-HR	411	372.7	407.6	407.8	405.2	406.0
AIR FLOW	LB/MIN	82.9	80.8	83.5	83.2	81.7	79.7
STOICH. F/A		.0691	.0691	.0691	.0691	.0691	.0691
MEAS. F/A		.0362	.0348	.0355	.0357	.0366	.0379
CALC. F/A		.0326	.0345	.0343	.0343	.0336	.0358
X DIFF.	PCT	-9.98	-9.98	-3.49	-4.00	-8.19	-5.61
COOLANT IN	DEG F	178	1172	172	163	176	174
COOLANT OUT	DEG F	188	184	184	182	187	186
OIL SUMP	DEG F	222	218	217	216	219	220
FUEL IN	DEG F	106	111	107	107	109	112
FUEL RETURN	DEG F	153	156	152	149	153	155
FUEL SUPPLY	DEG F	91	98	92	92	153	97
FUEL COOLER	DEG F	109	113	109	11	110	111
INTAKE AIR	DEG F	85	97	81	84	84	91
TURB. INLET (L)	DEG F	952	958	934	937	946	942
TURB. INLET (R)	DEG F	929	965	943	944	952	968
COMP. OUT (L)	DEG F	231	240	225	225	227	235
COMP. OUT (R)	DEG F	229	240	224	223	225	233
CHARGE AIR (L)	DEG F	195	193	189	184	190	192
CHARGE AIR (R)	DEG F	195	194	190	187	191	193
EXH. STACK (R)	DEG F	808	812	794	793	803	817
EXH. STACK (L)	DEG F	799	807	780	765	791	807
WATER INLET	DEG F	83	89	84	84	89	96
CELL AIR	DEG F	88	94	82	83	86	92
EXHAUST 1R	DEG F	937	947	925	929	934	946
EXHAUST 2R	DEG F	914	920	899	905	913	921
EXHAUST 3R	DEG F	928	939	915	915	925	935
EXHAUST 4R	DEG F	905	911	894	894	903	916
EXHAUST 5R	DEG F	920	926	906	899	910	928
EXHAUST 6R	DEG F	940	949	931	931	945	945
EXHAUST 1L	DEG F	925	100	931	971	977	995
EXHAUST 2L	DEG F	952	957	935	936	943	958
EXHAUST 3L	DEG F	909	915	894	900	906	922
EXHAUST 4L	DEG F	921	925	906	899	912	923
EXHAUST 5L	DEG F	921	923	907	903	913	927
EXHAUST 6L	DEG F	934	945	919	927	938	948
OIL PRESSURE	PSI	75	76	76	77	76	76
RAIL PRESSURE	PSI	78.0	89.0	78.0	80.0	78.0	80.0
BOOST (R)	PSI	10.9	10.7	11.0	10.8	10.8	10.6
BOOST (L)	PSI	10.7	10.9	10.8	10.5	10.5	10.8
INLET VAC. (R)	IN-H2O	12.3	13.1	13.6	13.8	14.5	15.8
EXH. PRESS. (R)	PSI	3	3	1	2	1	1
EXH. PRESS. (L)	PSI	3	3	1	2	1	1
TURB. IN. (R)	IN-HG	11	11	11	11	11	10
TURB. IN. (L)	IN-HG	22	20	20	20	20	20
FUEL PRESS.	PSI	100	150	100	100	100	100
EMULSION PRESS.	PSI	2	2	2	3	2	2
FUEL SUPPLY	PSI	60	50	50	50	65	0
WATER PRESS.	PSI	60	50	50	50	65	0
HYDROCARBONS	PPMC	110	150	95	50	55	90
CARBON MONOXIDE	PPM	263	592	246	229	219	219
NITRIC OXIDE	PPM	825	870	890	745	625	640
NITROGEN OXIDE	PPM	825	915	890	635	645	645
CARBON DIOXIDE	PCT	7.0	7.4	7.4	7.4	7.3	7.7
OXYGEN	PCT	10.0	10.5	12.5	13.4	13.2	9.9
SMOKE OPACITY	PCT	0.0	5.1	4.2	4.3	3.5	4.2
HC MASS	GM-HR	136.23	165.36	110.81	58.392	65.327	102.49
CO MASS	GM-HR	619.35	123.8	546.95	205.92	427.47	420.64
NOX MASS	GM-HR	3790.1	3868.4	3681.6	2680.0	2774.6	2584.2
BSHC	GM/BHP-HR	1.4154	2.3647	1.2423	1.133	1.1776	1.2295
BSCO	GM/BHP-HR	1.4154	2.3647	1.2423	1.133	1.1776	1.2295
BSNO	GM/BHP-HR	8.6618	8.5346	8.4237	5.9613	6.2647	5.7870

TABLE C-15. ENGINE TEST RESULTS, CUMMINS ENGINE,
1800 RPM, 10% WATER

DYNAMOMETER CONSTANT: 3000		API GRAVITY OF DIESEL FUEL: 35.3 AT 60F					
H/C RATIO: 1.78		173	185	197	219	233	247
RUN NUMBER		10	10	10	10	10	10
NOM. WATER PCT.							
ENGINE SPEED	RPM	1800	1800	1800	1800	1800	1800
ORBS TORQUE	LB-FT	1257	1257	1257	1257	1257	1257
KAR PRESS	IN-HG	29.25	28.92	29.23	29.23	28.98	28.95
DRY BULB	DEG F	82	83	79	82	83	89
WET BULB	DEG F	73	80	74	73	75	76
REL HUMIDITY	PCT	65	57	79	65	69	56
CORR. BHP	HP	438.5	450.9	437.0	437.1	443.1	447.8
CORR. BMEP	PSI	112.8	116.0	112.5	112.5	114.0	115.2
FUEL FLOW	LB/HR	179.18	174.68	177.73	178.31	177.60	179.91
WATER FLOW	CC/MIN	175.1	171.8	175.1	171.8	171.8	175.1
CALC. VOL. %	PCT	9.7	9.5	9.8	9.6	9.6	9.6
BSEC	LB/BHP-HR	4087	3985	4067	4080	4008	4018
AIR FLOW	LB/MIN	81.7	80.8	82.6	82.2	80.7	79.1
STOICH. F/A		.0691	.0691	.0691	.0691	.0691	.0691
MEAS. F/A		.0365	.0370	.0358	.0362	.0367	.0379
CALC. F/A		.0332	.0349	.0348	.0343	.0346	.0369
% DIFF.	PCT	-9.21	-5.76	-2.85	-5.24	-5.67	-2.71
COOLANT IN	DEG F	178	173	172	163	176	175
COOLANT OUT	DEG F	188	185	184	182	188	186
OIL SUMP	DEG F	222	218	217	216	219	219
FUEL IN	DEG F	109	114	109	109	111	114
FUEL RETURN	DEG F	153	156	152	149	153	155
FUEL SUPPLY	DEG F	92	98	92	92	94	99
FUEL COOLER	DEG F	110	114	112	110	113	115
INTAKE AIR	DEG F	86	94	81	83	85	93
TURB. INLET (L)	DEG F	935	940	949	924	938	950
TURB. INLET (R)	DEG F	925	949	928	932	945	959
COMP. OUT (L)	DEG F	238	235	222	224	227	235
COMP. OUT (R)	DEG F	234	234	220	222	225	233
CHARGE AIR (L)	DEG F	193	192	188	186	190	192
CHARGE AIR (R)	DEG F	193	192	188	186	191	192
EXH. STACK (R)	DEG F	795	801	783	785	798	800
EXH. STACK (L)	DEG F	785	789	767	770	786	800
WATER INLET	DEG F	87	86	81	84	87	94
CELL AIR	DEG F	928	930	911	917	922	940
EXHAUST 1R	DEG F	902	906	889	901	905	918
EXHAUST 2R	DEG F	916	921	904	910	913	928
EXHAUST 3R	DEG F	891	896	879	887	892	905
EXHAUST 4R	DEG F	906	914	895	896	903	920
EXHAUST 5R	DEG F	927	933	916	918	920	925
EXHAUST 6R	DEG F	937	941	922	922	923	930
EXHAUST 1L	DEG F	901	905	885	898	900	914
EXHAUST 2L	DEG F	910	911	893	896	906	917
EXHAUST 3L	DEG F	906	911	897	896	905	920
EXHAUST 4L	DEG F	925	932	908	919	923	947
EXHAUST 5L	DEG F						
EXHAUST 6L	DEG F						
OIL PRESSURE	PSI	76	76	76	77	76	76
WALL PRESSURE	PSI	84.0	83.0	83.0	85.0	83.0	85.0
BOOST (R)	PSI	10	10	10.6	10	10	11
BOOST (L)	PSI	10	11	10.8	10	10	11
INLET VAC. (R)	IN-H2O	12	13	13.4	13.7	14.4	15
EXH. PRESS. (R)	PSI	3	3	3.2	3	3	3
EXH. PRESS. (L)	PSI	3	3	3.2	3	3	3
TURB. IN. (R)	IN-HG	10	10	11.0	10	10	10
TURB. IN. (L)	IN-HG	22	22	22	20	20	20
FUEL PRESS.	PSI	100	100	100	100	100	100
EMULSION PRESS.	PSI	2	2	2	3	2	2
FUEL SUPPLY	PSI	60	50	50	50	65	65
WATER PRESS.	PSI						
HYDROCARBONS	PPMC	38	166	91	58	54	70
CARBON MONOXIDE	PPM	476	592	488	212	193	202
NITRIC OXIDE	PPM	938	930	888	775	663	683
NITROGEN OXIDES	PPM	900	940	900	430	695	683
CARBON DIOXIDE	PCT	7.1	7.5	7.5	7.4	7.5	8.0
OXYGEN	PCT	10.5	10.7	12.0	14.0	12.8	11.8
SMOKE OPACITY	PCT	0.0	4.5	3.3	3.4	3.0	3.4
HC MASS	GM-HR	46.217	192.62	104.78	67.210	41.831	76.989
CO MASS	GM-HR	1823.0	1293.2	1072.7	468.53	419.70	418.81
NOX MASS	GM-HR	3728.1	4193.2	3892.7	2698.2	2998.4	2744.6
BSEC	GM/BHP-HR	2.4929	2.4272	2.397	1.538	1.395	1.719
BSCO	GM/BHP-HR	2.4929	2.8698	2.4197	1.0720	9471	9353
BONO	GM/BHP-HR	9.0734	9.3034	8.9068	6.1276	6.7662	6.1294

TABLE C-16. ENGINE TEST RESULTS, CUMMINS ENGINE,
1800 RPM, 15% WATER

DYNAMOMETER CONSTANT: 3000 H/C RATIO: 1.78		API GRAVITY OF DIESEL FUEL: 35.3 AT 60F					
RUN NUMBER		174	186	198	220	234	248
NOM. WATER PCT.		15	15	15	15	15	15
ENGINE SPEED	RPM	1800	1800	1800	1800	1800	1800
OBS. TORQUE	LB-FT	1257	1257	1257	1257	1257	1257
BAR. PRESS.	IN-HG	29.22	28.90	29.24	29.25	29.00	28.96
DRY BULB	DEG F	85	100	82	86	87	90
WET BULB	DEG F	73	94	76	76	77	77
REL. HUMIDITY	PCT	47	80	76	63	64	44
CORR. BHP	HP	439.4	462.6	438.2	440.2	444.0	448.9
CORR. BMEP	PSI	113.1	119.0	112.8	113.3	114.2	115.5
FUEL FLOW	LB/HR	178.39	178.32	176.90	176.82	177.37	179.00
WATER FLOW	CC/MIN	284.9	288.5	288.5	288.5	277.7	284.9
CALC. VOL. X	PCT	14.9	15.0	15.2	15.2	14.6	14.8
BSFC	LB/BHP-HR	406.0	385.5	403.7	401.7	399.6	398.7
AIR FLOW	LB/MIN	81.0	79.3	81.4	80.2	79.5	77.6
STOICH. F/A		.0691	.0691	.0691	.0691	.0691	.0691
MEAS. F/A		.0367	.0375	.0362	.0368	.0372	.0384
CALC. F/A		.0332	.0353	.0348	.0349	.0349	.0372
X DIFF.	PCT	-9.50	-5.76	-3.83	-5.00	-6.09	-3.19
COOLANT IN	DEG F	178	174	172	174	175	174
COOLANT OUT	DEG F	189	185	184	186	186	185
OIL SUMP	DEG F	222	219	218	219	219	220
FUEL IN	DEG F	110	114	110	111	112	114
FUEL RETURN	DEG F	152	157	151	151	152	154
FUEL SUPPLY	DEG F	93	100	93	95	95	99
FUEL COOLER	DEG F	111	117	112	112	113	115
INTAKE AIR	DEG F	89	95	82	87	86	94
TURB. INLET (L)	DEG F	921	929	902	916	921	935
TURB. INLET (R)	DEG F	931	939	914	924	931	945
COMP. OUT (L)	DEG F	228	234	218	225	225	234
COMP. OUT (R)	DEG F	226	233	217	222	223	232
CHARGE AIR (L)	DEG F	193	192	187	189	189	192
CHARGE AIR (R)	DEG F	193	193	188	190	190	192
EXH. STACK (R)	DEG F	788	793	771	781	786	792
EXH. STACK (L)	DEG F	775	783	775	785	788	792
WATER INLET	DEG F	101	110	102	104	102	108
CELL AIR	DEG F	91	99	81	86	88	96
EXHAUST 1R	DEG F	915	925	896	907	914	930
EXHAUST 2R	DEG F	893	901	876	896	898	911
EXHAUST 3R	DEG F	910	921	892	903	904	919
EXHAUST 4R	DEG F	883	895	869	881	882	896
EXHAUST 5R	DEG F	902	914	886	893	895	911
EXHAUST 6R	DEG F	914	928	900	913	913	921
EXHAUST 1L	DEG F	948	983	946	948	954	971
EXHAUST 2L	DEG F	927	938	908	916	920	938
EXHAUST 3L	DEG F	891	901	872	892	890	906
EXHAUST 4L	DEG F	898	906	879	888	892	910
EXHAUST 5L	DEG F	902	914	884	893	897	913
EXHAUST 6L	DEG F	911	932	898	911	917	932
OIL PRESSURE	PSI	75	76	76	76	76	76
RAIL PRESSURE	PSI	90.0	88	90.0	90.0	88.0	90.0
BOOST (R)	PSI	10.3	10	10.3	10.4	10.2	10.0
BOOST (L)	PSI	10.9	10	10.8	10.5	10.1	10.5
INLET VAC. (R)	IN-H2O	12.0	12.8	13.1	13.5	14.1	15.4
EXH. PRESS. (R)	PSI	2.5	2.5	2.5	2.4	2.5	2.5
EXH. PRESS. (L)	PSI	2.5	2.5	2.5	2.4	2.5	2.5
TURB. IN. (R)	IN-HG	10	10	10	10	10	10
TURB. IN. (L)	IN-HG	9	9	9	9	9	9
FUEL PRESS.	PSI	22	22	20	20	20	20
EMULSION PRESS.	PSI	100	100	100	100	100	100
FUEL SUPPLY	PSI	2	2	2	2	2	2
WATER PRESS.	PSI	60	50	50	60	65	65
HYDROCARBONS	PPMC	46	150	94	54	65	67
CARBON MONOXIDE	PPM	212	571	468	186	130	163
NITRIC OXIDE	PPM	1018	988	950	875	895	780
NITROGEN OXIDES	PPM	985	975	963	813	708	740
CARBON DIOXIDE	PCT	7.2	7.6	7.5	7.6	7.6	8.1
OXYGEN	PCT	10.3	8.7	12.0	11.9	13.0	11.6
SMOKE OPACITY	PCT	0.0	4.7	3.0	2.6	3.5	3.0
HC MASS	GM-HR	55.774	171.43	107.30	60.978	73.797	72.733
CO MASS	GM-HR	485.17	1228.8	1092.8	399.94	279.54	333.28
NOX MASS	GM-HR	438.24	878.8	447.3	366.0	322.9	385.1
BSHC	GM/BHP-HR	1.269	2.706	2.245	1.86	1.86	1.85
BSCO	GM/BHP-HR	1.1041	2.0429	2.3039	0.886	0.886	0.886
BSNO	GM/BHP-HR	9.9733	14.009	10.208	8.3195	7.2722	6.7974

TABLE C-17. ENGINE TEST RESULTS, CUMMINS ENGINE,
1800 RPM, 20% WATER

DYNAMOMETER CONSTANT: 3000 H/C RATIO: 1.78		API GRAVITY OF DIESEL FUEL 35.3 AT 60F					
RUN NUMBER		175	187	199	221	235	249
NOM WATER PCT		20	20	20	20	20	20
ENGINE SPEED	RPM	1800	1800	1800	1800	1800	1800
OBS. TORQUE	LB-FT	1257	1257	1257	1257	1257	1257
BAR PRESS.	IN-HG	29.21	28.88	29.24	29.25	29.03	28.95
DRY BULB	DEG F	90	98	82	86	87	97
WET BULB	DEG F	73	84	76	76	77	79
REL HUMIDITY	PCT	44	56	76	63	64	45
CORR BHP	HP	440.5	455.4	437.6	439.6	445.8	451.2
CORR BMEP	PSI	113.4	117.2	112.6	113.1	114.7	116.1
FUEL FLOW	LB/HR	177.48	178.82	176.82	176.64	175.61	178.35
WATER FLOW	CC/MIN	398.0	394.5	394.5	394.5	384.0	394.5
CALC. VOL. %		19.7	19.4	19.7	19.7	19.3	19.5
BSFC	LB/BHP-HR	40.29	39.27	40.40	40.18	39.49	39.52
AIR FLOW	LB/MIN	79.6	78.0	80.8	80.4	77.8	76.2
STOICH. F/A		.0691	.0691	.0691	.0691	.0691	.0691
MEAS. F/A		.0371	.0382	.0365	.0366	.0376	.0390
CALC. F/A		.0334	.0356	.0337	.0356	.0358	.0372
% DIFF	PCT	-10.00	-6.80	-2.20	-2.77	-4.88	-4.66
COOLANT IN	DEG F	177	172	171	164	175	174
COOLANT OUT	DEG F	188	184	185	181	186	185
OIL SUMP	DEG F	223	219	217	217	219	221
FUEL IN	DEG F	110	115	108	111	112	115
FUEL RETURN	DEG F	152	157	148	147	151	153
FUEL SUPPLY	DEG F	94	102	92	95	95	100
FUEL COOLER	DEG F	112	124	110	111	113	116
INTAKE AIR	DEG F	91	97	84	86	90	98
TURB. INLET (L)	DEG F	906	906	887	898	905	921
TURB. INLET (R)	DEG F	919	920	899	904	917	935
COMP. OUT (L)	DEG F	226	231	216	221	224	233
COMP. OUT (R)	DEG F	227	232	215	218	222	232
CHARGE AIR (L)	DEG F	192	193	186	184	189	191
CHARGE AIR (R)	DEG F	193	194	187	184	189	192
EXH. STACK (R)	DEG F	768	779	760	768	777	794
EXH. STACK (L)	DEG F	764	765	745	752	762	778
WATER INLET	DEG F	102	115	99	101	101	107
CELL AIR	DEG F	94	100	83	88	91	98
EXHAUST 1R	DEG F	901	915	880	896	905	921
EXHAUST 2R	DEG F	881	898	868	885	890	899
EXHAUST 3R	DEG F	900	906	879	891	897	912
EXHAUST 4R	DEG F	873	885	853	868	873	888
EXHAUST 5R	DEG F	892	905	881	884	890	903
EXHAUST 6R	DEG F	902	913	888	894	898	912
EXHAUST 1L	DEG F	953	964	928	932	939	955
EXHAUST 2L	DEG F	916	923	896	906	913	928
EXHAUST 3L	DEG F	878	885	859	877	880	891
EXHAUST 4L	DEG F	883	883	862	872	882	894
EXHAUST 5L	DEG F	894	900	873	884	892	904
EXHAUST 6L	DEG F	904	914	883	902	904	920
OIL PRESSURE	PSI	75	76	76	77	76	76
RAIL PRESSURE	PSI	97.0	98.0	96.0	95.0	96.0	97.0
BOOST (R)	PSI	10.0	9.8	10.0	10.0	9.9	9.8
BOOST (L)	PSI	10.5	10.0	11.0	10.0	10.0	10.0
INLET VAC (R)	IN-H2O	11.8	12.7	12.9	13.3	13.9	15.3
EXH. PRESS (R)	PSI	3	2	2	1	2	1
EXH. PRESS (L)	PSI	5	5	5	5	5	5
TURB. IN. (R)	IN-HG	10.0	10.0	10.2	10.0	10.0	10.0
TURB. IN. (L)	IN-HG	9.0	9.0	9.1	9.0	9.0	9.0
FUEL PRESS	PSI	22	22	20	20	20	20
EMULSION PRESS	PSI	100	100	100	100	100	100
FUEL SUPPLY	PSI	2	2	2	3	2	2
WATER PRESS.	PSI	60	65	60	60	65	65
HYDROCARBONS	PPMC	47	144	95	55	56	69
CARBON MONOXIDE	PPM	163	281	448	164	148	154
NITRIC OXIDE	PPM	1125	180	1000	880	713	888
NITROGEN OXIDES	PPM	1100	1050	1013	705	770	711
CARBON DIOXIDE	PCT	7.2	7.7	7.7	7.7	7.8	8.1
OXYGEN	PCT	10.2	8.8	11.9	11.8	12.8	11.6
SMOKE OPACITY	PCT	0.0	4.0	2.7	2.4	3.3	2.8
HC MASS	GM-HR	55.778	163.08	106.31	61.570	61.964	74.740
CO MASS	GM-HR	368.94	598.46	942.87	344.31	307.07	312.68
NOX MASS	GM-HR	5115.1	5482.2	4872.0	3304.0	3601.3	3189.8
BSHC	GM/HP-HR	1266	1358.1	1401	1401	1390	1630
BSHC	GM/HP-HR	8375	13143	21545	7832	6888	6330
BSNO	GM/HP-HR	11.611	12.039	11.133	7.5156	8.0784	7.0691

