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MULTI-CYLINDER 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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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 partol boats. Furthermore, it was considered necessary to view

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.

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 spped-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.

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

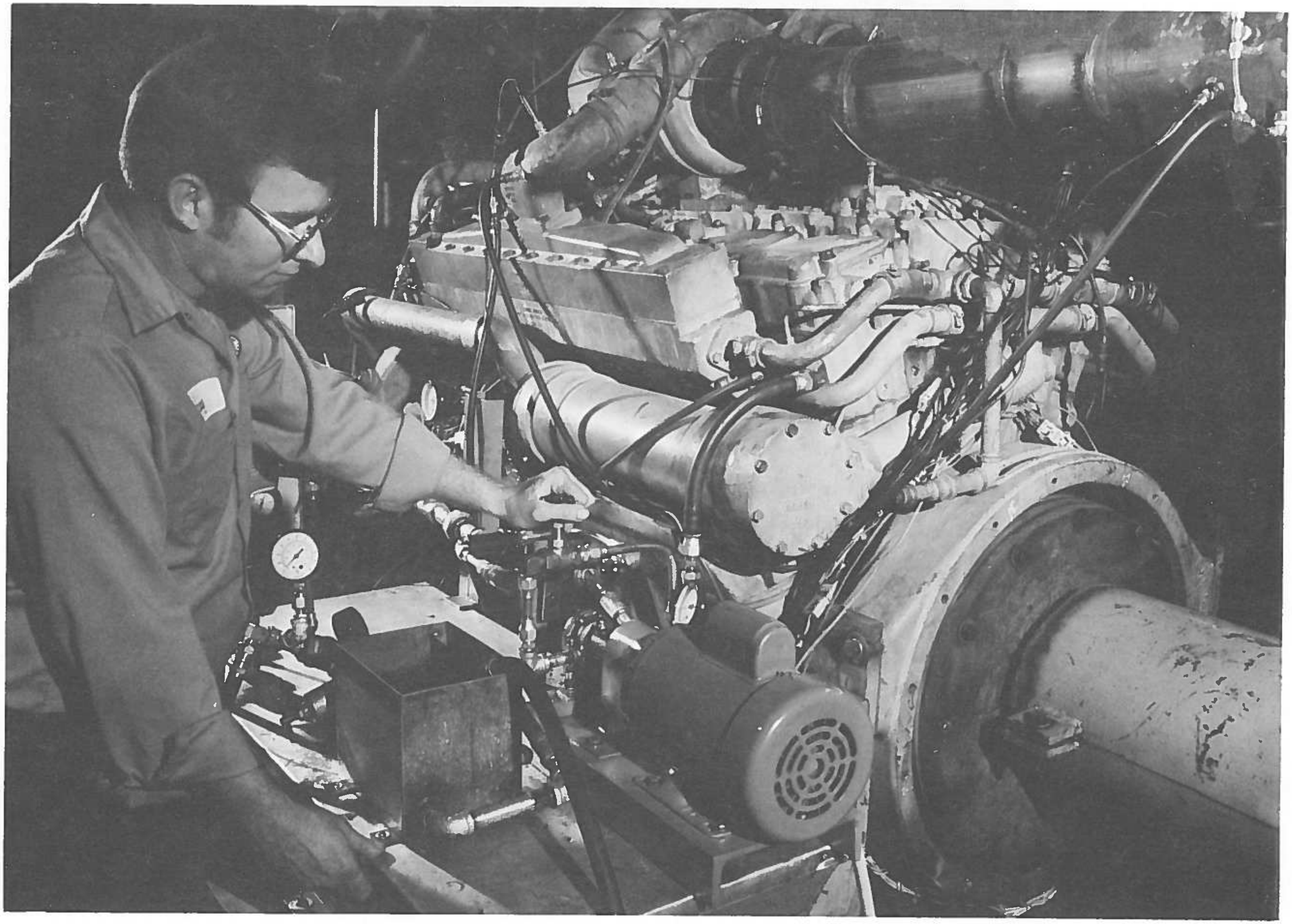


FIGURE 2-1. ENGINE INSTALLATION; CUMMINS ENGINE TESTS

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 Lawson[11] is shown in Figure 2-3. The pressure at the outlet of the emulsifier was typically 20 to 25 psi.