TABLE C-18. ENGINE TEST RESULTS, CUMMINS ENGINE,
1800 RPM, 25% WATER

DYNAMOMETER CONSTANT: 3000		API GRAVITY OF DIESEL FUEL: 35.3 AT 60F				
H/C RATIO: 1.78						
RUN NUMBER		176	200	222	236	250
NOM. WATER PCT.		25	25	25	25	25
ENGINE SPEED	RPM	1800	1800	1800	1800	1800
OBS. TORQUE	LB-FT	1257	1257	1257	1257	1257
BAR. PRESS.	IN-HG	29.19	29.26	29.25	29.03	28.92
DRY BULB	DEG F	90	81	86	91	98
WET BULB	DEG F	73	75	76	79	77
REL. HUMIDITY	PCT	44	76	63	59	39
CORR. BHP	HP	440.3	436.9	441.9	445.9	450.7
CORR. BMEP	PSI	113.3	112.4	113.7	114.7	116.0
FUEL FLOW	LB/HR	178.04	176.54	176.64	176.71	179.43
WATER FLOW	CC/MIN	478.9	494.2	501.7	501.7	501.7
CALC. VOL. %	PCT	22.8	23.5	23.7	23.7	23.4
BSFC	LB/BHP-HR	4044	4041	3990	3963	3981
AIR FLOW	LB/MIN	79.8	80.1	77.7	77.9	76.1
STOICH. F/A		.0691	.0691	.0691	.0691	.0671
MEAS. F/A		.0372	.0368	.0379	.0378	.0393
CALC. F/A		.0334	.0356	.0358	.0362	.0369
% DIFF.	PCT	-10.05	-3.00	-5.39	-4.07	-6.10
COOLANT IN	DEG F	177	174	162	174	176
COOLANT OUT	DEG F	188	186	180	185	186
OIL SUMP	DEG F	223	219	217	219	221
FUEL IN	DEG F	110	109	112	112	117
FUEL RETURN	DEG F	150	149	147	149	154
FUEL SUPPLY	DEG F	95	93	97	95	102
FUEL COOLER	DEG F	110	111	112	113	117
INTAKE AIR	DEG F	90	81	90	89	99
TURB. INLET (L)	DEG F	89	87	88	88	90
TURB. INLET (R)	DEG F	90	88	89	90	92
COMP. OUT (L)	DEG F	225	213	221	221	232
COMP. OUT (R)	DEG F	222	212	219	219	230
CHARGE AIR (L)	DEG F	191	187	184	188	192
CHARGE AIR (R)	DEG F	191	188	184	188	192
EXH. STACK (R)	DEG F	765	749	758	765	787
EXH. STACK (L)	DEG F	754	733	742	746	771
WATER INLET	DEG F	100	99	102	100	109
CELL AIR	DEG F	94	80	80	92	100
EXHAUST 1R	DEG F	893	872	881	894	907
EXHAUST 2R	DEG F	824	857	868	876	884
EXHAUST 3R	DEG F	893	853	880	888	899
EXHAUST 4R	DEG F	864	849	853	867	877
EXHAUST 5R	DEG F	889	873	875	882	897
EXHAUST 6R	DEG F	883	878	880	894	905
EXHAUST 1L	DEG F	940	917	908	920	939
EXHAUST 2L	DEG F	907	889	894	905	919
EXHAUST 3L	DEG F	868	848	855	867	877
EXHAUST 4L	DEG F	874	855	853	867	879
EXHAUST 5L	DEG F	885	872	875	882	894
EXHAUST 6L	DEG F	894	872	880	894	908
OIL PRESSURE	PSI	75	76	77	76	76
KAIL PRESSURE	PSI	102.0	104.0	107.0	112.0	105.0
BOOST (R)	PSI	9.8	10.0	9.8	9.7	9.5
BOOST (L)	PSI	9.8	10.0	10.0	10.0	9.8
INLET VAC. (R) IN-H2O		11.7	12.7	13.0	13.6	15.1
EXH. PRESS. (R) PSI		3	1	1	1	1
EXH. PRESS. (L) PSI		5	5	5	5	5
TURB. IN. (R) IN-HG		10.0	10.0	10.0	10.0	10.0
TURB. IN. (L) IN-HG		9.0	9.0	9.0	8.8	8.8
FUEL PRESS.	PSI	22	20	20	20	20
EMULSION PRESS.	PSI	100	100	100	100	100
FUEL SUPPLY	PSI	2	2	3	2	2
WATER PRESS.	PSI	60	60	70	62	65
HYDROCARBONS	PPHC	46	100	55	55	69
CARBON MONOXIDE	PPH	163	429	148	151	148
NITRIC OXIDE	PPH	1188	1113	770	788	748
NITROGEN OXIDES	PPH	1163	1113	750	795	763
CARBON DIOXIDE	PCT	7.2	7.7	7.8	7.9	8.0
OXYGEN	PCT	10.0	11.9	12.5	13.1	11.8
SMOKE OPACITY	PCT	0.0	2.4	2.2	3.1	2.8
HC MASS	GM-HR	55.392	111.82	61.187	60.594	75.744
CO MASS	GM-HR	370.11	900.50	308.49	311.64	303.91
NOX MASS	GM-HR	5662.8	5600.0	3712.8	4021.8	3517.1
BSHC	GM/BHP-HR	1258	2560	1385	1359	1680
BSCO	GM/BHP-HR	8406	20613	6982	6989	6743
BSNO	GM/BHP-HR	12.862	12.819	8.4027	9.0196	7.8030

TABLE C-19. ENGINE TEST RESULTS, DETROIT DIESEL
ENGINE, 500 RPM

DYNAMOMETER CONSTANT: 2000.
H/C RATIO: 1.82

API GRAVITY OF DIESEL FUEL: 33.9 AT 60F

RUN NUMBER		1	7	13	47	48	49	50
NOM. WATER PCT.		0	0	0	0	5	10	15
ENGINE SPEED	RPM	600	600	600	600	600	600	600
OBS. TORQUE	LB-FT	386	386	386	386	386	386	386
BAR. PRESS.	IN-HG	29.26	29.30	29.07	29.02	29.03	28.99	28.94
DRY BULB	DEG F	72	70	72	72	78	79	69
WET BULB	DEG F	64	63	66	59	60	61	56
REL. HUMIDITY	PCT	65	68	73	46	34	35	44
CORR. BHP	HP	43.6	43.6	44.6	44.5	44.4	44.6	44.4
CORR. BMEP	PSI	16.1	16.1	16.5	16.4	16.4	16.5	16.4
FUEL FLOW	LB/HR	24.89	24.41	24.60	23.82	23.43	24.22	24.60
WATER FLOW	CC/MIN	0.0	0.0	0.0	0.0	11.5	20.6	33.8
CALC. VOL. %	PCT	0.0	0.0	0.0	0.0	5.2	8.7	13.3
BSFC	LB/BHP-HR	5712	5604	5515	5358	5279	5431	5542
AIR FLOW L	LB/MIN	24.0	23.1	22.6	22.5	22.3	22.1	22.0
AIR FLOW R	LB/MIN	24.7	23.6	23.0	21.6	21.2	21.1	21.2
COOLANT IN	DEG F	179	177	179	180	179	179	182
COOLANT OUT	DEG F	184	183	183	185	184	184	187
OIL SUMP	DEG F	193	194	192	192	191	192	194
FUEL IN	DEG F	95	93	92	97	93	92	98
FUEL RETURN	DEG F	119	119	116	121	117	115	119
FUEL SUPPLY	DEG F	98	91	102	116	112	112	112
FUEL COOLER	DEG F	93	93	90	95	90	90	95
INTAKE AIR (RF)	DEG F	74	81	85	82	84	85	85
INTAKE AIR (RR)	DEG F	75	80	78	81	84	84	84
INTAKE AIR (LF)	DEG F	73	78	78	81	83	85	82
INTAKE AIR (LR)	DEG F	73	77	80	82	84	85	82
HP AIR (RF)	DEG F	84	92	88	92	93	94	92
HP AIR (RR)	DEG F	85	93	89	92	94	94	93
HP AIR (LF)	DEG F	85	91	91	93	95	96	93
HP AIR (LR)	DEG F	84	88	89	91	92	94	91
EXH. STACK	DEG F	299	346	301	307	303	300	297
WATER INLET	DEG F	69	69	78	80	81	81	84
CELL AIR	DEG F	69	70	80	82	82	84	80
EXHAUST 1R	DEG F	319	320	324	330	326	324	328
EXHAUST 2R	DEG F	306	310	310	315	315	315	315
EXHAUST 3R	DEG F	305	306	305	308	305	304	307
EXHAUST 4R	DEG F	313	313	316	314	312	311	314
EXHAUST 5R	DEG F	303	303	308	306	303	303	344
EXHAUST 6R	DEG F	299	290	297	306	302	301	305
EXHAUST 1L	DEG F	337	344	342	337	332	331	333
EXHAUST 2L	DEG F	320	323	324	328	327	319	370
EXHAUST 3L	DEG F	316	320	321	324	318	316	316
EXHAUST 4L	DEG F	326	332	330	330	328	325	326
EXHAUST 5L	DEG F	331	339	337	342	338	335	335
EXHAUST 6L	DEG F	335	339	340	338	337	333	331
OIL PRESSURE	PSI	20.0	18.0	19.0	19.0	19.0	19.0	19.0
FUEL SPILL	PSI	28.0	20.0	22.0	20.0	20.0	20.0	20.0
BOOST (RF)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BOOST (RR)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BOOST (LF)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BOOST (LR)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AIR BOX	PSI	0.0	0.0	0.0	8.0	8.0	8.0	8.0
INLET VAC. (RF)	IN-H2O	.5	.4	.5	.5	.5	.5	.5
INLET VAC. (RR)	IN-H2O	.6	.4	.5	.5	.5	.5	.5
INLET VAC. (LF)	IN-H2O	1.8	1.7	1.8	1.9	1.8	1.8	1.8
INLET VAC. (LR)	IN-H2O	1.7	1.7	1.8	1.8	1.8	1.8	1.8
EXH. PRESS. (R)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EXH. PRESS. (L)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TURB. IN. (RF)	IN-HG	0.0	0.0	0.0	.9	.8	.8	.8
TURB. IN. (RR)	IN-HG	0.0	0.0	0.0	.9	.8	.8	.8
TURB. IN. (LF)	IN-HG	0.0	0.0	0.0	.9	.8	.8	.8
TURB. IN. (LR)	IN-HG	0.0	0.0	0.0	.9	.8	.8	.8
FUEL PRESS.	PSI	20.0	20.0	20.0	20.0	20.0	20.0	20.0
EMULSION PRESS.	PSI	100	100	100	100	100	100	100
FUEL SUPPLY	PSI	4.0	3.7	4.0	3.5	4.0	4.0	4.5
WATER PRESS	PSI	0	0	0	0	50	50	50

TABLE C-20. ENGINE TEST RESULTS, DETROIT DIESEL
ENGINE, 800 RPM, BASELINE

DYNAMOMETER CONSTANT: 2000.
H/C RATIO: 1.82

API GRAVITY OF DIESEL FUEL: 33.9 AT 60F

RUN NUMBER		2.	8.	14.	40.	46.
NOM. WATER PCT.		0.	0.	0.	0.	0.
ENGINE SPEED	RPM	800.	800.	800.	800.	800.
OBS. TORQUE	LB-FT	591.	591.	591.	591.	591.
BAR. PRESS.	IN-HG	29.20	29.29	29.04	29.33	29.13
DRY BULB	DEG F	72.	74.	74.	71.	79.
WET BULB	DEG F	64.	64.	68.	58.	62.
REL. HUMIDITY	PCT	65.	58.	74.	45.	38.
CORR. BHP	HP	89.8	89.5	91.0	88.4	90.4
CORR. BMEP	PSI	24.9	24.8	25.2	24.5	25.0
FUEL FLOW	LB/HR	43.10	43.06	42.87	42.15	42.43
WATER FLOW	CC/MIN	0.0	0.0	0.0	0.0	0.0
CALC. VOL. %	PCT	0.0	0.0	0.0	0.0	0.0
BSFC	LB/BHP-HR	4799	4813	4710	4768	4692
AIR FLOW L	LB/MIN	31.9	31.9	31.0	31.0	30.8
AIR FLOW R	LB/MIN	32.7	32.6	31.6	31.1	29.8
COOLANT IN	DEG F	180.	180.	181.	180.	179.
COOLANT OUT	DEG F	186.	185.	186.	185.	185.
OIL SUMP	DEG F	196.	196.	197.	195.	196.
FUEL IN	DEG F	99.	95.	95.	95.	102.
FUEL RETURN	DEG F	120.	117.	117.	118.	123.
FUEL SUPPLY	DEG F	95.	90.	91.	96.	108.
FUEL COOLER	DEG F	99.	93.	93.	95.	100.
INTAKE AIR (RF)	DEG F	79.	85.	89.	76.	87.
INTAKE AIR (RR)	DEG F	79.	85.	81.	75.	86.
INTAKE AIR (LF)	DEG F	80.	79.	78.	72.	84.
INTAKE AIR (LR)	DEG F	81.	79.	80.	74.	84.
HP AIR (RF)	DEG F	92.	98.	95.	90.	100.
HP AIR (RR)	DEG F	93.	98.	95.	90.	100.
HP AIR (LF)	DEG F	93.	92.	95.	89.	99.
HP AIR (LR)	DEG F	94.	92.	93.	88.	97.
EXH. STACK	DEG F	362.	368.	370.	379.	378.
WATER INLET	DEG F	75.	73.	75.	78.	87.
CELL AIR	DEG F	75.	75.	78.	71.	82.
EXHAUST 1R	DEG F	385.	386.	393.	402.	402.
EXHAUST 2R	DEG F	368.	371.	375.	381.	380.
EXHAUST 3R	DEG F	363.	360.	370.	370.	368.
EXHAUST 4R	DEG F	377.	375.	381.	384.	382.
EXHAUST 5R	DEG F	364.	384.	370.	370.	370.
EXHAUST 6R	DEG F	368.	364.	368.	373.	372.
EXHAUST 1L	DEG F	418.	418.	426.	431.	426.
EXHAUST 2L	DEG F	396.	398.	403.	406.	400.
EXHAUST 3L	DEG F	381.	381.	386.	390.	388.
EXHAUST 4L	DEG F	407.	411.	414.	416.	420.
EXHAUST 5L	DEG F	413.	417.	424.	432.	430.
EXHAUST 6L	DEG F	420.	425.	426.	435.	434.
OIL PRESSURE	PSI	26.0	27.0	26.0	26.0	26.0
FUEL SPILL	PSI	28.0	29.0	28.0	25.0	25.0
BOOST (RF)	PSI	0.0	0.0	0.0	0.0	0.0
BOOST (RR)	PSI	1.0	0.0	0.0	0.0	0.0
BOOST (LF)	PSI	0.0	0.0	0.0	0.0	0.0
BOOST (LR)	PSI	1.0	0.0	0.0	0.0	0.0
AIR BOX	PSI	0.0	1.0	0.0	8.0	8.0
INLET VAC. (RF)	IN-H2O	9.	9.	9.	1.0	1.0
INLET VAC. (RR)	IN-H2O	1.0	9.	9.	1.0	1.0
INLET VAC. (LF)	IN-H2O	2.6	2.7	2.8	2.8	2.8
INLET VAC. (LR)	IN-H2O	2.7	2.6	2.8	2.7	2.8
EXH. PRESS. (R)	PSI	0.0	0.0	0.0	0.0	0.0
EXH. PRESS. (L)	PSI	0.0	0.0	0.0	0.0	0.0
TURB. IN. (RF)	IN-HG	0.0	8.	0.0	1.8	1.8
TURB. IN. (RR)	IN-HG	0.0	8.	0.0	1.8	1.7
TURB. IN. (LF)	IN-HG	0.0	8.	0.0	1.8	1.7
TURB. IN. (LR)	IN-HG	0.0	8.	0.0	1.8	1.7
FUEL PRESS.	PSI	20.0	20.0	20.0	20.0	20.0
FUEL SUPPLY PRESS.	PSI	100.	100.	100.	100.	100.
FUEL SUPPLY	PSI	4.5	3.7	3.5	3.0	3.7
WATER PRESS.	PSI	0.	0.	0.	0.	0.

TABLE C-21. ENGINE TEST RESULTS, DETROIT DIESEL
ENGINE, 800 RPM, WITH WATER ADDITION

DYNAMOMETER CONSTANT: 2000.
H/C RATIO: 1.82

API GRAVITY OF DIESEL FUEL: 33.9 AT 60F

RUN NUMBER NOM. WATER PCT.		41 5	42 10	43 15	44 20	45 25
ENGINE SPEED	RPM	800	800	800	800	800
UBS. TORQUE	LB-FT	591	591	591	591	591
BAR. PRESS.	IN-HG	29.32	29.30	29.26	29.21	29.17
DRY BULB	DEG F	80	80	80	79	79
WET BULB	DEG F	60	61	61	59	59
REL. HUMIDITY	PCT	29	32	32	29	29
CORR. BHP	HP	89.8	90.0	90.3	89.9	90.5
CORR. BMEP	PSI	24.9	24.9	25.0	24.9	25.0
FUEL FLOW	LB/HR	42.60	42.83	43.28	44.19	43.69
WATER FLOW	CC/MIN	19.7	40.0	66.4	90.9	119.3
CALC. VOL. %	PCT	4.9	9.4	14.6	18.6	23.3
BSFC	LB/BHP-HR	4742	4760	4791	4916	4829
AIR FLOW L	LB/MIN	31.1	30.9	30.6	31.6	30.6
AIR FLOW R	LB/MIN	30.0	30.0	30.6	30.0	29.9
COOLANT IN	DEG F	180	180	181	180	179
COOLANT OUT	DEG F	185	186	186	185	185
OIL SUMP	DEG F	197	197	197	198	197
FUEL IN	DEG F	103	104	99	99	95
FUEL RETURN	DEG F	123	123	118	117	114
FUEL SUPPLY	DEG F	101	102	101	100	100
FUEL COOLER	DEG F	102	102	97	98	93
INTAKE AIR (RF)	DEG F	86	89	88	85	88
INTAKE AIR (RR)	DEG F	85	89	88	85	88
INTAKE AIR (LF)	DEG F	84	86	85	82	86
INTAKE AIR (LR)	DEG F	85	87	87	84	88
HP AIR (RF)	DEG F	99	103	102	98	102
HP AIR (RR)	DEG F	99	103	102	99	102
HP AIR (LF)	DEG F	100	102	101	97	102
HP AIR (LR)	DEG F	99	100	101	94	100
EXH. STACK	DEG F	378	375	368	361	363
WATER INLET	DEG F	78	83	85	83	83
CELL AIR	DEG F	84	84	86	82	86
EXHAUST 1R	DEG F	400	396	392	370	388
EXHAUST 2R	DEG F	379	376	375	376	374
EXHAUST 3R	DEG F	366	366	363	364	364
EXHAUST 4R	DEG F	380	378	376	373	372
EXHAUST 5R	DEG F	369	366	363	362	362
EXHAUST 6R	DEG F	372	373	371	370	369
EXHAUST 1L	DEG F	426	417	411	405	404
EXHAUST 2L	DEG F	401	395	389	385	384
EXHAUST 3L	DEG F	388	384	379	376	375
EXHAUST 4L	DEG F	415	411	404	399	401
EXHAUST 5L	DEG F	424	421	412	407	407
EXHAUST 6L	DEG F	428	424	416	409	409
OIL PRESSURE	PSI	26.0	26.0	26.0	26.0	26.0
FUEL SPILL	PSI	25.0	25.0	27.0	27.0	27.0
BOOST (RF)	PSI	.5	.5	.5	.5	.5
BOOST (RR)	PSI	.5	.5	.5	.5	.5
BOOST (LF)	PSI	0.0	0.0	0.0	0.0	0.0
BOOST (LR)	PSI	.5	.5	.5	.5	.5
AIR BOX	PSI	8.0	8.0	8.0	8.0	8.0
INLET VAC. (RF) IN-H2O		1.0	1.0	1.0	1.0	1.0
INLET VAC. (RR) IN-H2O		1.0	1.0	1.0	1.0	1.0
INLET VAC. (LF) IN-H2O		2.8	2.8	2.8	2.8	2.8
INLET VAC. (LR) IN-H2O		2.8	2.8	2.8	2.7	2.8
EXH. PRESS. (R) PSI		0.0	0.0	0.0	0.0	0.0
EXH. PRESS. (L) PSI		0.0	0.0	0.0	0.0	0.0
TURB. IN. (RF) IN-HG		1.8	1.8	1.8	1.8	1.8
TURB. IN. (RR) IN-HG		1.9	1.8	1.7	1.8	1.7
TURB. IN. (LF) IN-HG		1.8	1.8	1.7	1.8	1.7
TURB. IN. (LR) IN-HG		1.8	1.8	1.8	1.8	1.8
FUEL PRESS.	PSI	20.0	20.0	20.0	20.0	20.0
EMULSION PRESS.	PSI	100	100	100	100	100
FUEL SUPPLY	PSI	3.0	3.5	4.0	4.5	5.0
WATER PRESS.	PSI	50	50	50	50	50

TABLE C-22. ENGINE TEST RESULTS, DETROIT DIESEL
ENGINE, 1000 RPM, BASELINE

DYNAMOMETER CONSTANT: 2000.
H/C RATIO: 1.82

API GRAVITY OF DIESEL FUEL: 33.9 AT 60F

RUN NUMBER		3.	9.	15.	19.	25.	51.	57.	65.	71.
NOM. WATER PCT.		0.	0.	0.	0.	0.	0.	0.	0.	0.
ENGINE SPEED	RPM	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.
OBS. TORQUE	LB-FT	877.	877.	877.	877.	877.	877.	877.	877.	877.
BAR. PRESS.	IN-HG	29.17	29.26	28.99	29.33	29.25	29.29	29.15	29.07	29.00
DRY BULB	DEG F	72.	72.	74.	73.	73.	62.	68.	67.	71.
WET BULB	DEG F	64.	64.	68.	66.	67.	55.	62.	62.	64.
REL. HUMIDITY	PCT	65.	65.	74.	69.	73.	64.	72.	76.	69.
CORR. BHP	HP	167.0	165.9	169.6	166.4	168.4	162.9	166.2	168.2	167.2
CORR. BMEP	PSI	37.0	36.7	37.6	36.9	37.3	36.1	36.8	37.3	37.0
FUEL FLOW	LB/HR	72.43	72.17	71.76	72.25	72.43	71.91	73.17	71.97	71.32
WATER FLOW	CC/MIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CALC. VOL. %	PCT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BSFC	LB/BHP-HR	4336	4351	4230	4341	4301	4416	4403	4278	4265
AIR FLOW L	LB/MIN	40.7	40.7	39.8	40.9	39.9	41.4	41.0	39.6	41.0
AIR FLOW R	LB/MIN	41.8	42.0	40.8	41.5	40.2	41.6	40.8	40.2	39.9
COOLANT IN	DEG F	179.	179.	179.	177.	182.	178.	176.	178.	174.
COOLANT OUT	DEG F	185.	186.	186.	184.	188.	184.	182.	184.	182.
OIL SUMP	DEG F	201.	201.	201.	200.	202.	198.	197.	198.	198.
FUEL IN	DEG F	102.	99.	99.	100.	100.	103.	100.	97.	100.
FUEL RETURN	DEG F	122.	120.	121.	121.	121.	122.	120.	119.	120.
FUEL SUPPLY	DEG F	89.	86.	87.	86.	88.	85.	84.	81.	88.
FUEL COOLER	DEG F	100.	96.	98.	100.	99.	102.	100.	96.	90.
INTAKE AIR (RF)	DEG F	81.	89.	89.	84.	89.	73.	82.	78.	79.
INTAKE AIR (RR)	DEG F	81.	89.	89.	84.	89.	72.	81.	78.	79.
INTAKE AIR (LF)	DEG F	79.	80.	82.	81.	86.	68.	75.	73.	77.
INTAKE AIR (LR)	DEG F	81.	80.	83.	82.	86.	68.	75.	73.	78.
HP AIR (RF)	DEG F	102.	111.	111.	106.	110.	92.	102.	98.	98.
HP AIR (RR)	DEG F	103.	111.	111.	107.	111.	93.	102.	99.	99.
HP AIR (LF)	DEG F	103.	103.	107.	106.	110.	92.	98.	96.	99.
HP AIR (LR)	DEG F	103.	103.	104.	105.	109.	90.	96.	94.	100.
EXH. STACK	DEG F	442.	451.	453.	461.	457.	468.	472.	476.	469.
WATER INLET	DEG F	74.	78.	76.	79.	79.	70.	73.	73.	75.
CELL AIR	DEG F	76.	73.	80.	76.	82.	64.	72.	72.	72.
EXHAUST 1R	DEG F	479.	485.	489.	486.	494.	481.	487.	486.	479.
EXHAUST 2R	DEG F	459.	463.	469.	466.	472.	459.	459.	463.	458.
EXHAUST 3R	DEG F	466.	466.	475.	476.	473.	455.	460.	457.	452.
EXHAUST 4R	DEG F	477.	481.	487.	481.	481.	466.	469.	474.	471.
EXHAUST 5R	DEG F	462.	464.	466.	466.	466.	447.	488.	453.	456.
EXHAUST 6R	DEG F	465.	470.	474.	474.	480.	460.	457.	463.	458.
EXHAUST 1L	DEG F	505.	508.	514.	512.	514.	527.	527.	535.	528.
EXHAUST 2L	DEG F	495.	499.	504.	505.	509.	522.	524.	533.	526.
EXHAUST 3L	DEG F	471.	476.	483.	480.	480.	495.	497.	506.	500.
EXHAUST 4L	DEG F	495.	503.	505.	506.	567.	524.	526.	483.	474.
EXHAUST 5L	DEG F	508.	518.	523.	519.	521.	537.	544.	549.	544.
EXHAUST 6L	DEG F	534.	537.	537.	543.	538.	557.	552.	568.	563.
OIL PRESSURE	PSI	34.0	35.0	34.0	35.0	34.0	34.0	35.0	35.0	35.0
FUEL SPILL	PSI	37.0	37.0	37.0	36.0	36.0	35.0	35.0	35.0	35.0
BOOST (RF)	PSI	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BOOST (RR)	PSI	1.0	1.0	1.0	2.0	2.0	0.0	0.0	0.0	0.0
BOOST (LF)	PSI	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
BOOST (LR)	PSI	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
AIR BOX	PSI	0.0	2.0	4.0	4.0	5.0	10.0	10.0	10.0	10.0
INLET VAC. (RF)	IN-H2O	1.6	1.7	1.5	1.6	1.6	1.5	1.5	1.5	1.6
INLET VAC. (RR)	IN-H2O	1.7	1.7	1.6	1.7	1.5	1.5	1.5	1.6	1.6
INLET VAC. (LF)	IN-H2O	3.9	3.8	4.0	4.0	3.9	3.9	4.0	4.0	4.0
INLET VAC. (LR)	IN-H2O	3.9	3.8	3.9	3.9	3.9	3.9	4.0	4.0	4.0
EXH. PRESS. (R)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EXH. PRESS. (L)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TURB. IN. (RF)	IN-HG	0.0	1.2	1.2	3.7	2.4	3.1	3.1	3.1	3.1
TURB. IN. (RR)	IN-HG	0.0	1.8	1.6	3.7	2.4	3.1	3.1	3.1	3.1
TURB. IN. (LF)	IN-HG	0.0	1.0	1.0	3.7	2.4	3.1	3.1	3.1	3.1
TURB. IN. (LR)	IN-HG	0.0	1.8	1.2	3.7	2.4	3.1	3.1	3.1	3.1
FUEL PRESS	PSI	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
EMULSION PRESS.	PSI	100.	100.	100.	100.	100.	100.	100.	100.	100.
FUEL SUPPLY	PSI	4.2	3.7	3.5	3.5	3.2	2.5	3.7	2.5	3.5
WATER PRESS.	PSI	0.	0.	0.	0.	0.	0.	0.	0.	0.

TABLE C-23. ENGINE TEST RESULTS, DETROIT DIESEL
ENGINE, 1000 RPM, 5, 10, 15% WATER

DYNAMOMETER CONSTANT: 2000.
H/C RATIO: 1.82

API GRAVITY OF DIESEL FUEL: 33.9 AT 60F

RUN NUMBER NOM. WATER PCT.		20 5	52 5	66 5	21 10	53 10	67 10	22 15	54 15	68 15
ENGINE SPEED OBS. TORQUE	RPM LB-FT	1000 877	1000 877	1000 877	1000 877	1000 877	1000 877	1000 877	1000 877	1000 877
BAR. PRESS.	IN-HG	29.33	29.30	29.08	29.33	29.28	29.09	29.31	29.25	29.09
DRY BULB	DEG F	73	62	67	73	68	72	72	68	72
WET BULB	DEG F	66	55	62	66	58	66	66	58	66
REL. HUMIDITY	PCT	69	64	76	66	55	73	73	55	73
CORR. BHP	HP	168.2	163.2	167.1	168.6	164.3	167.9	168.8	164.5	167.9
CORR. BMEP	PSI	37.2	36.2	37.0	37.3	36.4	37.2	37.4	36.4	37.2
FUEL FLOW	LB/HR	72.55	71.96	71.68	73.11	72.06	72.35	73.34	72.52	72.37
WATER FLOW	CC/MIN	33.8	32.3	30.8	66.4	69.7	66.4	111.0	109.5	111.0
CALC. VOL. %		4.9	4.8	4.6	9.2	9.7	9.3	14.4	14.4	14.6
BSFC	LB/BHP-HR	4314	4408	4290	4337	4385	4309	4345	4409	4310
AIR FLOW L	LB/MIN	39.8	41.4	40.4	39.5	40.8	40.5	39.5	40.9	40.2
AIR FLOW R	LB/MIN	40.7	41.5	40.2	40.1	41.1	40.3	40.1	41.3	40.0
COOLANT IN	DEG F	177	177	180	179	181	177	182	180	177
COOLANT OUT	DEG F	184	184	186	185	187	184	188	189	184
OIL SUMP	DEG F	199	199	201	200	201	198	203	202	199
FUEL IN	DEG F	98	97	99	98	98	100	99	99	98
FUEL RETURN	DEG F	119	118	120	120	118	119	118	118	117
FUEL SUPPLY	DEG F	87	82	86	89	85	87	87	86	87
FUEL COOLER	DEG F	96	98	99	99	100	100	98	100	99
INTAKE AIR (RF)	DEG F	86	73	85	89	74	86	85	76	85
INTAKE AIR (RR)	DEG F	86	72	85	89	74	85	85	75	85
INTAKE AIR (LF)	DEG F	84	67	78	87	71	78	86	73	78
INTAKE AIR (LR)	DEG F	85	68	76	88	71	78	86	72	78
HP AIR (RF)	DEG F	107	92	104	110	93	104	106	95	104
HP AIR (RR)	DEG F	108	92	104	110	93	105	106	95	104
HP AIR (LF)	DEG F	108	90	100	110	94	100	106	93	100
HP AIR (LR)	DEG F	107	89	97	110	93	98	109	93	98
EXH. STACK	DEG F	449	464	474	447	458	466	443	454	461
WATER INLET	DEG F	76	65	72	85	68	75	85	73	79
CELL AIR	DEG F	84	66	74	86	70	76	86	70	76
EXHAUST 1R	DEG F	489	473	483	487	471	477	469	469	473
EXHAUST 2R	DEG F	462	450	457	460	446	450	459	446	446
EXHAUST 3R	DEG F	467	447	453	463	442	447	458	446	441
EXHAUST 4R	DEG F	476	460	470	470	455	461	466	451	452
EXHAUST 5R	DEG F	460	440	452	460	438	445	460	438	442
EXHAUST 6R	DEG F	472	449	460	462	449	453	466	444	443
EXHAUST 1L	DEG F	506	523	533	505	519	523	505	515	515
EXHAUST 2L	DEG F	501	518	531	502	516	525	499	510	517
EXHAUST 3L	DEG F	469	482	500	469	478	491	466	476	484
EXHAUST 4L	DEG F	497	519	481	499	516	477	495	512	469
EXHAUST 5L	DEG F	515	534	544	512	525	534	504	520	528
EXHAUST 6L	DEG F	527	547	559	526	539	548	518	533	538
OIL PRESSURE	PSI	35.0	34.0	34.0	35.0	34.0	35.0	34.0	34.0	34.0
FUEL SPILL	PSI	36.0	35.0	35.0	37.0	35.0	35.0	37.0	35.0	35.0
BOOST (RF)	PSI	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BOOST (RR)	PSI	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BOOST (LF)	PSI	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BOOST (LR)	PSI	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
AIR BOX	PSI	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
INLET VAC. (RF)	IN-H2O	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
INLET VAC. (RR)	IN-H2O	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
INLET VAC. (LF)	IN-H2O	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
INLET VAC. (LR)	IN-H2O	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
EXH. PRESS. (R)	PSI	4.0	3.8	4.0	4.0	3.8	4.0	4.0	3.9	4.0
EXH. PRESS. (L)	PSI	4.0	3.8	4.0	4.0	3.8	4.0	4.0	3.9	4.0
TURB. IN. (RF)	IN-HG	3.2	3.1	3.1	3.2	3.2	3.2	3.2	3.1	3.1
TURB. IN. (RR)	IN-HG	3.2	3.1	3.1	3.2	3.2	3.2	3.2	3.1	3.1
TURB. IN. (LF)	IN-HG	3.2	3.1	3.1	3.2	3.2	3.2	3.2	3.1	3.1
TURB. IN. (LR)	IN-HG	3.2	3.1	3.1	3.2	3.2	3.2	3.2	3.1	3.1
FUEL PRESS.	PSI	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
EMULSION PRESS.	PSI	100	100	100	100	100	100	100	100	100
FUEL SUPPLY	PSI	3.5	3.0	3.0	3.6	3.0	3.0	3.7	3.7	3.3
WATER PRESS.	PSI	55	50	50	55	50	50	6	50	50

TABLE C-24. ENGINE TEST RESULTS, DETROIT DIESEL
ENGINE, 1000 RPM, 20, 25% WATER

DYNAMOMETER CONSTANT: 2000.
H/C RATIO: 1.82

API GRAVITY OF DIESEL FUEL: 33.9 AT 60F

RUN NUMBER		23.	55.	69.	24.	56.	70.
NOM. WATER PCT.		20.	20.	20.	25.	25.	25.
ENGINE SPEED		1000.	1000.	1000.	1000.	1000.	1000.
OBS. TORQUE		877.	877.	877.	877.	877.	877.
RPM		1000.	1000.	1000.	1000.	1000.	1000.
LB-FT		877.	877.	877.	877.	877.	877.
BAR. PRESS.	IN-HG	29.29	29.21	29.09	29.27	29.18	29.04
DRY BULB	DEG F	72.	69.	72.	72.	69.	72.
WET BULB	DEG F	66.	60.	66.	66.	60.	66.
REL. HUMIDITY	PCT	73.	59.	73.	73.	59.	73.
CORR. BHP	HP	167.6	165.0	167.9	167.7	165.2	168.2
CORR. BMEP	PSI	37.1	36.5	37.2	37.1	36.6	37.3
FUEL FLOW	LB/HR	73.83	73.68	73.02	73.91	73.77	73.53
WATER FLOW	CC/MIN	159.0	155.9	155.9	208.0	208.0	211.0
CALC. VOL. %	PCT	19.3	19.1	19.2	23.9	23.9	24.2
BSFC	LB/BHP-HR	4405	4466	4349	4407	4467	4372
AIR FLOW L	LB/MIN	40.1	40.8	40.1	39.9	41.0	40.0
AIR FLOW R	LB/MIN	40.3	41.5	39.7	40.3	41.2	40.2
COOLANT IN	DEG F	179.	176.	177.	179.	177.	176.
COOLANT OUT	DEG F	185.	182.	184.	185.	184.	183.
OIL SUMP	DEG F	201.	198.	200.	202.	200.	200.
FUEL IN	DEG F	96.	96.	97.	95.	94.	96.
FUEL RETURN	DEG F	115.	114.	115.	114.	112.	114.
FUEL SUPPLY	DEG F	88.	88.	86.	87.	90.	87.
FUEL COOLER	DEG F	96.	97.	97.	96.	93.	96.
INTAKE AIR (RF)	DEG F	87.	77.	87.	86.	79.	87.
INTAKE AIR (RR)	DEG F	87.	76.	86.	85.	78.	86.
INTAKE AIR (LF)	DEG F	80.	73.	78.	81.	73.	80.
INTAKE AIR (LR)	DEG F	81.	72.	77.	82.	73.	79.
HP AIR (RF)	DEG F	109.	95.	106.	106.	97.	105.
HP AIR (RR)	DEG F	109.	95.	106.	107.	97.	106.
HP AIR (LF)	DEG F	104.	95.	99.	104.	95.	102.
HP AIR (LR)	DEG F	104.	93.	97.	103.	93.	99.
EXH. STACK	DEG F	439.	446.	456.	430.	443.	450.
WATER INLET	DEG F	85.	75.	79.	83.	76.	81.
CELL AIR	DEG F	80.	70.	76.	80.	70.	76.
EXHAUST 1R	DEG F	476.	463.	471.	471.	463.	465.
EXHAUST 2R	DEG F	453.	447.	450.	451.	447.	451.
EXHAUST 3R	DEG F	453.	432.	443.	455.	433.	443.
EXHAUST 4R	DEG F	456.	445.	451.	458.	447.	453.
EXHAUST 5R	DEG F	451.	432.	441.	453.	433.	442.
EXHAUST 6R	DEG F	458.	435.	443.	463.	439.	446.
EXHAUST 1L	DEG F	495.	505.	510.	489.	500.	504.
EXHAUST 2L	DEG F	487.	500.	509.	483.	495.	504.
EXHAUST 3L	DEG F	456.	469.	482.	445.	466.	476.
EXHAUST 4L	DEG F	487.	502.	464.	482.	496.	461.
EXHAUST 5L	DEG F	492.	505.	516.	487.	50.	510.
EXHAUST 6L	DEG F	509.	521.	531.	507.	515.	523.
OIL PRESSURE	PSI	35.0	35.0	34.0	35.0	35.0	34.0
FUEL SPILL	PSI	38.0	35.0	35.0	38.0	36.0	36.0
BOOST (RF)	PSI	1.0	1.0	1.0	1.0	1.0	1.0
BOOST (RR)	PSI	2.0	0.0	0.0	2.0	0.0	0.0
BOOST (LF)	PSI	0.0	0.0	0.0	0.0	0.0	0.0
BOOST (LR)	PSI	1.0	1.0	1.0	1.0	1.0	1.0
AIR BOX	PSI	5.0	10.0	10.0	5.0	10.0	10.0
INLET VAC. (RF) IN-H2O		1.5	1.5	1.6	1.5	1.5	1.6
INLET VAC. (RR) IN-H2O		1.6	1.5	1.6	1.6	1.6	1.6
INLET VAC. (LF) IN-H2O		3.9	4.0	4.1	3.9	3.9	4.0
INLET VAC. (LR) IN-H2O		3.9	3.9	4.0	3.9	3.9	4.0
EXH. PRESS. (R) PSI		0.0	0.0	0.0	0.0	0.0	0.0
EXH. PRESS. (L) PSI		0.0	0.0	0.0	0.0	0.0	0.0
TURB. IN. (RF) IN-HG		3.1	3.1	3.0	3.1	3.1	3.1
TURB. IN. (RR) IN-HG		3.1	3.1	3.0	3.1	3.1	3.0
TURB. IN. (LF) IN-HG		2.9	3.1	3.1	2.9	3.1	3.1
TURB. IN. (LR) IN-HG		2.9	3.2	3.1	2.9	3.2	3.1
FUEL PRESS.	PSI	20.0	20.0	20.0	20.0	20.0	20.0
EMULSION PRESS.	PSI	100.	100.	100.	100.	100.	100.
FUEL SUPPLY	PSI	3.5	4.0	3.9	4.5	4.2	4.0
WATER PRESS.	PSI	55.	50.	50.	55.	50.	50.