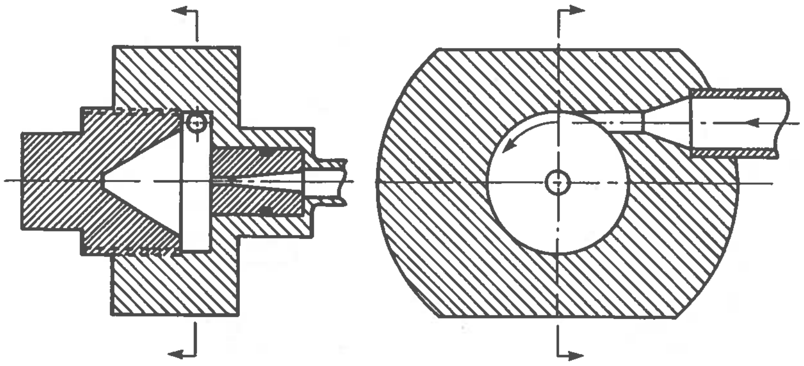


FIGURE 2-3. TYPICAL HYDROSHEAR

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.

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. Nondispersive 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.

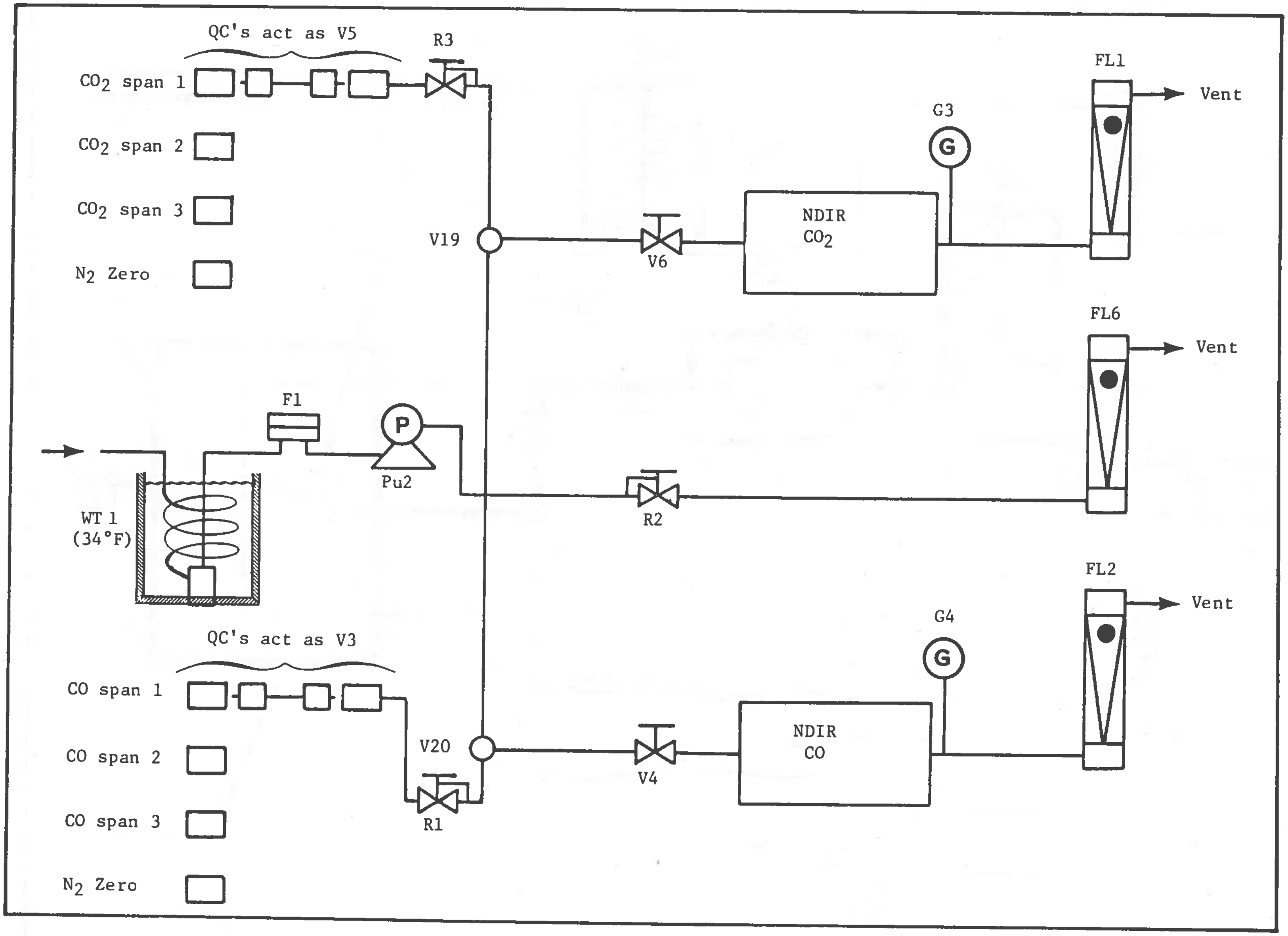


FIGURE 2-6. ANALYZER SYSTEM FOR CARBON MONOXIDE AND CARBON DIOXIDE

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

Emission	Detection Method	Instrument	Range	Nominal Concentration
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 2-5. NDIR CO AND CO_2 FLOW SCHEMATIC COMPONENT DESCRIPTION

Component	Description	Description of Function
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/sero 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

FIGURE 2-8. EMISSION INSTRUMENT CONSOLE, FRONT 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.