TABLE C-25. ENGINE TEST RESULTS, DETROIT DIESEL
ENGINE, 1000 RPM, FUEL INJECTION TIMING RETARDED
2.4 DEGREES

DYNAMOMETER CONSTANT: 2000.
H/C RATIO: 1.82

API GRAVITY OF DIESEL FUEL: 33.9 AT 60F

RUN NUMBER		72	78	73	74	75	76	77
NOM. WATER PCT.		0	0	5	10	15	20	25
ENGINE SPEED	KPM	1000	1000	1000	1000	1000	1000	1000
OBS. TORQUE	LB-FT	877	877	877	877	877	877	877
BAR. PRESS.	IN-HG	29.23	29.21	29.25	29.25	29.24	29.32	29.23
DRY BULB	DEG F	74	82	74	80	80	85	89
WET BULB	DEG F	62	60	62	61	61	61	61
REL. HUMIDITY	PCT	51	26	51	32	32	32	32
CURR. BHP	HP	166.2	166.8	166.5	166.4	166.7	166.4	166.5
CORR. BMEP	PSI	36.8	36.9	36.9	36.9	36.9	36.9	36.9
FUEL FLOW	LB/HR	72.29	72.23	71.72	72.17	72.32	72.64	73.22
WATER FLOW	CC/MIN	0.0	0.0	32.3	68.1	109.5	157.4	208.0
CALC. VOL. %	PCT	0.0	0.0	1.8	9.5	14.4	19.4	24.0
BSFC	LB/BHP-HR	4.349	4.331	4.307	4.337	4.339	4.365	4.397
AIR FLOW L	LB/MIN	40.8	40.1	40.7	40.4	40.3	40.3	40.4
AIR FLOW R	LB/MIN	40.8	40.7	40.7	40.5	40.3	40.4	40.5
COOLANT IN	DEG F	176	178	177	177	176	179	179
COOLANT OUT	DEG F	183	184	184	183	183	185	185
OIL SUMP	DEG F	195	200	198	198	198	200	201
FUEL IN	DEG F	97	100	99	100	97	97	95
FUEL RETURN	DEG F	117	122	119	119	116	116	114
FUEL SUPPLY	DEG F	88	101	90	90	90	90	90
FUEL COOLER	DEG F	97	98	99	99	97	96	96
INTAKE AIR (RF)	DEG F	86	93	90	92	93	95	95
INTAKE AIR (RR)	DEG F	86	93	90	93	92	94	95
INTAKE AIR (LF)	DEG F	79	85	81	83	84	85	84
INTAKE AIR (LR)	DEG F	78	86	80	83	84	86	84
HP AIR (RF)	DEG F	106	112	109	111	111	112	113
HP AIR (RR)	DEG F	107	113	107	112	112	113	114
HP AIR (LF)	DEG F	101	108	102	105	106	108	106
HP AIR (LR)	DEG F	99	107	101	103	104	106	104
EXH. STACK	DEG F	460	487	477	473	466	462	456
WATER INLET	DEG F	78	87	77	84	85	84	84
CELL AIR	DEG F	76	82	78	80	81	82	80
EXHAUST 1R	DEG F	488	489	480	478	471	472	465
EXHAUST 2R	DEG F	466	468	456	452	451	452	452
EXHAUST 3R	DEG F	461	462	451	448	443	442	443
EXHAUST 4R	DEG F	480	478	470	462	455	457	453
EXHAUST 5R	DEG F	460	460	453	450	445	445	443
EXHAUST 6R	DEG F	465	466	459	454	448	447	447
EXHAUST 1L	DEG F	533	533	528	522	516	509	503
EXHAUST 2L	DEG F	533	538	530	527	519	513	505
EXHAUST 3L	DEG F	510	512	503	496	490	485	477
EXHAUST 4L	DEG F	534	539	532	525	518	512	502
EXHAUST 5L	DEG F	551	559	545	538	530	524	514
EXHAUST 6L	DEG F	568	573	556	547	540	534	525
OIL PRESSURE	PSI	36.0	35.0	35.0	35.0	35.0	34.0	34.0
FUEL SPILL	PSI	35.0	34.0	35.0	34.0	34.0	34.0	35.0
BOOST (RF)	PSI	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BOOST (RR)	PSI	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BOOST (LF)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BOOST (LR)	PSI	1.0	1.0	1.0	1.0	1.0	1.0	1.0
AIR BOX	PSI	2.4	2.0	2.0	2.2	2.2	2.0	2.0
INLET VAC. (RF)	IN-H2O	1.5	1.5	1.5	1.5	1.5	1.5	1.5
INLET VAC. (RR)	IN-H2O	1.5	1.6	1.5	1.5	1.5	1.5	1.5
INLET VAC. (LF)	IN-H2O	4.0	4.1	4.0	4.1	4.0	4.0	4.0
INLET VAC. (LR)	IN-H2O	4.0	4.0	4.0	4.0	4.0	4.0	4.0
EXH. PRESS. (R)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EXH. PRESS. (L)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TURB. IN. (RF)	IN-HG	3.1	3.1	3.1	3.1	3.0	3.1	3.0
TURB. IN. (RR)	IN-HG	3.1	3.1	3.1	3.1	3.0	3.0	3.0
TURB. IN. (LF)	IN-HG	3.1	3.1	3.0	3.0	3.0	3.0	3.0
TURB. IN. (LR)	IN-HG	3.2	3.2	3.2	3.1	3.1	3.1	3.1
FUEL PRESS.	PSI	20.0	20.0	20.0	20.0	20.0	20.0	20.0
EMULSION PRESS.	PSI	100	100	100	100	100	100	100
FUEL SUPPLY	PSI	3.0	3.0	3.0	3.5	3.5	3.6	3.5
WATER PRESS.	PSI	0	0	50	50	50	50	50

TABLE C-26. ENGINE TEST RESULTS, DETROIT DIESEL
ENGINE, 1000 RPM, FUEL INJECTION TIMING RETARDED
4.1 DEGREES

DYNAMOMETER CONSTANT: 2000.
H/C RATIO: 1.82

API GRAVITY OF DIESEL FUEL: 33.9 AT 60F

KUN NUMBER	79	85	80	81	82	83	84
NOM WATER PCT	0.	0.	5.	10.	15.	20.	25.
ENGINE SPEED	1000.	1000.	1000.	1000.	1000.	1000.	1000.
OBS TORQUE	877.	877.	877.	877.	877.	877.	877.
BAR PRESS	29.04	28.93	29.06	29.06	29.03	29.00	28.96
DRY BULB	80.	94.	80.	83.	83.	84.	92.
WET BULB	70.	70.	70.	71.	71.	71.	71.
REL HUMIDITY	61.	30.	61.	56.	56.	53.	35.
CORR BHP	170.3	172.6	170.6	170.6	171.2	172.6	172.8
CORR BMEP	37.7	38.2	37.8	37.8	37.9	38.2	38.3
FUEL FLOW	72.58	72.52	72.09	72.93	73.51	73.82	74.52
WATER FLOW	0.0	0.0	33.8	69.7	108.0	154.4	211.7
CALC. VOL. %	0.0	0.0	4.9	9.6	14.0	18.8	23.9
BSFC	4263	4201	4226	4275	4293	4276	4315
AIR FLOW L	39.3	39.6	39.1	39.1	40.7	38.0	39.6
AIR FLOW R	40.4	39.5	39.8	39.8	39.7	39.5	39.5
COOLANT IN	178.	177.	178.	177.	178.	177.	177.
COOLANT OUT	184.	184.	184.	184.	184.	184.	184.
OIL SUMP	197.	199.	198.	199.	200.	199.	200.
FUEL IN	104.	108.	105.	107.	107.	105.	104.
FUEL RETURN	123.	127.	124.	125.	124.	122.	121.
FUEL SUPPLY	95.	108.	97.	99.	101.	103.	104.
FUEL COOLER	103.	106.	105.	106.	106.	104.	104.
INTAKE AIR (RF)	89.	100.	92.	95.	95.	100.	101.
INTAKE AIR (RR)	89.	100.	92.	95.	95.	100.	101.
INTAKE AIR (LF)	85.	100.	86.	88.	93.	95.	96.
INTAKE AIR (LR)	85.	100.	86.	88.	93.	96.	97.
HP AIR (RF)	109.	120.	113.	114.	113.	118.	120.
HP AIR (RR)	109.	121.	112.	115.	114.	119.	120.
HP AIR (LF)	109.	124.	110.	111.	116.	120.	119.
HP AIR (LR)	106.	121.	108.	109.	114.	116.	117.
EXH. STACK	493.	504.	493.	483.	480.	473.	469.
WATER INLET	82.	99.	83.	88.	92.	95.	94.
CELL AIR	84.	96.	84.	86.	88.	94.	96.
EXHAUST 1R	500.	505.	494.	490.	484.	482.	479.
EXHAUST 2R	477.	480.	468.	463.	464.	464.	464.
EXHAUST 3R	467.	472.	463.	457.	451.	451.	453.
EXHAUST 4R	484.	487.	480.	470.	465.	464.	464.
EXHAUST 5R	466.	469.	461.	456.	453.	450.	450.
EXHAUST 6R	473.	476.	467.	461.	453.	450.	452.
EXHAUST 1L	544.	552.	542.	536.	530.	523.	520.
EXHAUST 2L	549.	554.	544.	539.	533.	523.	518.
EXHAUST 3L	522.	525.	513.	505.	502.	496.	489.
EXHAUST 4L	547.	548.	542.	533.	528.	518.	512.
EXHAUST 5L	572.	578.	567.	554.	547.	537.	530.
EXHAUST 6L	584.	592.	579.	566.	558.	549.	543.
OIL PRESSURE	35.0	35.0	35.0	35.0	35.0	35.0	35.0
FUEL SPILL	35.0	35.0	35.0	35.0	35.0	35.0	35.0
BOOST (RF)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BOOST (RR)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BOOST (LF)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BOOST (LR)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
ATK BOX	2.0	2.0	2.0	2.0	2.0	2.0	2.0
INLET VAC. (RF) IN-H2O	1.5	1.5	1.5	1.5	1.5	1.5	1.5
INLET VAC. (RR) IN-H2O	1.5	1.5	1.5	1.6	1.5	1.6	1.6
INLET VAC. (LF) IN-H2O	4.1	4.2	4.2	4.2	4.2	4.2	4.2
INLET VAC. (LR) IN-H2O	4.1	4.2	4.0	4.1	4.1	4.1	4.1
EXH. PRESS. (R) PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EXH. PRESS. (L) PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TURB. IN. (RF) IN-HG	3.1	3.1	3.1	3.1	3.1	3.0	3.0
TURB. IN. (RR) IN-HG	3.1	3.1	3.1	3.1	3.1	3.0	3.0
TURB. IN. (LF) IN-HG	3.2	3.2	3.2	3.2	3.2	3.1	3.1
TURB. IN. (LR) IN-HG	3.2	3.2	3.2	3.2	3.2	3.1	3.1
FUEL PRESS. PSI	30.0	26.0	25.0	26.0	26.0	26.0	26.0
EMULSION PRESS. PSI	100.	100.	100.	100.	100.	100.	100.
FUEL SUPPLY	3.0	3.8	3.2	3.2	3.5	3.6	3.7
WATER PRESS. PSI	0.	0.	50.	0.	50.	50.	50.

TABLE C-27. ENGINE TEST RESULTS, DETROIT DIESEL
ENGINE, 1000 RPM, FUEL INJECTION TIMING ADVANCED
2.8 DEGREES

DYNAMOMETER CONSTANT: 2000.		API GRAVITY OF DIESEL FUEL: 33.9 AT 60F						
H/C RATIO: 1.82								
RUN NUMBER		93.	99.	94.	95.	96.	97.	98.
NOM. WATER PCT.		0.	0.	5.	10.	15.	20.	25.
ENGINE SPEED	RPM	1000.	1000.	1000.	1000.	1000.	1000.	1000.
OBS. TORQUE	LB-FT	877.	877.	877.	877.	877.	877.	877.
BAR. PRESS.	IN-HG	29.24	29.04	29.22	29.20	29.16	29.12	29.09
DRY BULB	DEG F	72.	85.	72.	80.	80.	84.	84.
WET BULB	DEG F	60.	65.	60.	61.	61.	64.	64.
REL. HUMIDITY	PCT	49.	33.	49.	32.	32.	33.	33.
CORR. BHP	HP	165.1	169.8	166.0	166.5	167.4	168.7	168.9
CORR. BMEP	PSI	36.6	37.6	36.8	36.9	37.1	37.4	37.4
FUEL FLOW	LB/HR	72.32	71.68	72.35	72.91	73.59	74.10	74.60
WATER FLOW	CC/MIN	0.0	0.0	30.8	68.1	111.0	157.4	208.0
CALC. VOL. %	PCT	0.0	0.0	4.5	9.4	14.3	19.1	23.7
BSFC	LB/BHP-HR	4382	4222	4357	4380	4397	4392	4416
AIR FLOW L	LB/MIN	41.0	39.0	40.9	40.5	40.0	39.4	39.4
AIR FLOW R	LB/MIN	40.7	39.2	40.3	40.5	39.8	39.6	39.8
COOLANT IN	DEG F	177.	176.	177.	178.	178.	179.	178.
COOLANT OUT	DEG F	183.	183.	184.	185.	185.	185.	185.
OIL SUMP	DEG F	198.	197.	198.	201.	202.	202.	202.
FUEL IN	DEG F	96.	104.	101.	100.	102.	100.	99.
FUEL RETURN	DEG F	118.	124.	121.	120.	120.	118.	118.
FUEL SUPPLY	DEG F	84.	95.	89.	90.	92.	93.	94.
FUEL COOLER	DEG F	96.	103.	99.	100.	101.	100.	99.
INTAKE AIR (RF)	DEG F	85.	95.	88.	89.	92.	90.	92.
INTAKE AIR (RR)	DEG F	84.	95.	87.	89.	92.	90.	92.
INTAKE AIR (LF)	DEG F	75.	91.	80.	82.	84.	88.	90.
INTAKE AIR (LR)	DEG F	75.	92.	80.	82.	85.	89.	90.
HP AIR (RF)	DEG F	104.	114.	106.	109.	110.	110.	112.
HP AIR (RR)	DEG F	104.	114.	107.	109.	110.	111.	112.
HP AIR (LF)	DEG F	97.	114.	102.	104.	107.	110.	112.
HP AIR (LR)	DEG F	96.	112.	101.	103.	106.	109.	111.
EXH. STACK	DEG F	471.	416.	469.	467.	463.	456.	451.
WATER INLET	DEG F	72.	90.	76.	84.	87.	88.	89.
CELL AIR	DEG F	72.	88.	76.	79.	82.	86.	86.
EXHAUST 1R	DEG F	483.	485.	482.	476.	474.	473.	467.
EXHAUST 2R	DEG F	460.	462.	456.	451.	455.	456.	455.
EXHAUST 3R	DEG F	451.	452.	451.	452.	446.	446.	447.
EXHAUST 4R	DEG F	463.	466.	461.	457.	453.	453.	453.
EXHAUST 5R	DEG F	448.	454.	447.	446.	443.	442.	443.
EXHAUST 6R	DEG F	456.	454.	453.	450.	445.	445.	448.
EXHAUST 1L	DEG F	525.	527.	523.	519.	515.	510.	506.
EXHAUST 2L	DEG F	525.	524.	524.	520.	514.	507.	502.
EXHAUST 3L	DEG F	494.	497.	485.	482.	480.	481.	471.
EXHAUST 4L	DEG F	526.	533.	524.	520.	514.	506.	501.
EXHAUST 5L	DEG F	541.	545.	535.	533.	521.	515.	508.
EXHAUST 6L	DEG F	561.	567.	556.	548.	544.	536.	525.
OIL PRESSURE	PSI	34.0	34.0	34.0	34.0	34.0	34.0	34.0
FUEL SPILL	PSI	34.0	33.0	34.0	34.0	34.0	34.0	34.0
BOOST (RF)	PSI	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BOOST (RR)	PSI	0.0	1.0	0.0	0.0	0.0	0.0	0.0
BOOST (LF)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BOOST (LR)	PSI	1.0	1.0	1.0	1.0	1.0	1.0	1.0
AIR BOX	PSI	2.0	2.0	2.0	2.0	2.0	2.0	2.0
INLET VAC. (RF)	IN-H2O	1.5	1.5	1.5	1.5	1.5	1.5	1.5
INLET VAC. (RR)	IN-H2O	1.5	1.5	1.5	1.5	1.6	1.5	1.6
INLET VAC. (LF)	IN-H2O	4.0	4.1	4.0	4.0	3.9	4.0	4.0
INLET VAC. (LR)	IN-H2O	3.9	4.1	4.0	4.0	4.0	4.0	4.0
EXH. PRESS. (R)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EXH. PRESS. (L)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TURB. IN. (RF)	IN-HG	3.2	3.0	3.1	3.1	3.1	3.0	3.1
TURB. IN. (RR)	IN-HG	3.1	3.0	3.0	3.0	3.0	3.0	3.0
TURB. IN. (LF)	IN-HG	3.1	3.0	3.0	3.0	3.0	3.0	3.0
TURB. IN. (LR)	IN-HG	3.2	3.1	3.1	3.2	3.1	3.1	3.1
FUEL PRESS.	PSI	22.0	20.0	22.0	22.0	22.0	22.0	22.0
EMULSION PRESS.	PSI	100.	100.	100.	100.	100.	100.	100.
FUEL SUPPLY	PSI	3.2	3.0	3.4	3.0	3.5	3.6	3.7
WATER PRESS.	PSI	0.	0.	50.	50.	50.	50.	50.

TABLE C-28. ENGINE TEST RESULTS, DETROIT DIESEL
ENGINE, 1000 RPM, FUEL INJECTION TIMING ADVANCED
5.5 DEGREES

DYNAMOMETER CONSTANT: 2000.
H/C RATIO: 1.82

API GRAVITY OF DIESEL FUEL: 33.9 AT 60F

RUN NUMBER		100.	106.	101.	102.	103.	104.	105.
NOM. WATER PCT.		0.	0.	5.	10.	15.	20.	25.
ENGINE SPEED	RPM	1000.	1000.	1000.	1000.	1000.	1000.	1000.
OBS. TORQUE	LB-FT	877.	877.	877.	877.	877.	877.	877.
BAR. PRESS.	IN-HG	28.98	28.95	28.99	29.00	29.00	28.99	28.97
DRY BULB	DEG F	75.	82.	75.	75.	82.	82.	82.
WET BULB	DEG F	69.	70.	69.	70.	70.	70.	70.
REL. HUMIDITY	PCT	74.	55.	74.	78.	55.	55.	55.
CORR. BHP	HP	169.4	171.5	170.2	169.9	170.8	170.6	171.0
CORR. BMEP	PSI	37.5	38.0	37.7	37.6	37.8	37.8	37.9
FUEL FLOW	LB/HR	73.41	72.85	73.77	74.04	75.47	76.11	76.50
WATER FLOW	CC/MIN	0.0	0.0	32.3	68.1	112.5	160.6	215.5
CALC. VOL. X	PCT	0.0	0.0	4.6	9.3	14.2	19.0	23.8
BSFC	LB/BHP-HR	433.3	424.7	433.4	435.7	441.9	446.0	447.4
AIR FLOW L	LB/MIN	40.0	38.7	39.5	39.7	40.9	39.2	39.0
AIR FLOW R	LB/MIN	40.1	39.2	39.9	40.2	39.8	39.9	40.1
COOLANT IN	DEG F	177.	179.	178.	178.	178.	178.	178.
COOLANT OUT	DEG F	184.	186.	185.	184.	185.	185.	185.
OIL SUMP	DEG F	200.	202.	202.	201.	203.	203.	204.
FUEL IN	DEG F	104.	104.	104.	103.	104.	103.	102.
FUEL RETURN	DEG F	126.	125.	125.	122.	122.	120.	119.
FUEL SUPPLY	DEG F	90.	96.	93.	91.	94.	94.	95.
FUEL COOLER	DEG F	103.	104.	104.	103.	104.	103.	102.
INTAKE AIR (RF)	DEG F	83.	90.	85.	84.	91.	89.	91.
INTAKE AIR (RR)	DEG F	83.	91.	85.	85.	91.	89.	92.
INTAKE AIR (LF)	DEG F	79.	93.	82.	87.	91.	89.	92.
INTAKE AIR (LR)	DEG F	78.	94.	81.	87.	92.	89.	93.
HP AIR (RF)	DEG F	101.	110.	104.	103.	110.	108.	110.
HP AIR (RR)	DEG F	103.	112.	105.	104.	111.	109.	112.
HP AIR (LF)	DEG F	101.	112.	104.	108.	112.	110.	113.
HP AIR (LR)	DEG F	99.	114.	102.	107.	112.	110.	113.
EXH. STACK	DEG F	469.	474.	466.	462.	462.	453.	451.
WATER INLET	DEG F	78.	88.	79.	83.	88.	88.	89.
CELL AIR	DEG F	78.	88.	82.	80.	86.	85.	86.
EXHAUST 1R	DEG F	486.	494.	477.	476.	476.	475.	471.
EXHAUST 2R	DEG F	465.	470.	460.	457.	464.	465.	464.
EXHAUST 3R	DEG F	459.	461.	457.	452.	452.	453.	456.
EXHAUST 4R	DEG F	461.	468.	460.	456.	454.	457.	451.
EXHAUST 5R	DEG F	449.	453.	444.	446.	446.	446.	446.
EXHAUST 6R	DEG F	455.	459.	451.	447.	443.	446.	448.
EXHAUST 1L	DEG F	522.	536.	520.	517.	513.	508.	505.
EXHAUST 2L	DEG F	518.	530.	521.	517.	512.	506.	503.
EXHAUST 3L	DEG F	498.	506.	494.	490.	488.	483.	477.
EXHAUST 4L	DEG F	523.	529.	521.	518.	516.	508.	502.
EXHAUST 5L	DEG F	536.	538.	532.	526.	521.	512.	509.
EXHAUST 6L	DEG F	557.	557.	550.	543.	540.	530.	527.
OIL PRESSURE	PSI	35.0	34.0	34.0	34.0	34.0	34.0	34.0
FUEL SPILL	PSI	34.0	34.0	34.0	34.0	34.0	34.0	34.0
BOOST (RF)	PSI	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BOOST (RR)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BOOST (LF)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BOOST (LR)	PSI	1.0	1.0	1.0	1.0	1.0	1.0	1.0
AIR BOX	PSI	2.0	2.0	2.0	2.0	2.0	2.0	2.0
INLET VAC. (RF) IN-H2O		1.5	1.5	1.5	1.5	1.5	1.5	1.5
INLET VAC. (RR) IN-H2O		1.5	1.5	1.5	1.5	1.5	1.5	1.5
INLET VAC. (LF) IN-H2O		4.1	4.0	4.1	4.0	4.1	4.1	4.1
INLET VAC. (LR) IN-H2O		4.0	4.0	4.0	4.0	4.0	4.0	4.0
EXH. PRESS. (R) PSI		0.0	0.0	0.0	0.0	0.0	0.0	0.0
EXH. PRESS. (L) PSI		0.0	0.0	0.0	0.0	0.0	0.0	0.0
TURB. IN. (RF) IN-HG		3.1	3.0	3.1	3.1	3.1	3.1	3.0
TURB. IN. (RR) IN-HG		3.0	3.0	3.0	3.0	3.0	3.0	3.0
TURB. IN. (LF) IN-HG		3.1	3.0	3.0	3.0	3.0	3.0	3.1
TURB. IN. (LR) IN-HG		3.1	3.1	3.1	3.1	3.1	3.1	3.1
FUEL PRESS.	PSI	25.0	20.0	25.0	24.0	24.0	24.0	24.0
EMULSION PRESS.	PSI	100.	100.	100.	100.	100.	100.	100.
FUEL SUPPLY	PSI	3.0	3.2	3.0	3.0	3.2	3.4	3.5
WATER PRESS.	PSI	0.	0.	50.	50.	50.	50.	50.

TABLE C-29. ENGINE TEST RESULTS, DETROIT DIESEL
ENGINE, 1200 RPM, BASELINE

DYNAMOMETER CONSTANT: 2000
H/C RATIO: 1.82

API GRAVITY OF DIESEL FUEL: 33.9 AT 60F

RUN NUMBER		4	10	16	26	32
NOM. WATER PCT.		0	0	0	0	0
ENGINE SPEED	RPM	1200	1200	1200	1200	1200
OBS. TORQUE	LB-FT	1229	1229	1229	1229	1229
BAR. PRESS.	IN-HG	29.16	29.25	28.96	29.31	29.18
DRY BULB	DEG F	75	72	75	79	72
WET BULB	DEG F	65	64	70	61	62
REL. HUMIDITY	PCT	59	65	78	34	57
CORR. BHP	HP	281.3	280.1	286.1	277.9	282.4
CORR. BMEP	PSI	51.9	51.7	52.8	51.3	52.1
FUEL FLOW	LB/HR	115.57	115.85	115.13	115.76	115.11
WATER FLOW	CC/MIN	0.0	0.0	0.0	0.0	0.0
CALC. VOL. %	PCT	0.0	0.0	0.0	0.0	0.0
BSFC	LB/BHP-HR	4108	4136	4023	4166	4077
AIR FLOW L	LB/MIN	52.1	50.5	49.1	50.8	49.4
AIR FLOW R	LB/MIN	51.8	52.9	50.2	52.3	52.2
COOLANT IN	DEG F	180	179	181	180	177
COOLANT OUT	DEG F	188	187	189	188	185
OIL SUMP	DEG F	206	206	207	204	204
FUEL IN	DEG F	102	101	102	101	99
FUEL RETURN	DEG F	125	123	124	122	122
FUEL SUPPLY	DEG F	85	83	83	79	81
FUEL COOLER	DEG F	101	100	101	107	100
INTAKE AIR (RF)	DEG F	85	91	84	88	90
INTAKE AIR (RR)	DEG F	86	91	84	87	89
INTAKE AIR (LF)	DEG F	83	80	84	78	85
INTAKE AIR (LR)	DEG F	84	80	84	78	82
HP AIR (RF)	DEG F	122	127	121	123	125
HP AIR (RR)	DEG F	123	129	121	123	126
HP AIR (LF)	DEG F	122	120	124	117	125
HP AIR (LR)	DEG F	122	119	121	116	123
EXH. STACK	DEG F	537	545	548	545	553
WATER INLET	DEG F	78	78	78	69	82
CELL AIR	DEG F	77	76	80	76	82
EXHAUST 1R	DEG F	586	598	605	607	606
EXHAUST 2R	DEG F	567	573	578	583	582
EXHAUST 3R	DEG F	587	588	593	594	594
EXHAUST 4R	DEG F	598	603	607	595	599
EXHAUST 5R	DEG F	578	585	587	582	584
EXHAUST 6R	DEG F	568	573	580	585	585
EXHAUST 1L	DEG F	611	620	621	614	616
EXHAUST 2L	DEG F	624	628	631	638	643
EXHAUST 3L	DEG F	585	591	595	590	594
EXHAUST 4L	DEG F	628	638	638	634	639
EXHAUST 5L	DEG F	628	636	640	630	637
EXHAUST 6L	DEG F	640	649	648	645	649
OIL PRESSURE	PSI	42.0	43.0	42.0	43.0	42.0
FUEL SPILL	PSI	46.0	45.0	45.0	45.0	45.0
BOOST (RF)	PSI	2.0	2.0	2.1	2.0	2.0
BOOST (RR)	PSI	1.2	1.5	1.0	1.0	1.0
BOOST (LF)	PSI	1.0	1.5	1.0	1.0	1.0
BOOST (LR)	PSI	2.5	2.5	2.5	2.0	2.0
AIR BOX	PSI	2.0	5.0	6.0	7.0	7.0
INLET VAC. (RF) IN-H2O		2.6	2.7	2.5	2.6	2.5
INLET VAC. (RR) IN-H2O		2.7	2.7	2.7	2.7	2.7
INLET VAC. (LF) IN-H2O		5.6	5.6	5.6	5.7	5.7
INLET VAC. (LR) IN-H2O		5.4	5.5	5.5	5.5	5.6
EXH. PRESS. (R) PSI		0.0	0.0	0.0	0.0	0.0
EXH. PRESS. (L) PSI		0.0	0.0	0.0	0.0	0.0
TURB. IN. (RF) IN-HG		0.0	2.4	3.3	2.4	3.7
TURB. IN. (RR) IN-HG		0.0	2.4	3.3	3.4	3.7
TURB. IN. (LF) IN-HG		0.0	2.4	2.9	3.4	3.7
TURB. IN. (LR) IN-HG		0.0	2.4	2.9	3.4	3.7
FUEL PRESS.	PSI	20.0	20.0	20.0	20.0	20.0
EMULSION PRESS.	PSI	100	100	100	100	100
FUEL SUPPLY	PSI	4.2	3.1	3.5	3.2	3.0
WATER PRESS.	PSI	0	0	0	0	0

TABLE C-30. ENGINE TEST RESULTS, DETROIT DIESEL
ENGINE, 1200 RPM, WITH WATER ADDITION

DYNAMOMETER CONSTANT: 2000.
H/C RATIO: 1.82

API GRAVITY OF DIESEL FUEL: 33.9 AT 60F

RUN NUMBER		27.	28.	29.	30.	31.
NOM. WATER PCT.		5.	10.	15.	20.	25.
ENGINE SPEED	RPM	1200.	1200.	1200.	1200.	1200.
OBS. TORQUE	LB-FT	1229.	1229.	1229.	1229.	1229.
BAR. PRESS.	IN-HG	29.31	29.29	29.25	29.20	29.18
DRY BULB	DEG F	79.	72.	72.	75.	72.
WET BULB	DEG F	61.	62.	62.	64.	62.
REL. HUMIDITY	PCT	34.	57.	57.	55.	57.
CORR. BHP	HP	280.0	280.5	280.9	283.2	282.4
CORR. BMEP	PSI	51.7	51.8	51.9	52.3	52.1
FUEL FLOW	LB/HR	116.26	115.70	116.43	116.22	116.43
WATER FLOW	CC/MIN	49.8	114.0	175.1	215.5	366.4
CALC. VOL. %	PCT	4.5	9.9	14.3	17.1	25.9
BSFC	LB/BHP-HR	4152	4124	4144	4104	4123
AIR FLOW L	LB/MIN	50.7	50.9	50.8	51.0	49.4
AIR FLOW R	LB/MIN	51.6	51.8	51.6	51.1	51.2
COOLANT IN	DEG F	179.	179.	179.	179.	178.
COOLANT OUT	DEG F	186.	186.	187.	187.	185.
OIL SUMP	DEG F	206.	206.	206.	206.	206.
FUEL IN	DEG F	102.	102.	103.	101.	95.
FUEL RETURN	DEG F	123.	123.	122.	119.	115.
FUEL SUPPLY	DEG F	84.	84.	82.	82.	82.
FUEL COOLER	DEG F	102.	104.	104.	105.	100.
INTAKE AIR (RF)	DEG F	93.	88.	87.	88.	90.
INTAKE AIR (RR)	DEG F	92.	87.	86.	88.	89.
INTAKE AIR (LF)	DEG F	84.	84.	84.	84.	85.
INTAKE AIR (LR)	DEG F	84.	84.	83.	84.	86.
HP AIR (RF)	DEG F	128.	122.	122.	123.	123.
HP AIR (RR)	DEG F	129.	123.	123.	124.	124.
HP AIR (LF)	DEG F	122.	122.	122.	122.	122.
HP AIR (LR)	DEG F	121.	121.	119.	120.	122.
EXH. STACK	DEG F	545.	536.	531.	525.	519.
WATER INLET	DEG F	70.	80.	84.	84.	84.
CELL AIR	DEG F	82.	80.	80.	84.	82.
EXHAUST 1R	DEG F	599.	587.	585.	567.	561.
EXHAUST 2R	DEG F	575.	563.	564.	551.	546.
EXHAUST 3R	DEG F	590.	582.	578.	574.	564.
EXHAUST 4R	DEG F	591.	584.	577.	571.	564.
EXHAUST 5R	DEG F	584.	575.	570.	563.	557.
EXHAUST 6R	DEG F	586.	570.	564.	557.	550.
EXHAUST 1L	DEG F	606.	591.	587.	584.	579.
EXHAUST 2L	DEG F	629.	616.	611.	609.	604.
EXHAUST 3L	DEG F	588.	574.	564.	564.	557.
EXHAUST 4L	DEG F	627.	613.	607.	607.	601.
EXHAUST 5L	DEG F	626.	612.	609.	599.	588.
EXHAUST 6L	DEG F	641.	629.	622.	619.	609.
OIL PRESSURE	PSI	43.0	43.0	42.0	42.0	42.0
FUEL SPILL	PSI	45.0	45.0	44.0	44.0	43.0
BOOST (RF)	PSI	2.0	2.0	2.0	2.0	2.0
BOOST (RR)	PSI	1.0	1.5	1.5	1.5	1.5
BOOST (LF)	PSI	1.0	1.0	1.0	1.0	1.0
BOOST (LR)	PSI	2.5	2.0	2.5	2.5	2.0
AIR BOX	PSI	7.0	7.0	7.0	7.0	7.0
INLET VAC. (RF)	IN-H2O	2.6	2.6	2.6	2.5	2.5
INLET VAC. (RR)	IN-H2O	3.7	2.7	2.6	2.6	2.6
INLET VAC. (LF)	IN-H2O	5.7	5.6	5.7	5.7	5.7
INLET VAC. (LR)	IN-H2O	5.6	5.6	5.5	5.5	5.5
EXH. PRESS. (R)	PSI	0.0	0.0	0.0	0.0	0.0
EXH. PRESS. (L)	PSI	0.0	0.0	0.0	0.0	0.0
TURB. IN. (RF)	IN-HG	2.9	3.3	3.3	3.3	3.3
TURB. IN. (RR)	IN-HG	2.9	3.3	3.3	3.3	3.3
TURB. IN. (LF)	IN-HG	2.9	3.3	3.3	3.3	3.3
TURB. IN. (LR)	IN-HG	2.9	3.3	3.3	3.3	3.3
FUEL PRESS.	PSI	20.0	20.0	20.0	20.0	20.0
EMULSION PRESS.	PSI	100.	100.	100.	100.	100.
FUEL SUPPLY	PSI	3.5	3.4	3.5	3.0	3.2
WATER PRESS.	PSI	50.	50.	50.	50.	50.

TABLE C-31. ENGINE TEST RESULTS, DETROIT DIESEL
ENGINE, 1400 RPM, BASELINE

DYNAMOMETER CONSTANT: 2000.
H/C RATIO: 1.82

API GRAVITY OF DIESEL FUEL: 33.9 AT 60F

RUN NUMBER		5.	11.	17.	33.	39.	58.	54.
NOM. WATER PCT.		0.	0.	0.	0.	0.	0.	0.
ENGINE SPEED	RPM	1400.	1400.	1400.	1400.	1400.	1400.	1400.
OBS. TORQUE	LB-FT	1654.	1654.	1654.	1654.	1654.	1654.	1654.
BAR. PRESS.	IN-HG	29.30	29.12	29.17	29.17	29.23	29.22	29.15
DRY BULB	DEG F	67.	74.	75.	75.	71.	65.	68.
WET BULB	DEG F	62.	67.	64.	62.	59.	59.	64.
REL. HUMIDITY	PCT	76.	70.	55.	48.	49.	70.	81.
CORR. BHP	HP	435.0	446.5	444.1	442.5	437.5	431.1	438.6
CORR. BMEP	PSI	68.8	70.6	70.2	70.0	69.2	68.2	69.4
FUEL FLOW	LB/HR	177.76	177.08	177.47	176.47	177.44	176.38	176.47
WATER FLOW	CC/MIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CALC. VOL. %	PCT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BSFC	LB/BHP-HR	4087.	3965.	3997.	3988.	4056.	4091.	4023.
AIR FLOW L	LB/MIN	66.3	64.8	66.0	66.3	66.7	66.8	64.7
AIR FLOW R	LB/MIN	68.6	67.4	68.4	69.0	69.7	69.5	68.7
COOLANT IN	DEG F	178.	179.	177.	176.	177.	179.	177.
COOLANT OUT	DEG F	187.	189.	186.	185.	185.	187.	185.
OIL SUMP	DEG F	211.	211.	209.	210.	210.	208.	209.
FUEL IN	DEG F	104.	105.	105.	104.	104.	100.	101.
FUEL RETURN	DEG F	126.	127.	126.	127.	126.	122.	123.
FUEL SUPPLY	DEG F	81.	82.	80.	81.	84.	75.	79.
FUEL COOLER	DEG F	105.	104.	106.	103.	100.	99.	99.
INTAKE AIR (RF)	DEG F	76.	94.	90.	90.	87.	82.	73.
INTAKE AIR (RR)	DEG F	77.	93.	90.	90.	85.	81.	92.
INTAKE AIR (LF)	DEG F	74.	86.	89.	85.	77.	68.	75.
INTAKE AIR (LR)	DEG F	74.	86.	89.	85.	77.	67.	73.
HP AIR (RF)	DEG F	140.	156.	153.	154.	152.	143.	153.
HP AIR (RR)	DEG F	141.	157.	154.	154.	152.	142.	152.
HP AIR (LF)	DEG F	141.	153.	157.	153.	147.	134.	139.
HP AIR (LR)	DEG F	137.	149.	153.	149.	143.	129.	134.
EXH. STACK	DEG F	617.	634.	633.	641.	636.	653.	660.
WATER INLET	DEG F	69.	75.	75.	78.	83.	67.	71.
CELL AIR	DEG F	69.	82.	82.	81.	75.	62.	70.
EXHAUST 1R	DEG F	670.	686.	694.	697.	693.	690.	695.
EXHAUST 2R	DEG F	674.	688.	693.	695.	693.	685.	690.
EXHAUST 3R	DEG F	700.	722.	723.	721.	714.	698.	713.
EXHAUST 4R	DEG F	678.	698.	701.	697.	690.	679.	691.
EXHAUST 5R	DEG F	676.	690.	694.	691.	692.	673.	687.
EXHAUST 6R	DEG F	662.	680.	680.	683.	689.	664.	678.
EXHAUST 1L	DEG F	708.	726.	730.	720.	731.	739.	747.
EXHAUST 2L	DEG F	737.	748.	751.	768.	767.	773.	779.
EXHAUST 3L	DEG F	684.	701.	702.	698.	694.	720.	732.
EXHAUST 4L	DEG F	722.	740.	742.	740.	742.	756.	771.
EXHAUST 5L	DEG F	728.	749.	753.	752.	752.	766.	779.
EXHAUST 6L	DEG F	0.	745.	748.	747.	739.	762.	777.
OIL PRESSURE	PSI	50.0	51.0	51.0	50.0	50.0	50.0	50.0
FUEL SPILL	PSI	50.0	48.0	47.0	47.0	45.0	47.0	47.0
BOOST (RF)	PSI	4.2	4.0	4.0	4.0	4.0	4.0	4.0
BOOST (RR)	PSI	3.5	3.0	3.0	3.0	3.5	3.0	3.0
BOOST (LF)	PSI	3.5	3.0	3.0	3.0	3.0	3.5	3.0
BOOST (LR)	PSI	4.5	4.0	4.0	4.5	4.5	4.0	4.0
AIR BOX	PSI	6.0	8.0	8.0	10.0	10.0	12.0	13.0
INLET VAC. (RF) IN-H2O		4.4	4.2	4.5	4.4	4.5	4.1	4.2
INLET VAC. (RR) IN-H2O		4.6	4.5	4.5	4.5	4.5	4.3	4.3
INLET VAC. (LF) IN-H2O		8.2	7.8	8.1	8.5	8.3	8.3	8.3
INLET VAC. (LR) IN-H2O		8.0	8.	8.2	8.2	8.5	8.	8.1
EXH. PRESS. (R) PSI		1.	2.	2.	0.0	0.0	1.	1.
EXH. PRESS. (L) PSI		1.	2.	2.	0.0	0.0	1.	1.
TURB. IN. (RF) IN-HG		2.0	2.0	6.9	9.8	10.0	9.5	9.4
TURB. IN. (RR) IN-HG		2.0	2.0	6.9	9.7	9.9	9.4	9.4
TURB. IN. (LF) IN-HG		2.0	2.0	7.1	9.7	9.9	9.4	9.4
TURB. IN. (LR) IN-HG		2.0	2.0	6.9	9.5	9.9	9.4	9.4
FUEL PRESS.	PSI	20.0	20.0	20.0	20.0	20.0	20.0	20.0
EMULSION PRESS.	PSI	100.	100.	100.	100.	100.	100.	100.
FUEL SUPPLY	PSI	3.5	3.4	3.2	3.5	2.9	3.5	4.0
WATER PRESS.	PSI	0.	0.	0.	0.	0.	0.	0.

TABLE C-32. ENGINE TEST RESULTS, DETROIT DIESEL
ENGINE, 1400 RPM, WITH WATER ADDITION

DYNAMOMETER CONSTANT: 2000.
H/C RATIO: 1.82

API GRAVITY OF DIESEL FUEL: 33.9 AT 60F

RUN NUMBER		34	59	35	60	36	61	37	62	38
NOM. WATER PCT.		5	5	10	10	15	15	20	20	25
ENGINE SPEED	RPM	1400	1400	1400	1400	1400	1400	1400	1400	1400
OBS. TORQUE	LB-FT	1654	1654	1654	1654	1654	1654	1654	1654	1654
BAR. PRESS.	IN-HG	29.18	29.23	29.19	29.23	29.19	29.21	29.18	29.19	29.18
DRY BULB	DEG F	75	65	75	67	75	68	76	68	72
WET BULB	DEG F	62	60	62	62	61	62	63	62	59
REL. HUMIDITY	PCT	48	75	48	76	44	72	48	72	46
CORR. BHP	HP	442.9	433.2	442.2	434.3	441.2	435.6	441.0	437.1	435.2
CORR. BMEP	PSI	70.1	68.5	70.0	68.7	69.8	68.9	69.8	69.1	68.6
FUEL FLOW	LB/HR	175.30	177.80	176.84	175.95	176.73	176.82	176.38	176.13	177.25
WATER FLOW	CC/MIN	82.8	81.2	173.4	170.1	292.1	270.5	418.9	380.5	501.7
CALC. VOL. %	PCT	5.0	4.8	9.6	9.7	15.5	14.5	20.9	19.4	23.9
BSFC	LB/BHP-HR	3958	4105	3995	4051	4008	4059	4000	4030	4073
AIR FLOW L	LB/MIN	65.2	66.1	64.5	65.8	64.8	65.4	65.1	64.9	65.1
AIR FLOW R	LB/MIN	69.0	69.9	68.7	69.5	68.9	69.3	69.2	68.5	70.0
COOLANT IN	DEG F	178	174	178	174	176	174	176	175	177
COOLANT OUT	DEG F	186	182	186	182	184	183	184	184	186
OIL SUMP	DEG F	211	207	210	207	209	208	210	208	211
FUEL IN	DEG F	105	99	104	99	102	99	100	99	99
FUEL RETURN	DEG F	126	120	125	119	122	118	120	118	118
FUEL SUPPLY	DEG F	83	78	83	81	82	82	82	83	82
FUEL COOLER	DEG F	103	97	103	98	103	98	98	99	98
INTAKE AIR (RF)	DEG F	90	83	93	87	90	85	90	85	84
INTAKE AIR (RR)	DEG F	89	82	92	85	89	84	89	84	84
INTAKE AIR (LF)	DEG F	85	70	84	70	81	73	79	75	75
INTAKE AIR (LR)	DEG F	85	70	84	69	81	72	79	73	75
HP AIR (RF)	DEG F	155	144	155	147	152	145	152	144	147
HP AIR (RR)	DEG F	155	143	155	147	155	144	153	143	148
HP AIR (LF)	DEG F	153	136	150	136	147	138	146	139	141
HP AIR (LR)	DEG F	150	131	147	131	144	133	142	134	138
EXH. STACK	DEG F	637	647	627	640	615	630	606	622	599
WATER INLET	DEG F	78	67	92	84	93	88	93	88	88
CELL AIR	DEG F	82	65	81	66	80	68	78	70	70
EXHAUST 1R	DEG F	689	676	683	673	692	669	662	666	654
EXHAUST 2R	DEG F	690	679	682	674	675	669	662	663	656
EXHAUST 3R	DEG F	711	685	702	686	696	682	682	679	676
EXHAUST 4R	DEG F	692	671	681	667	676	662	661	657	654
EXHAUST 5R	DEG F	690	668	682	664	675	662	666	659	661
EXHAUST 6R	DEG F	681	677	678	659	671	655	659	651	656
EXHAUST 1L	DEG F	712	731	709	726	699	713	688	706	682
EXHAUST 2L	DEG F	759	764	744	752	734	743	719	734	713
EXHAUST 3L	DEG F	690	708	679	703	676	692	656	684	651
EXHAUST 4L	DEG F	736	753	727	746	716	736	705	727	703
EXHAUST 5L	DEG F	746	760	734	749	723	739	708	730	701
EXHAUST 6L	DEG F	740	756	731	750	725	737	713	732	709
OIL PRESSURE	PSI	50.0	51.0	50.0	51.0	50.0	51.0	50.0	50.0	50.0
FUEL SPILL	PSI	46.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0
BOOST (RF)	PSI	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
BOOST (RR)	PSI	3.0	4.0	4.0	4.0	4.0	4.5	4.0	4.0	4.0
BOOST (LF)	PSI	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.5	3.0
BOOST (LR)	PSI	4.0	4.0	4.5	4.0	4.5	4.0	4.5	3.0	4.5
AIR BOX	PSI	10.0	13.0	10.0	13.0	10.0	13.0	10.0	12.0	10.0
INLET VAC. (RF) IN-H2O		4.4	4.2	4.3	4.3	4.3	4.2	4.4	4.3	4.4
INLET VAC. (RR) IN-H2O		4.6	4.4	4.5	4.4	4.5	4.4	4.6	4.4	4.5
INLET VAC. (LF) IN-H2O		8.3	8.4	8.4	8.3	8.4	8.3	8.3	8.0	8.1
INLET VAC. (LR) IN-H2O		8.3	8.1	8.2	8.1	8.2	8.1	8.0	8.0	8.0
EXH. PRESS. (R) PSI		0.0	1.1	0.0	1.1	0.0	1.1	0.0	1.1	0.0
EXH. PRESS. (L) PSI		0.0	9.6	0.0	9.5	0.0	9.5	0.0	9.4	0.0
TURB. IN. (RF) IN-HG		9.8	9.5	9.7	9.4	9.8	9.5	9.7	9.4	9.7
TURB. IN. (RR) IN-HG		9.8	9.4	9.7	9.4	9.7	9.4	9.6	9.3	9.6
TURB. IN. (LF) IN-HG		9.7	9.5	9.6	9.4	9.5	9.4	9.5	9.3	9.5
TURB. IN. (LR) IN-HG		9.7	9.5	9.6	9.4	9.5	9.4	9.5	9.3	9.5
FUEL PRESS.	PSI	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
EMULSION PRESS.	PSI	100	100	100	100	100	100	100	100	100
FUEL SUPPLY	PSI	3.5	3.3	3.5	3.2	3.5	3.2	3.5	3.2	3.5
WATER PRESS.	PSI	50	50	50	50	50	50	50	50	50

TABLE C-33. ENGINE TEST RESULTS, DETROIT DIESEL
ENGINE, 1400 RPM, FUEL INJECTION TIMING RETARDED
4.1 DEGREES

DYNAMOMETER CONSTANT: 2000.
H/C RATIO: 1.82

API GRAVITY OF DIESEL FUEL: 33.9 AT 60F

RUN NUMBER NOM. WATER PCT.		86. 0.	92. 0.	87. 5.	88. 10.	89. 15.	90. 20.	91. 25.
ENGINE SPEED RPM		1400.	1400.	1400.	1400.	1400.	1400.	1400.
OBS. TORQUE LB-FT		1654.	1654.	1654.	1654.	1654.	1654.	1654.
BAR. PRESS.	IN-HG	29.49	29.43	29.50	29.50	29.48	29.46	29.45
DRY BULB	DEG F	74.	80.	74.	74.	77.	77.	80.
WET BULB	DEG F	52.	54.	52.	52.	64.	64.	54.
REL. HUMIDITY	PCT	18.	13.	18.	18.	49.	49.	13.
CORR. BHP	HP	430.8	436.0	431.8	432.4	437.8	439.3	433.5
CORR. BMEP	PSI	68.2	69.0	68.3	68.4	69.3	69.5	68.6
FUEL FLOW	LB/HK	180.81	181.54	180.36	179.78	178.66	178.31	178.44
WATER FLOW	CC/MIN	0.0	0.0	82.8	171.8	277.7	387.5	522.4
CALC. VOL. %	PCT	0.0	0.0	4.9	9.6	14.7	19.4	24.6
BSFC	LB/BHP-HR	4197	4164	4177	4159	4081	4059	4117
AIR FLOW L	LB/MIN	68.6	66.7	68.1	67.9	67.2	66.7	66.7
AIR FLOW R	LB/MIN	70.9	70.3	70.8	70.4	69.6	69.7	70.0
COOLANT IN	DEG F	174.	175.	174.	174.	174.	176.	171.
COOLANT OUT	DEG F	183.	184.	183.	184.	182.	184.	181.
OIL SUMP	DEG F	206.	207.	207.	207.	206.	208.	206.
FUEL IN	DEG F	100.	103.	101.	103.	100.	103.	97.
FUEL RETURN	DEG F	123.	124.	122.	122.	120.	120.	115.
FUEL SUPPLY	DEG F	81.	84.	84.	84.	84.	86.	85.
FUEL COOLER	DEG F	99.	100.	98.	103.	99.	100.	95.
INTAKE AIR (RF)	DEG F	90.	95.	88.	92.	94.	94.	95.
INTAKE AIR (RR)	DEG F	90.	96.	89.	92.	94.	94.	95.
INTAKE AIR (LF)	DEG F	82.	88.	84.	84.	85.	85.	86.
INTAKE AIR (LR)	DEG F	83.	87.	84.	84.	85.	85.	86.
HP AIR (RF)	DEG F	155.	162.	154.	156.	156.	156.	157.
HP AIR (RR)	DEG F	155.	161.	153.	155.	155.	156.	156.
HP AIR (LF)	DEG F	152.	158.	152.	153.	152.	152.	151.
HP AIR (LR)	DEG F	147.	153.	147.	148.	147.	147.	146.
EXH. STACK	DEG F	695.	704.	685.	678.	664.	655.	640.
WATER INLET	DEG F	78.	84.	81.	93.	93.	93.	89.
CELL AIR	DEG F	76.	84.	78.	79.	80.	82.	80.
EXHAUST 1R	DEG F	711.	720.	699.	694.	672.	687.	676.
EXHAUST 2R	DEG F	715.	732.	711.	705.	702.	695.	684.
EXHAUST 3R	DEG F	739.	753.	736.	733.	724.	716.	705.
EXHAUST 4R	DEG F	706.	710.	704.	696.	685.	678.	666.
EXHAUST 5R	DEG F	705.	711.	702.	690.	684.	679.	669.
EXHAUST 6R	DEG F	687.	701.	685.	679.	674.	674.	665.
EXHAUST 1L	DEG F	779.	795.	769.	758.	750.	736.	717.
EXHAUST 2L	DEG F	825.	831.	850.	800.	788.	774.	753.
EXHAUST 3L	DEG F	761.	765.	750.	741.	730.	719.	706.
EXHAUST 4L	DEG F	784.	792.	776.	763.	753.	742.	726.
EXHAUST 5L	DEG F	821.	832.	815.	803.	792.	779.	763.
EXHAUST 6L	DEG F	812.	818.	807.	796.	783.	774.	765.
OIL PRESSURE	PSI	51.0	51.0	51.0	51.0	51.0	51.0	51.0
FUEL SPILL	PSI	47.0	46.0	46.0	45.0	45.0	45.0	44.0
BOOST (RF)	PSI	4.5	4.5	4.5	4.5	4.2	4.0	4.0
BOOST (RR)	PSI	3.0	4.0	4.5	4.5	4.0	4.5	4.5
BOOST (LF)	PSI	3.0	4.0	3.5	3.5	3.0	3.5	3.2
BOOST (LR)	PSI	4.5	4.5	4.5	4.5	4.5	4.0	4.0
AIR BOX	PSI	6.0	6.0	6.0	6.0	6.0	6.0	6.0
INLET VAC. (RF)	IN-H2O	4.3	4.4	4.3	4.7	4.5	4.6	4.3
INLET VAC. (RR)	IN-H2O	4.5	4.6	4.5	4.5	4.5	4.5	4.5
INLET VAC. (LF)	IN-H2O	8.7	8.5	8.7	8.6	8.3	8.3	8.4
INLET VAC. (LR)	IN-H2O	8.4	8.4	8.4	8.3	8.3	8.3	8.2
EXH. PRESS. (R)	PSI	1.	1.	1.	1.	1.	1.	1.
EXH. PRESS. (L)	PSI	1.	1.	1.	1.	1.	1.	1.
TURB. IN. (RF)	IN-HG	10.0	9.8	9.9	9.8	9.6	9.6	9.5
TURB. IN. (RR)	IN-HG	9.7	9.7	9.6	9.6	9.4	9.5	9.3
TURB. IN. (LF)	IN-HG	9.7	9.7	9.6	9.6	9.5	9.4	9.3
TURB. IN. (LR)	IN-HG	9.7	9.7	9.6	9.6	9.5	9.4	9.3
FUEL PRESS.	PSI	26.0	22.0	26.0	26.0	26.0	26.0	26.0
EMULSION PRESS.	PSI	100.	100.	100.	100.	100.	100.	100.
FUEL SUPPLY	PSI	3.0	3.3	3.0	3.0	3.0	3.0	3.2
WATER PRESS.	PSI	0.	0.	50.	50.	50.	60.	65.

TABLE C-34. ENGINE TEST RESULTS, DETROIT DIESEL
ENGINE, 1600 RPM, BASELINE

DYNAMOMETER CONSTANT: 2000.
H/C RATIO: 1.82

API GRAVITY OF DIESEL FUEL: 33.9 AT 60F

RUN NUMBER		6.	12.	18.
NOM. WATER PCT.		0.	0.	0.
ENGINE SPEED	RPM	1600.	1600.	1600.
OBS. TORQUE	LB-FT	2143.	2143.	2143.
BAR. PRESS.	IN-HG	29.31	29.11	29.17
DRY BULB	DEG F	75.	78.	75.
WET BULB	DEG F	65.	69.	64.
REL. HUMIDITY	PCT	59.	64.	55.
CORR. BHP	HP	648.1	660.1	660.7
CORR. BMEP	PSI	89.7	91.4	91.5
FUEL FLOW	LB/HR	259.27	260.12	260.37
WATER FLOW	CC/MIN	0.0	0.0	0.0
CALC. VOL. %	PCT	0.0	0.0	0.0
BSFC	LB/BHP-HR	400.1	394.0	394.1
AIR FLOW L	LB/MIN	85.7	82.0	84.4
AIR FLOW R	LB/MIN	93.1	91.5	91.9
COOLANT IN	DEG F	177.	177.	174.
COOLANT OUT	DEG F	187.	188.	184.
OIL SUMP	DEG F	216.	217.	214.
FUEL IN	DEG F	104.	105.	108.
FUEL RETURN	DEG F	128.	130.	130.
FUEL SUPPLY	DEG F	79.	81.	82.
FUEL COOLER	DEG F	103.	103.	107.
INTAKE AIR (RF)	DEG F	77.	109.	82.
INTAKE AIR (RR)	DEG F	78.	91.	82.
INTAKE AIR (LF)	DEG F	79.	90.	89.
INTAKE AIR (LR)	DEG F	80.	90.	89.
HP AIR (RF)	DEG F	183.	199.	195.
HP AIR (RR)	DEG F	184.	200.	196.
HP AIR (LF)	DEG F	189.	202.	202.
HP AIR (LR)	DEG F	186.	199.	199.
EXH. STACK	DEG F	679.	700.	699.
WATER INLET	DEG F	73.	83.	79.
CELL AIR	DEG F	74.	80.	86.
EXHAUST 1R	DEG F	758.	774.	772.
EXHAUST 2R	DEG F	785.	800.	795.
EXHAUST 3R	DEG F	814.	828.	830.
EXHAUST 4R	DEG F	780.	798.	794.
EXHAUST 5R	DEG F	787.	802.	797.
EXHAUST 6R	DEG F	751.	752.	762.
EXHAUST 1L	DEG F	810.	831.	826.
EXHAUST 2L	DEG F	866.	882.	880.
EXHAUST 3L	DEG F	775.	794.	790.
EXHAUST 4L	DEG F	822.	841.	835.
EXHAUST 5L	DEG F	817.	835.	837.
EXHAUST 6L	DEG F	829.	844.	848.
OIL PRESSURE	PSI	55.0	56.0	56.0
FUEL SPILL	PSI	50.0	50.0	50.0
BOOST (RF)	PSI	7.5	7.5	7.5
BOOST (RR)	PSI	8.0	7.0	7.0
BOOST (LF)	PSI	7.0	7.0	7.0
BOOST (LR)	PSI	8.0	8.0	8.0
AIR BOX	PSI	11.0	12.0	12.0
INLET VAC. (RF) IN-H2O		7.8	7.8	7.8
INLET VAC. (RR) IN-H2O		8.2	8.1	7.8
INLET VAC. (LF) IN-H2O		12.8	13.1	12.8
INLET VAC. (LR) IN-H2O		12.3	12.6	13.1
EXH. PRESS. (R) PSI		1.2	1.3	1.3
EXH. PRESS. (L) PSI		2.2	2.3	2.3
TURB. IN. (RF) IN-HG		2.4	4.1	14.3
TURB. IN. (RR) IN-HG		2.6	4.1	14.3
TURB. IN. (LF) IN-HG		2.9	4.1	14.7
TURB. IN. (LR) IN-HG		2.9	4.1	14.7
FUEL PRESS.	PSI	20.0	20.0	20.0
EMULSION PRESS.	PSI	100.	100.	100.
FUEL SUPPLY	PSI	3.0	3.0	3.0
WATER PRESS.	PSI	0.	0.	0.

TABLE C-35. PERFORMANCE AND EMISSION TEST RESULTS,
DETROIT DIESEL ENGINE, 600 RPM

DYNAMOMETER CONSTANT: 3000.		API GRAVITY OF DIESEL FUEL: 33.9 AT 60F	
H/C RATIO: 1.82			
RUN NUMBER		142.	143.
NOM. WATER PCT.		0.	5.
ENGINE SPEED	RPM	600.	600.
OBS. TORQUE	LB-FT	385.	385.
BAR. PRESS.	IN-HG	29.13	29.12
DRY BULB	DEG F	88.	90.
WET BULB	DEG F	74.	73.
REL. HUMIDITY	PCT	52.	44.
CORR. BHP	HP	45.0	45.3
CORR. BMEP	PSI	16.6	16.7
FUEL FLOW	LB/HR	24.10	24.32
WATER FLOW	CC/MIN	0.0	10.3
CALC. VOL. %	PCT	0.0	4.5
BSFC	LB/BHP-HR	551.	517.4
AIR FLOW L	LB/MIN	22.9	23.0
AIR FLOW R	LB/MIN	23.3	23.2
STOICH. F/A		.0689	.0689
MEAS. F/A		.0087	.0088
CALC. F/A		.0072	.0072
% DIFF.	PCT	-17.48	-18.37
COOLANT IN	DEG F	178.	183.
COOLANT OUT	DEG F	184.	190.
OIL SUMP	DEG F	189.	198.
FUEL IN	DEG F	97.	103.
FUEL RETURN	DEG F	121.	126.
FUEL SUPPLY	DEG F	118.	126.
FUEL COOLER	DEG F	95.	101.
INTAKE AIR (RF)	DEG F	151.	159.
INTAKE AIR (RR)	DEG F	89.	92.
INTAKE AIR (LF)	DEG F	92.	96.
INTAKE AIR (LR)	DEG F	91.	95.
HP AIR (RF)	DEG F	96.	99.
HP AIR (RR)	DEG F	97.	100.
HP AIR (LF)	DEG F	103.	106.
HP AIR (LR)	DEG F	99.	102.
EXH. STACK	DEG F	313.	312.
WATER INLET	DEG F	88.	90.
CELL AIR	DEG F	88.	93.
EXHAUST 1R	DEG F	319.	318.
EXHAUST 2R	DEG F	305.	302.
EXHAUST 3R	DEG F	293.	291.
EXHAUST 4R	DEG F	301.	300.
EXHAUST 5R	DEG F	281.	284.
EXHAUST 6R	DEG F	279.	282.
EXHAUST 1L	DEG F	325.	327.
EXHAUST 2L	DEG F	325.	328.
EXHAUST 3L	DEG F	334.	328.
EXHAUST 4L	DEG F	332.	332.
EXHAUST 5L	DEG F	334.	340.
EXHAUST 6L	DEG F	348.	344.
OIL PRESSURE	PSI	18.3	18.0
FUEL SPILL	PSI	17.0	18.0
BOOST (RF)	PSI	1.3	1.0
BOOST (RR)	PSI	1.1	1.0
BOOST (LF)	PSI	0.0	0.0
BOOST (LR)	PSI	1.3	1.3
AIR BOX	PSI	1.5	2.5
INLET VAC. (RF) IN-H2O		4.	4.
INLET VAC. (RR) IN-H2O		4.	4.
INLET VAC. (LF) IN-H2O		1.8	1.9
INLET VAC. (LR) IN-H2O		1.8	1.8
EXH. PRESS. (R) PSI		0.0	0.0
EXH. PRESS. (L) PSI		0.0	0.0
TURB. IN. (RF) IN-HG		7.	6.
TURB. IN. (RR) IN-HG		7.	7.
TURB. IN. (LF) IN-HG		5.	7.
TURB. IN. (LR) IN-HG		9.	9.
FUEL PRESS.	PSI	34.0	33.8
EMULSION PRESS.	PSI	100.	100.
FUEL SUPPLY	PSI	2.5	5.0
WATER PRESS.	PSI	0.	50.
HYDROCARBONS	PPHC	421.	491.
CARBON MONOXIDE	PPM	178.	181.
NITRIC OXIDE	PPM	302.	285.
NITROGEN OXIDES	PPM	361.	354.
CARBON DIOXIDE	PCT	1.5	1.4
OXYGEN	PCT	19.1	18.8
PARTICULATE	MG/SCF	1.4	2.5
HC MASS	GM-HR	310.	366.
CO MASS	GM-HR	260.	276.
NOX MASS	GM-HR	251.	271.
BSHC	GM/BHP-HR	2.86	4.31
BSCO	GM/BHP-HR	5.91	6.27
BSNO	GM/BHP-HR	21.62	20.75

TABLE C-36. PERFORMANCE AND EMISSION TEST RESULTS,
DETROIT DIESEL ENGINE, 800 RPM

DYNAMOMETER CONSTANT: 3000		API GRAVITY OF DIESEL FUEL 33.9 AT 60F					
M/C RATIO: 1.82							
RUN NUMBER		114	120	115	116	117	118
NOM WATER PCI		0	0	5	10	15	20
ENGINE SPEED	RPM	800	800	800	800	800	800
OBS TORQUE	LB-FT	592	592	592	592	592	592
BAR PRESS	IN-HG	29.22	29.14	29.22	29.21	29.21	29.19
DRY BULB	DEG F	88	99	89	91	92	95
WET BULB	DEG F	77	78	77	78	78	78
REL HUMIDITY	PCT	61	93	58	56	54	47
LOWR BHP	HP	25.4	33.8	25.6	25.9	25.8	25.9
CORR BHP	PSI	25.6	26.0	25.6	25.7	25.8	26.0
FUEL FLOW	LB/HR	42.95	43.25	43.18	43.69	43.80	44.10
WATER FLOW	CC/MIN	0.0	0.0	1.3	4.5	6.4	9.0
CALE VOL %		0.0	0.0	4.3	10.5	13.4	19.1
BSFC	LB/BHP-HR	4650	4612	4665	4702	4704	4715
AIR FLOW L	LB/MIN	31.0	30.9	30.8	30.4	30.4	30.2
AIR FLOW R	LB/MIN	30.9	30.6	30.9	30.8	30.7	30.5
STOICH F/A		0.689	0.689	0.689	0.689	0.689	0.689
MEAS F/A		0.116	0.117	0.117	0.119	0.119	0.121
CALC F/A		0.101	0.100	0.100	0.102	0.103	0.103
% DIFF	PCI	-12.64	-14.39	-13.02	-13.97	-14.05	-14.35
COOLANT IN	DEG F	168	163	174	183	173	168
COOLANT OUT	DEG F	178	174	181	189	186	187
OIL SUMP	DEG F	193	187	193	208	194	200
FUEL IN	DEG F	105	106	106	108	106	106
FUEL RETURN	DEG F	125	124	125	127	123	125
FUEL SUPPLY	DEG F	110	117	111	113	114	115
FUEL COOLER	DEG F	184	183	184	187	184	184
INTAKE AIR (RF)	DEG F	97	110	98	102	103	107
INTAKE AIR (RR)	DEG F	92	107	95	97	99	104
INTAKE AIR (LF)	DEG F	90	105	92	95	98	103
INTAKE AIR (LR)	DEG F	89	105	91	94	97	102
HP AIR (RF)	DEG F	102	117	105	107	109	114
HP AIR (RR)	DEG F	102	118	105	108	110	114
HP AIR (LF)	DEG F	104	119	106	110	111	115
HP AIR (LR)	DEG F	101	116	104	106	109	113
EXH STACK	DEG F	381	381	380	383	374	376
WATER INLET	DEG F	88	102	89	92	95	96
CELL AIR	DEG F	338	335	329	332	325	327
EXHAUST 1R	DEG F	358	355	357	362	355	357
EXHAUST 2R	DEG F	360	354	357	364	358	362
EXHAUST 3R	DEG F	342	335	341	346	340	346
EXHAUST 4R	DEG F	356	352	355	360	354	359
EXHAUST 5R	DEG F	342	341	341	347	342	349
EXHAUST 6R	DEG F	342	337	341	345	340	345
EXHAUST 1L	DEG F	429	423	422	425	414	413
EXHAUST 2L	DEG F	406	401	401	403	392	396
EXHAUST 3L	DEG F	397	390	393	397	388	389
EXHAUST 4L	DEG F	426	420	419	420	410	410
EXHAUST 5L	DEG F	426	418	417	420	412	413
EXHAUST 6L	DEG F	441	436	435	433	422	407
DIL PRESSURE	PSI	25.0	27.0	26.0	25.0	25.0	25.0
FUEL SPILL	PSI	25.0	25.0	25.0	25.0	25.0	25.0
BOOST (RF)	PSI	0.0	0.0	0.0	0.0	0.0	0.0
BOOST (RR)	PSI	0.0	0.0	0.0	0.0	0.0	0.0
BOOST (LF)	PSI	0.0	0.0	0.0	0.0	0.0	0.0
BOOST (LR)	PSI	0.0	0.0	0.0	0.0	0.0	0.0
AIR BOX	PSI	1.0	1.3	1.3	1.3	1.3	1.3
INLET VAC (RF) IN-H2O		2.0	2.0	2.0	2.0	2.0	2.0
INLET VAC (RR) IN-H2O		2.0	2.0	2.0	2.0	2.0	2.0
INLET VAC (LF) IN-H2O		2.0	2.0	2.0	2.0	2.0	2.0
INLET VAC (LR) IN-H2O		2.0	2.0	2.0	2.0	2.0	2.0
EXH PRESS (RR) PSI		0.0	0.0	0.0	0.0	0.0	0.0
EXH PRESS (L) PSI		0.0	0.0	0.0	0.0	0.0	0.0
TURB IN (RF) IN-HG		1.6	1.6	1.6	1.6	1.6	1.6
TURB IN (RR) IN-HG		1.5	1.5	1.5	1.5	1.5	1.5
TURB IN (LF) IN-HG		1.5	1.5	1.5	1.5	1.5	1.5
TURB IN (LR) IN-HG		1.7	1.7	1.7	1.7	1.6	1.6
FUEL PRESS	PSI	28.0	28.0	28.0	28.0	28.0	28.0
EMULSION PRESS	PSI	100	100	100	100	100	100
FUEL SUPPLY	PSI	3.3	3.2	3.3	3.3	3.3	3.3
WATER PRESS	PSI	0	0	50	50	50	50
HYDROCARBONS	PPMC	414	376	485	532	463	484
CARBON MONOXIDE	PPM	108	108	136	172	173	222
NITRIC OXIDE	PPM	485	428	385	341	375	481
NITROGEN OXIDES	PPM	446	469	439	483	455	585
CARBON DIOXIDE	PCT	2.1	2.1	2.1	2.1	2.1	2.1
OXYGEN	PCT	16.8	16.7	16.0	15.8	16.0	17.2
PARTICULATE	MG/SCF	1.0	1.0	1.2	1.3	1.2	1.1
HC MASS	GM-HR	388	356	455	500	436	373
CO MASS	GM-HR	199	202	252	328	359	466
NOX MASS	GM-HR	1588	1541	1572	1492	1685	1474
BSMC	GM/BHP-HR	4.30	3.95	5.04	5.55	4.83	5.05
BSCO	GM/BHP-HR	2.21	2.24	2.79	3.25	3.78	5.18
BSNO	GM/BHP-HR	17.61	17.09	17.44	16.55	16.78	12.25

TABLE C-37. PERFORMANCE AND EMISSION TEST RESULTS,
DETROIT DIESEL ENGINE, 1000 RPM

DYNAMOMETER CONSTANT: 3000.		API GRAVITY OF DIESEL FUEL: 33.9 AT 60F						
H/C RATIO: 1.82								
RUN NUMBER		107	113	108	109	110	111	112
NOM. WATER PCT.		0	0	5	10	15	20	25
ENGINE SPEED	RPM	1000	1000	1000	1000	1000	1000	1000
OBS. TORQUE	LB-FT	877	877	877	877	877	877	877
BAR. PRESS.	IN-HG	29.23	29.12	29.22	29.21	29.18	29.16	29.14
DRY BULB	DEG F	87	100	92	93	95	95	98
WET BULB	DEG F	77	77	77	77	78	77	76
REL. HUMIDITY	PCT	64	35	51	47	47	44	36
CORR. BHP	HP	172.0	174.4	171.8	172.0	172.7	174.1	173.3
CORR. BMEP	PSI	38.1	38.6	38.0	38.1	38.3	38.6	38.4
FUEL FLOW	LB/HR	73.26	73.38	74.14	73.65	74.50	74.53	74.01
WATER FLOW	CC/MIN	0.0	0.0	32.3	66.4	109.5	155.9	211.7
CALC. VOL. X	PCT	0.0	0.0	4.6	9.1	14.0	18.8	24.1
BSFC	LB/BHP-HR	425.9	420.7	431.6	428.3	431.4	428.1	427.0
AIR FLOW L	LB/MIN	40.3	38.7	40.3	40.2	39.9	39.0	39.3
AIR FLOW R	LB/MIN	40.1	39.5	39.6	39.6	39.5	39.2	39.4
STOICH. F/A		0.689	0.689	0.689	0.689	0.689	0.689	0.689
MEAS. F/A		0.152	0.156	0.155	0.154	0.157	0.159	0.157
CALC. F/A		0.140	0.138	0.139	0.138	0.137	0.139	0.139
X DIFF.	PCT	-7.72	-11.52	-9.95	-10.17	-11.11	-12.43	-11.43
COOLANT IN	DEG F	173	167	173	173	174	173	173
COOLANT OUT	DEG F	161	159	161	161	162	161	161
CYL. SUMP	DEG F	195	194	199	200	200	200	200
FUEL IN	DEG F	108	108	109	110	108	108	106
FUEL RETURN	DEG F	127	126	128	129	125	125	125
FUEL SUPPLY	DEG F	102	107	104	104	105	107	107
FUEL COOLER	DEG F	106	106	108	109	107	106	104
INTAKE AIR (RF)	DEG F	99	113	100	105	112	114	110
INTAKE AIR (RR)	DEG F	92	105	94	98	100	101	102
INTAKE AIR (LF)	DEG F	94	106	98	101	102	104	106
INTAKE AIR (LR)	DEG F	94	106	97	101	102	104	106
HP AIR (RF)	DEG F	110	122	111	115	117	118	119
HP AIR (RR)	DEG F	110	123	112	116	118	119	119
HP AIR (LF)	DEG F	110	122	110	116	118	119	119
HP AIR (LR)	DEG F	113	125	116	119	120	122	123
EXH. STACK	DEG F	466	467	465	461	455	448	443
WATER INLET	DEG F	90	97	92	92	92	96	96
CELL AIR	DEG F	92	104	92	93	95	102	100
EXHAUST 1R	DEG F	481	478	480	468	470	466	456
EXHAUST 2R	DEG F	448	451	446	440	444	444	442
EXHAUST 3R	DEG F	433	435	435	431	430	429	430
EXHAUST 4R	DEG F	441	441	441	441	441	441	441
EXHAUST 5R	DEG F	438	435	435	429	431	428	428
EXHAUST 6R	DEG F	435	440	433	427	426	424	429
EXHAUST 1L	DEG F	525	522	518	512	509	503	494
EXHAUST 2L	DEG F	519	519	517	507	504	493	487
EXHAUST 3L	DEG F	480	492	484	488	486	477	469
EXHAUST 4L	DEG F	525	518	519	509	505	497	488
EXHAUST 5L	DEG F	523	520	511	507	507	497	490
EXHAUST 6L	DEG F	547	547	542	532	527	520	508
OIL PRESSURE	PSI	34.2	34.8	34.0	33.7	33.8	33.8	33.9
FUEL SPILL	PSI	33.0	31.9	33.0	33.0	33.0	35.0	35.0
BOOST (RF)	PSI	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BOOST (RR)	PSI	1.8	2.1	1.8	1.8	1.9	1.9	2.0
BOOST (LF)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BOOST (LR)	PSI	1.1	1.2	1.0	1.1	1.1	1.1	1.1
AIR BOX	PSI	2.0	2.0	2.0	2.0	2.0	2.0	2.0
INLET VAC. (RF)	IN-H2O	1.4	4.1	1.4	1.4	1.5	1.5	1.5
INLET VAC. (RR)	IN-H2O	1.5	4.1	1.5	1.5	1.4	1.4	1.4
INLET VAC. (LF)	IN-H2O	1.5	4.1	1.5	1.5	1.4	1.4	1.4
INLET VAC. (LR)	IN-H2O	3.9	1.5	4.0	4.1	4.1	4.0	4.0
EXH. PRESS. (R)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EXH. PRESS. (L)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TURB. IN. (RF)	IN-HG	3.0	3.0	3.0	3.0	3.0	3.0	3.0
TURB. IN. (RR)	IN-HG	3.0	3.0	3.0	3.0	3.0	3.0	3.0
TURB. IN. (LF)	IN-HG	2.8	2.9	3.0	3.0	3.0	3.0	3.0
TURB. IN. (LR)	IN-HG	3.0	3.1	3.1	3.1	3.1	3.1	3.1
FUEL PRESS.	PSI	25.0	20.2	50.0	26.0	28.5	28.0	27.0
EMULSION PRESS.	PSI	100	100	105	100	100	100	100
FUEL SUPPLY	PSI	3.5	3.0	3.0	3.0	3.0	3.0	3.3
WATER PRESS.	PSI	0	0	50	50	50	50	50
HYDROCARBONS	PPMC	422	507	652	720	618	588	546
CARBON MONOXIDE	PPM	80	94	119	136	145	145	164
NITRIC OXIDE	PPM	549	578	527	491	500	481	444
NITROGEN OXIDE	PPM	576	619	563	543	554	538	492
CARBON DIOXIDE	PCT	2.9	2.9	2.9	2.8	2.9	2.9	2.9
OXYGEN	PCT	15.9	15.8	16.2	15.1	16.0	15.5	16.3
PARTICULATE	MG/SCF	1.0	1.3	1.4	1.5	1.4	1.3	1.3
HC MASS	GM-HR	488	594	767	848	723	697	644
CO MASS	GM-HR	180	217	275	314	235	235	228
NOX MASS	GM-HR	2513	2418	2435	2480	2525	2438	2348
BHHC	GM/BHP-HR	2.92	3.38	4.59	5.08	4.33	4.17	3.86
BSCD	GM/BHP-HR	1.08	1.30	1.65	1.88	1.61	1.58	1.48
BBDN	GM/BHP-HR	15.05	14.48	14.56	14.25	15.13	14.64	13.31

TABLE C-38. PERFORMANCE AND EMISSION TEST RESULTS,
DETROIT DIESEL ENGINE, 1200 RPM

DYNAMOMETER CONSTANT: 3000.		API GRAVITY OF DIESEL FUEL: 33.9 AT 60F							
H/C RATIO: 1.82									
RUN NUMBER		121	127	144	150	122	145	123	146
NOM. WATER PCT.		0	0	0	0	5	5	10	10
ENGINE SPEED	RPM	1200	1200	1200	1200	1200	1200	1200	1200
OBS. TORQUE	LB-FT	1231	1231	1231	1231	1231	1231	1231	1231
BAR. PRESS.	IN-HG	29.20	29.11	29.11	28.96	29.19	29.06	29.19	29.04
DRY BULB	DEG F	89	101	96	102	91	100	92	102
WET BULB	DEG F	77	78	74	73	77	76	78	77
REL. HUMIDITY	PCT	58	36	35	24	53	33	54	32
CORR. BHP	HP	289.4	294.2	298.8	294.6	290.4	293.2	291.1	294.7
CORR. BMEP	PSI	53.4	54.3	53.7	54.4	53.6	54.1	53.7	54.4
FUEL FLOW	LB/HR	114.65	116.46	115.86	116.46	115.76	116.22	116.18	116.69
WATER FLOW	CC/MIN	0.0	0.0	0.0	0.0	53.1	53.1	109.5	112.5
CALC. VOL. %	PCT	0.0	0.0	0.0	0.0	4.8	4.8	9.4	9.6
BSFC	LB/BHP-HR	3962	3959	3956	3953	3987	3964	3992	3960
AIR FLOW L	LB/MIN	49.5	50.9	50.2	49.5	49.9	49.4	50.6	50.7
AIR FLOW R	LB/MIN	51.8	52.0	52.0	51.6	51.7	52.1	52.0	51.6
STOICH. F/A		.0689	.0689	.0689	.0689	.0689	.0689	.0689	.0689
MEAS. F/A		.0189	.0189	.0188	.0192	.0190	.0191	.0189	.0190
CALC. F/A		.0175	.0175	.0173	.0173	.0176	.0175	.0176	.0177
% DIFF.	PCT	-7.22	-7.44	-7.55	-9.97	-7.28	-8.22	-6.52	-7.07
COOLANT IN	DEG F	177	167	178	168	172	159	176	165
COOLANT OUT	DEG F	184	179	186	179	181	172	184	178
OIL SUMP	DEG F	204	199	204	196	201	196	204	196
FUEL IN	DEG F	110	112	110	112	112	111	112	112
FUEL RETURN	DEG F	130	131	130	131	131	128	130	130
FUEL SUPPLY	DEG F	96	104	97	102	100	101	100	102
FUEL COOLER	DEG F	105	109	107	109	109	108	111	116
INTAKE AIR (RF)	DEG F	103	111	111	114	102	108	101	110
INTAKE AIR (RR)	DEG F	92	104	99	108	94	109	96	112
INTAKE AIR (LF)	DEG F	95	108	103	111	97	108	100	109
INTAKE AIR (LR)	DEG F	95	108	102	110	96	105	99	107
HP AIR (RF)	DEG F	125	137	132	142	126	142	128	146
HP AIR (RR)	DEG F	125	137	132	141	126	141	128	145
HP AIR (LF)	DEG F	133	147	142	149	136	143	139	146
HP AIR (LR)	DEG F	129	141	136	144	131	138	133	141
EXH. STACK	DEG F	564	566	568	571	554	551	549	553
WATER INLET	DEG F	89	104	96	107	91	100	97	102
CELL AIR	DEG F	99	104	96	107	91	100	97	102
EXHAUST 1R	DEG F	598	587	603	591	579	583	569	584
EXHAUST 2R	DEG F	558	557	577	567	546	554	539	552
EXHAUST 3R	DEG F	564	564	572	570	559	562	554	569
EXHAUST 4R	DEG F	588	579	587	584	572	570	566	573
EXHAUST 5R	DEG F	588	579	587	584	572	570	566	573
EXHAUST 6R	DEG F	546	544	552	548	541	546	534	541
EXHAUST 1L	DEG F	637	632	642	638	623	617	616	618
EXHAUST 2L	DEG F	653	646	649	655	638	632	627	636
EXHAUST 3L	DEG F	612	610	620	617	598	602	589	601
EXHAUST 4L	DEG F	653	646	649	655	638	632	627	636
EXHAUST 5L	DEG F	644	645	659	652	634	636	622	632
EXHAUST 6L	DEG F	670	661	678	672	655	655	643	653
OIL PRESSURE	PSI	41.7	43.5	42.8	43.8	42.8	44.8	41.8	43.8
FUEL SPILL	PSI	41.0	44.0	44.0	42.0	43.0	44.0	42.0	44.0
BOOST (RF)	PSI	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
BOOST (RR)	PSI	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0
BOOST (LF)	PSI	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
BOOST (LR)	PSI	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0
AIR BOX	PSI	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
INLET VAC. (RF) IN-H2O		22.4	22.2	22.2	22.6	22.5	22.2	22.5	22.5
INLET VAC. (RR) IN-H2O		22.4	22.2	22.2	22.6	22.5	22.2	22.5	22.5
INLET VAC. (LF) IN-H2O		22.4	22.2	22.2	22.6	22.5	22.2	22.5	22.5
INLET VAC. (LR) IN-H2O		22.4	22.2	22.2	22.6	22.5	22.2	22.5	22.5
EXH. PRESS. (R) PSI		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EXH. PRESS. (L) PSI		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TURB. IN. (RF) IN-HG		5.1	5.2	5.4	5.4	5.5	5.4	5.5	5.4
TURB. IN. (RR) IN-HG		5.1	5.2	5.4	5.4	5.5	5.4	5.5	5.4
TURB. IN. (LF) IN-HG		5.1	5.2	5.4	5.4	5.5	5.4	5.5	5.4
TURB. IN. (LR) IN-HG		5.1	5.2	5.4	5.4	5.5	5.4	5.5	5.4
FUEL PRESS.	PSI	28.0	27.5	28.0	28.0	28.0	28.0	28.0	28.0
EMULSION PRESS.	PSI	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
FUEL SUPPLY	PSI	2.0	3.0	2.0	3.7	2.9	2.6	2.8	2.7
WATER PRESS.	PSI	0	0	0	0	50	60	50	60
HYDROCARBONS	PPMC	513	510	568	522	791	774	768	758
CARBON MONOXIDE	PPH	83	83	81	84	99	88	98	94
NITRIC OXIDE	PPH	673	681	728	727	688	644	763	763
NITROGEN DIOXIDE	PPH	692	714	762	776	676	764	685	794
CARBON DIOXIDE	PCT	3.7	3.7	3.6	3.6	3.7	3.6	3.7	3.7
OXYGEN	PCT	15.8	16.8	15.8	15.8	15.2	14.8	15.5	15.2
PARTICULATE	MG/SCF	1.7	1.2	0.8	1.5	2.8	2.3	1.6	1.7
HC MASS	GM-HR	746	755	822	779	1154	1132	1123	1187
CO MASS	GM-HR	2343	2343	2343	2343	2343	2343	2343	2343
NOX MASS	GM-HR	3673	3673	3673	3673	3673	3673	3673	3673
BSHC	GM/BHP-HR	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83
BSCO	GM/BHP-HR	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38
BSNO	GM/BHP-HR	13.88	12.88	12.72	12.51	12.92	13.35	13.78	14.26

TABLE C-39. PERFORMANCE AND EMISSION TEST RESULTS,
DETROIT DIESEL ENGINE, 1200 RPM, 15, 20, AND 25% WATER

DYNAMOMETER CONSTANT: 3000.		API GRAVITY OF DIESEL FUEL: 33.9 AT 60F					
M/C RATIO: 1.82							
RUN NUMBER		124.	147.	125.	148.	126.	149.
NOM. WATER PCT.		15.	15.	20.	20.	25.	25.
ENGINE SPEED	RPM	1200.	1200.	1200.	1200.	1200.	1200.
DBS. TORQUE	LB-FT	1231.	1231.	1231.	1231.	1231.	1231.
BAR. PRESS.	IN-HG	29.17	29.02	29.17	29.00	29.14	28.98
DRY BULB	DEG F	92.	103.	92.	105.	97.	105.
WET BULB	DEG F	78.	77.	80.	75.	75.	75.
REL. HUMIDITY	PCT	54.	51.	59.	54.	45.	45.
CORR. BHP	HP	291.8	295.2	293.6	294.7	293.7	295.2
CORR. BMEP	PSI	53.8	54.5	54.2	54.4	54.2	54.5
FUEL FLOW	LB/HR	117.12	116.69	117.34	117.46	118.13	117.72
WATER FLOW	DC/MIN	180.1	180.1	252.3	252.3	341.7	341.7
CAL. VOL	X	14.5	14.6	11.2	10.3	14.2	14.3
BSFC	LB/BHP-HR	4016	3954	3996	3986	4023	3987
AIR FLOW	LB/MIN	50.4	50.3	48.4	50.4	49.6	49.4
AIR FLOW	LB/MIN	51.5	51.5	50.5	51.2	51.7	51.5
STOICH. F/A		.0689	.0689	.0689	.0689	.0689	.0689
MEAS. F/A		.0191	.0191	.0198	.0193	.0194	.0194
CALC. F/A		.0177	.0175	.0178	.0176	.0180	.0178
X DIFF.	PCT	-7.58	-8.56	-9.78	-8.73	-7.59	-8.56
COOLANT IN	DEG F	174.	168	177.	166.	169.	165.
COOLANT OUT	DEG F	184.	179.	186.	178.	180.	178.
OIL SUMP	DEG F	204.	202.	208.	202.	204.	202.
FUEL IN	DEG F	127.	127.	128.	125.	125.	123.
FUEL RETURN	DEG F	101.	103.	103.	103.	104.	102.
FUEL SUPPLY	DEG F	109.	108.	110.	106.	108.	103.
FUEL COOLER	DEG F	104.	112.	107.	113.	107.	114.
INTAKE AIR (RF)	DEG F	102.	110.	104.	111.	104.	110.
INTAKE AIR (LF)	DEG F	101.	110.	103.	111.	103.	109.
INTAKE AIR (LR)	DEG F	129.	138.	131.	139.	132.	140.
HP AIR (RF)	DEG F	129.	138.	131.	139.	132.	140.
HP AIR (RR)	DEG F	145.	149.	149.	140.	140.	140.
HP AIR (LF)	DEG F	134.	143.	136.	143.	135.	142.
HP AIR (LR)	DEG F	543.	546.	540.	540.	532.	534.
EXH. STACK	DEG F	97.	103.	99.	103.	100.	100.
WATER INLET	DEG F	96.	106.	99.	107.	104.	100.
CELL AIR	DEG F	537.	544.	540.	542.	538.	538.
EXHAUST 1R	DEG F	537.	544.	540.	542.	538.	538.
EXHAUST 2R	DEG F	552.	560.	549.	554.	559.	547.
EXHAUST 3R	DEG F	562.	565.	561.	561.	564.	566.
EXHAUST 4R	DEG F	543.	544.	543.	538.	532.	533.
EXHAUST 5R	DEG F	611.	608.	608.	603.	595.	591.
EXHAUST 1L	DEG F	625.	626.	619.	620.	611.	612.
EXHAUST 2L	DEG F	590.	587.	592.	580.	576.	574.
EXHAUST 3L	DEG F	625.	625.	621.	618.	610.	612.
EXHAUST 4L	DEG F	617.	616.	616.	616.	601.	608.
EXHAUST 5L	DEG F	638.	638.	633.	630.	617.	617.
FUEL PRESSURE	PSI	42.0	42.4	41.0	42.0	42.0	42.0
FUEL SPILL	PSI	42.0	42.0	42.0	42.0	42.0	42.0
BOOST (RF)	PSI	2.4	2.3	2.5	2.3	2.6	2.5
BOOST (RR)	PSI	1.1	1.1	1.0	1.1	1.1	1.1
BOOST (LF)	PSI	2.4	2.3	2.5	2.3	2.6	2.5
BOOST (LR)	PSI	2.4	2.3	2.5	2.3	2.6	2.5
AIR BOX	PSI	2.4	2.3	2.5	2.3	2.6	2.5
INLET VAC. (RF) IN-H2O		2.4	2.3	2.5	2.3	2.6	2.5
INLET VAC. (RR) IN-H2O		2.4	2.3	2.5	2.3	2.6	2.5
INLET VAC. (LF) IN-H2O		2.4	2.3	2.5	2.3	2.6	2.5
INLET VAC. (LR) IN-H2O		2.4	2.3	2.5	2.3	2.6	2.5
EXH. PRESS. (R) PSI		2.4	2.3	2.5	2.3	2.6	2.5
EXH. PRESS. (L) PSI		2.4	2.3	2.5	2.3	2.6	2.5
TURB. IN. (RF) IN-HG		2.4	2.3	2.5	2.3	2.6	2.5
TURB. IN. (RR) IN-HG		2.4	2.3	2.5	2.3	2.6	2.5
TURB. IN. (LF) IN-HG		2.4	2.3	2.5	2.3	2.6	2.5
TURB. IN. (LR) IN-HG		2.4	2.3	2.5	2.3	2.6	2.5
FUEL PRESS	PSI	2.4	2.3	2.5	2.3	2.6	2.5
EMULSION PRESS.	PSI	100.	100.	100.	100.	100.	100.
FUEL SUPPLY	PSI	2.8	2.7	2.5	2.7	2.8	2.8
WATER PRESS.	PSI	50.	60.	50.	60.	50.	60.
HYDROCARBONS	PPMC	785.	686.	789.	670.	685.	685.
CARBON MONOXIDE	PPM	96.	91.	94.	89.	91.	84.
NITRIC OXIDE	PPM	666.	748.	644.	701.	623.	654.
NITROGEN DIOXIDE	PPM	786.	789.	677.	737.	658.	694.
CARBON DIOXIDE	PCT	3.7	3.6	3.7	3.7	3.7	3.7
OXYGEN	PCT	14.8	15.0	15.4	16.0	15.0	15.3
PARTICULATE	MG/SCF	1.7	1.5	1.8	1.7	1.4	1.5
HC MASS	GM-HR	1154.	1018.	1155.	992.	1082.	889.
CO MASS	GM-HR	274.	243.	248.	256.	256.	241.
NOX MASS	GM-HR	4148.	4127.	4364.	3759.	4110.	3674.
BSHC	GM/BHP-HR	4.11	3.62	4.11	3.53	3.56	3.16
BSCO	GM/BHP-HR	97.	93.	95.	96.	92.	86.
BSNO	GM/BHP-HR	14.75	14.68	15.52	13.37	14.62	13.86

TABLE C-40. PERFORMANCE AND EMISSION TEST RESULTS,
DETROIT DIESEL ENGINE, 1400 RPM

DYNAMOMETER CONSTANT: 3000		API GRAVITY OF DIESEL FUEL: 33.9 AT 60F						
M/C RATIO: 1.82								
RUN NUMBER		128	134	129	130	131	132	133
NOM. WATER PCT.		0	0	5	10	15	20	25
ENGINE SPEED	RPM	1400	1400	1400	1400	1400	1400	1400
OB. TORQUE	LB-FT	1654	1654	1654	1654	1654	1654	1654
BAR. PRESS.	IN-HG	29.22	29.14	29.21	29.21	29.20	29.19	29.17
DRY BULB	DEC F	87	102	87	94	94	94	100
WET BULB	DEC F	77	76	87	74	78	78	77
REL. HUMIDITY	PCT	64	30	58	49	49	49	35
CORR. BHP	HP	453.3	459.3	453.7	457.5	458.8	459.0	458.7
CORR. BMEP	PSI	71.7	72.7	71.8	72.4	72.6	72.6	72.6
FUEL FLOW	LB/HR	178.17	178.39	178.39	177.78	177.95	178.22	179.37
WATER FLOW	CC/MIN	0.0	0.0	81.2	173.4	288.5	391.0	517.5
CALC. VOL. %		0.0	0.0	4.8	9.7	15.2	19.5	24.2
BSFC	LB/BHP-HR	3931	3884	3932	3886	3879	3883	3911
AIR FLOW L	LB/HR	63.9	64.6	65.5	65.3	61.9	61.9	63.3
AIR FLOW R	LB/MIN	68.0	66.6	68.3	67.9	65.9	65.9	66.0
STOICH. F/A		0.689	0.689	0.689	0.689	0.689	0.689	0.689
MEAS. F/A		0.225	0.227	0.222	0.228	0.232	0.232	0.231
CALC. F/A		0.170	0.171	0.172	0.174	0.176	0.175	0.176
% DIFF.	PCT	-24.56	-24.57	-22.53	-23.35	-24.19	-24.53	-24.10
COOLANT IN	DEC F	169	173	169	169	169	172	172
COOLANT OUT	DEC F	181	183	181	181	181	183	183
OIL SUMP	DEC F	207	209	206	207	207	209	210
FUEL IN	DEC F	112	114	112	114	112	111	109
FUEL RETURN	DEC F	131	135	131	130	130	128	126
FUEL SUPPLY	DEC F	95	101	95	98	98	99	100
FUEL COOLER	DEC F	119	109	110	112	109	108	105
INTAKE AIR (RF)	DEC F	103	114	102	107	109	110	112
INTAKE AIR (RR)	DEC F	92	105	92	99	100	102	104
INTAKE AIR (LF)	DEC F	95	110	95	103	104	104	105
INTAKE AIR (LR)	DEC F	93	110	94	100	102	103	105
HP AIR (RF)	DEC F	150	165	150	156	157	157	160
HP AIR (RR)	DEC F	149	163	149	155	155	157	159
HP AIR (LF)	DEC F	161	177	161	167	167	168	170
HP AIR (LR)	DEC F	152	170	154	159	159	160	163
EXH. STACK	DEC F	652	672	641	644	637	632	624
WATER INLET	DEC F	86	104	95	103	103	102	100
CELL AIR	DEC F	90	104	91	98	100	100	102
EXHAUST 1R	DEC F	693	712	673	677	675	686	679
EXHAUST 2R	DEC F	677	690	676	673	669	660	666
EXHAUST 3R	DEC F	692	715	670	675	672	686	684
EXHAUST 4R	DEC F	675	699	674	674	672	669	665
EXHAUST 5R	DEC F	668	686	664	666	666	662	661
EXHAUST 6R	DEC F	646	667	648	649	646	646	759
EXHAUST 1L	DEC F	745	771	735	736	726	720	713
EXHAUST 2L	DEC F	777	797	770	767	756	745	736
EXHAUST 3L	DEC F	714	736	709	710	702	678	693
EXHAUST 4L	DEC F	753	776	743	741	731	722	717
EXHAUST 5L	DEC F	755	776	748	746	737	729	720
EXHAUST 6L	DEC F	757	782	750	748	742	737	727
OIL PRESSURE	PSI	50.1	49.8	50.2	50.0	50.0	50.0	49.8
FUEL SPILL	PSI	47.8	47.8	48.0	48.0	48.0	48.0	48.0
BOOST (RF)	PSI	3.7	3.0	3.5	3.2	3.0	3.0	3.1
BOOST (RR)	PSI	3.1	2.3	2.2	2.8	2.1	2.1	2.1
BOOST (LF)	PSI	4.1	4.0	4.1	4.0	3.8	3.8	3.8
BOOST (LR)	PSI	4.5	4.0	4.1	4.0	3.8	3.8	3.8
AIR BOX	PSI	4.3	4.3	4.4	4.3	4.3	4.3	4.3
INLET VAC. (RF) IN-H2O		4.4	4.4	4.4	4.4	4.4	4.4	4.4
INLET VAC. (RR) IN-H2O		4.4	4.4	4.4	4.4	4.4	4.4	4.4
INLET VAC. (LF) IN-H2O		8.5	8.7	8.6	8.5	8.5	8.5	8.4
INLET VAC. (LR) IN-H2O		8.5	8.6	8.5	8.4	8.4	8.3	8.3
EXH. PRESS. (R) PSI		0.0	0.0	0.0	0.0	0.0	0.0	0.0
EXH. PRESS. (L) PSI		0.0	0.0	0.0	0.0	0.0	0.0	0.0
TURB. IN. (RF) IN-HG		9.1	9.1	9.2	9.0	8.9	8.8	8.9
TURB. IN. (RR) IN-HG		9.0	9.1	9.0	8.9	8.8	8.4	8.9
TURB. IN. (LF) IN-HG		9.0	9.0	9.2	8.7	8.8	8.7	8.7
TURB. IN. (LR) IN-HG		9.0	9.1	9.2	8.9	8.8	8.7	8.6
FUEL PRESS.	PSI	30.0	29.0	30.0	30.0	30.0	30.0	29.0
EMULSION PRESS.	PSI	100	100	100	100	100	100	100
FUEL SUPPLY	PSI	3.1	0.0	2.7	2.8	2.7	2.6	2.5
WATER PRESS.	PSI	0	0	60	60	60	60	65
HYDROCARBONS	PPHC	420	497	646	649	684	682	631
CARBON MONOXIDE	PPH	141	136	116	96	76	67	56
NITRIC OXIDE	PPH	683	764	676	689	725	706	674
NITROGEN DIOXIDE	PPH	691	778	709	706	744	737	698
CARBON DIOXIDE	PCT	3.6	3.6	3.6	3.6	3.7	3.7	3.7
OXYGEN	PCT	15.4	15.7	14.6	15.6	15.5	15.4	14.8
PARTICULATE	MG/SCF	1.5	1.2	1.8	1.6	1.5	1.6	1.6
HC MASS	GM-HR	977	1147	1483	1466	1536	1539	1437
CO MASS	GM-HR	640	613	518	422	334	293	245
NOX MASS	GM-HR	5940	5776	6100	6055	6640	6906	6395
BSHC	GM/BHP-HR	2.22	2.60	3.36	3.32	3.48	3.49	3.26
BSCO	GM/BHP-HR	1.45	1.39	1.18	.96	.76	.66	.56
BSNO	GM/BHP-HR	13.47	13.10	13.83	13.73	15.06	15.66	14.50

TABLE C-41. PERFORMANCE AND EMISSION TEST RESULTS,
DETROIT DIESEL ENGINE, 1600 RPM

DYNAMOMETER CONSTANT 3000. H/C RATIO 1.82		API GRAVITY OF DIESEL FUEL 33.9 AT 60F						
RUN NUMBER		135	141	136	137	138	139	140
NOM. WATER PCT		0	0	5	10	15	20	25
ENGINE SPEED	RPM	1600	1600	1600	1600	1600	1600	1600
OBS. TORQUE	LB-FT	2143	2143	2143	2143	2143	2143	2143
BAR PRESS	IN-HG	29.19	29.08	29.18	29.17	29.17	29.15	29.12
DRY BULB	DEG F	88	106	90	93	93	99	97
WET BULB	DEG F	78	77	78	78	75	78	77
REL HUMIDITY	PCT	64	27	99	51	45	39	41
CORR. BMEP	HP	678.5	686.3	673.9	675.9	673.8	677.3	681.0
CORR. BMEP	PSI	93.1	95.0	93.3	93.6	93.3	93.8	94.3
FUEL FLOW	LB/HK	262.97	263.45	263.16	262.68	262.77	264.32	262.97
WATER FLOW	CC/MIN	0.0	0.0	120.0	248.7	401.5	570.5	661.5
CALC. VOL. %		0.0	0.0	4.8	9.5	14.4	19.2	21.7
BSFC	LB/BHP-HR	3911	3838	3905	3886	3900	3902	3862
AIR FLOW L	LB/MIN	84.5	80.9	83.8	81.3	81.3	82.3	81.2
AIR FLOW R	LB/MIN	87.3	87.9	89.5	88.9	88.4	88.1	87.3
STOICH. F/A		0.689	0.689	0.689	0.689	0.689	0.689	0.689
MEAS. F/A		0.255	0.260	0.253	0.257	0.258	0.259	0.260
CALC. F/A		0.237	0.240	0.236	0.237	0.240	0.241	0.241
X DIFF.	PCT	-7.27	-7.73	-6.61	-7.67	-7.12	-6.93	-7.43
COOLANT IN	DEG F	175	174	171	164	172	173	173
COOLANT OUT	DEG F	186	186	179	179	184	184	184
OIL SUMP	DEG F	216	216	215	211	214	214	214
FUEL IN	DEG F	126	117	118	115	114	114	113
FUEL RETURN	DEG F	146	138	139	134	133	133	131
FUEL SUPPLY	DEG F	94	101	90	98	98	100	101
FUEL COOLER	DEG F	127	110	114	112	110	109	107
INTAKE AIR (RF)	DEG F	105	129	115	116	122	123	124
INTAKE AIR (RR)	DEG F	93	116	97	102	109	109	111
INTAKE AIR (LF)	DEG F	95	111	100	100	103	106	109
INTAKE AIR (LR)	DEG F	93	110	98	99	102	105	108
HP AIR (RF)	DEG F	194	220	198	201	206	208	210
HP AIR (RR)	DEG F	193	219	197	200	205	206	209
HP AIR (LF)	DEG F	204	221	208	207	209	212	213
HP AIR (LR)	DEG F	196	214	201	200	201	204	206
EXH. STACK	DEG F	734	757	726	718	718	713	713
WATER INLET	DEG F	87	109	110	112	109	109	107
CELL AIR	DEG F	90	110	96	96	96	98	102
EXHAUST 1R	DEG F	779	818	775	772	781	780	780
EXHAUST 2R	DEG F	779	830	773	787	795	790	794
EXHAUST 3R	DEG F	827	849	818	811	810	802	805
EXHAUST 4R	DEG F	793	815	784	781	779	775	772
EXHAUST 5R	DEG F	800	829	789	789	789	782	781
EXHAUST 6R	DEG F	762	784	752	746	745	745	747
EXHAUST 1L	DEG F	862	883	846	836	833	832	830
EXHAUST 2L	DEG F	925	944	901	893	892	885	882
EXHAUST 3L	DEG F	836	862	828	824	826	820	820
EXHAUST 4L	DEG F	867	893	859	851	848	844	840
EXHAUST 5L	DEG F	847	887	842	834	841	832	831
EXHAUST 6L	DEG F	872	904	873	868	870	870	864
OIL PRESSURE	PSI	54.4	54.8	55.0	55.8	55.0	55.0	55.0
FUEL SPILL	PSI	47.0	48.0	48.0	42.0	47.0	45.4	45.0
BOOST (RF)	PSI	6.5	6.9	6.9	6.8	6.8	6.7	6.6
BOOST (RR)	PSI	6.5	6.8	6.8	6.8	7.0	6.8	6.8
BOOST (LF)	PSI	6.1	5.7	6.0	6.5	6.3	6.1	5.9
BOOST (LR)	PSI	7.3	7.1	7.1	7.1	7.0	6.9	6.8
AIR BOX	PSI	9.5	8.5	9.5	9.5	9.0	9.5	9.0
INLET VAC. (RF) IN-H2O		7.3	7.4	7.4	7.3	7.2	7.3	7.2
INLET VAC. (RR) IN-H2O		7.5	7.7	7.7	7.7	7.6	7.5	7.5
INLET VAC. (LF) IN-H2O		13.1	13.4	13.1	13.2	13.1	13.1	13.0
INLET VAC. (LR) IN-H2O		12.9	13.0	12.9	12.9	12.8	12.8	12.7
EXH. PRESS. (R) PSI		0.0	0.0	0.0	0.0	0.0	0.0	0.0
EXH. PRESS. (L) PSI		0.0	0.0	0.0	0.0	0.0	0.0	0.0
TURB. IN. (RF) IN-HG		15.6	15.3	15.5	15.3	15.2	15.3	15.1
TURB. IN. (RR) IN-HG		15.5	15.0	15.4	15.2	15.0	15.0	14.8
TURB. IN. (LF) IN-HG		15.4	14.9	15.5	15.0	14.8	14.9	14.7
TURB. IN. (LR) IN-HG		15.6	15.2	15.5	15.2	15.0	15.0	15.0
FUEL PRESS.	PSI	28.0	29.0	28.0	28.0	30.0	28.7	30.0
FUEL SUPPLY PRESS.	PSI	100	100	100	100	100	100	100
FUEL SUPPLY	PSI	2.5	2.5	1.8	1.8	1.7	2.0	2.2
WATER PRESS.	PSI	0	0	70	70	67	70	70
HYDROCARBONS	PPMC	588	476	686	711	758	746	688
CARBON MONOXIDE	PPM	546	522	397	319	254	179	365
NITRIC OXIDE	PPM	617	950	84	948	621	600	958
NITROGEN OXIDES	PPM	627	636	647	648	641	615	658
CARBON DIOXIDE	PCT	4.9	5.0	4.9	5.0	5.0	5.1	5.1
OXYGEN	PCT	13.5	13.7	13.3	13.8	13.4	13.6	12.9
PARTICULATE	MG/SCF	1.3	1.3	1.4	1.2	1.2	1.2	1.1
HC MASS	GM-HR	1459	1165	1786	1756	1855	1833	1681
CO MASS	GM-HR	2405	2930	1897	1513	1194	845	775
NOX MASS	GM-HR	8439	7381	8707	8800	8556	8861	9276
BSHC	GM/BHP-HR	2.28	2.79	2.61	2.69	2.84	2.81	2.58
BSCO	GM/BHP-HR	3.99	4.49	2.91	2.32	1.83	1.29	2.19
BSNO	GM/BHP-HR	12.93	11.31	13.34	13.48	13.11	13.57	14.20

APPENDIX D

REPORT OF NEW TECHNOLOGY

This study documents the unique application of water-in-fuel emulsions to large (900hp to 1200hp) diesel engines. A laboratory system was developed to mix and meter the emulsions to the engine (p. 6 to 11). This system performed well and allowed a determination of the emulsion effects on diesel engine performance.

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