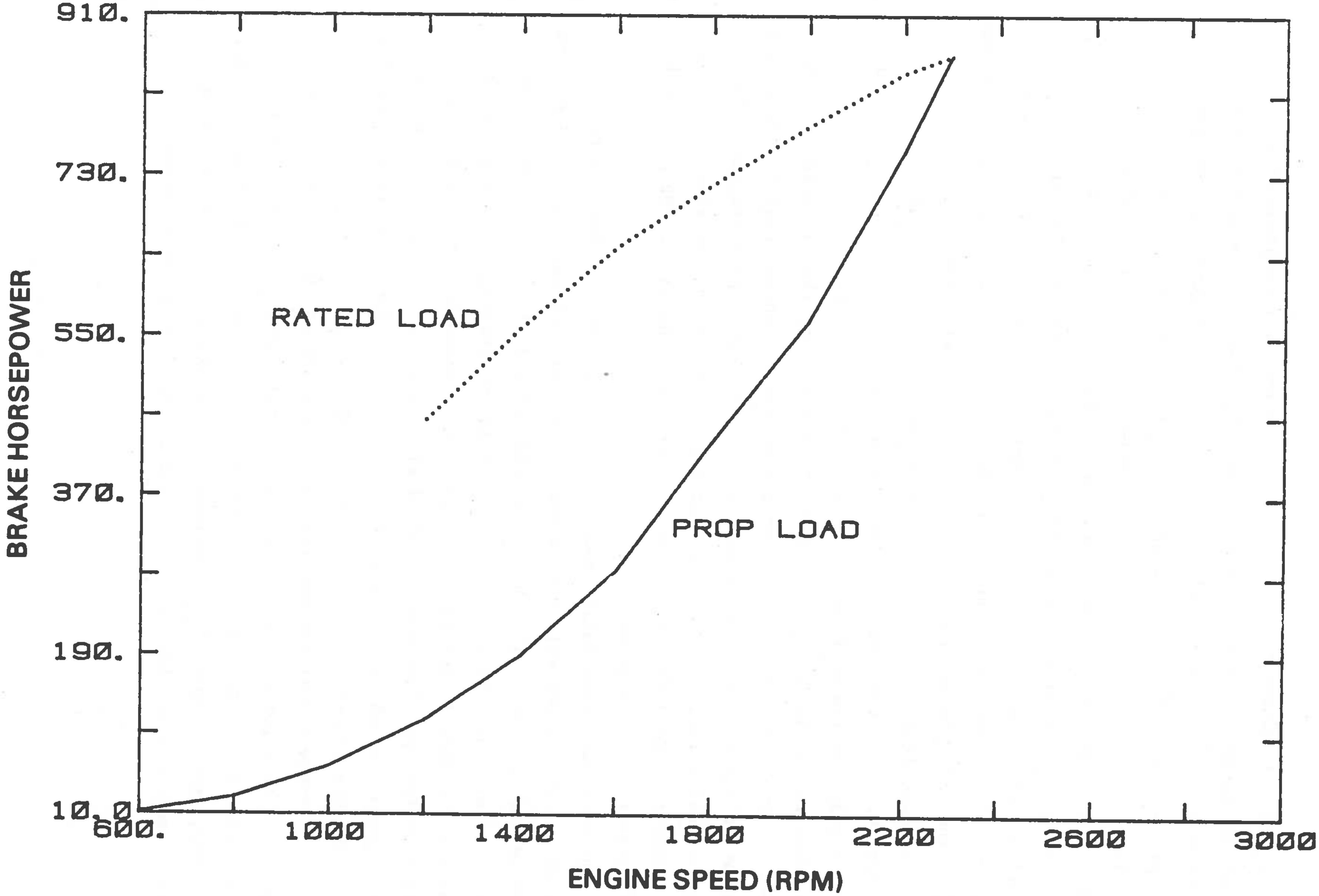


FIGURE 2-11. ENGINE SPEED AND POWER OUTPUT, MAXIMUM HORSEPOWER AND PROP LOAD, CUMMINS ENGINE

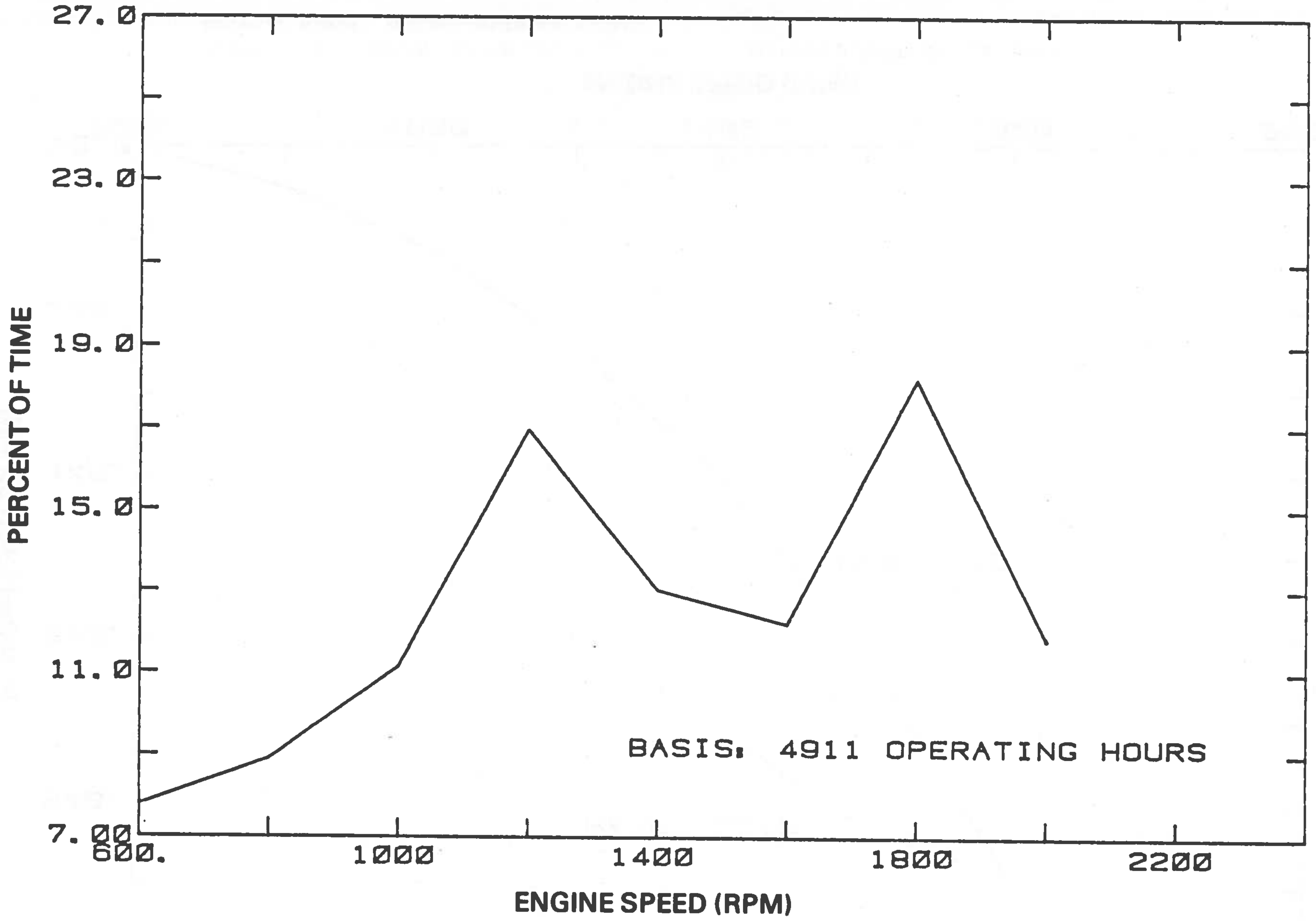


FIGURE 2-12. OPERATING TIME AS FUNCTION OF ENGINE SPEED FOR CUMMINS ENGINE-POWERED CUTTERS

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.

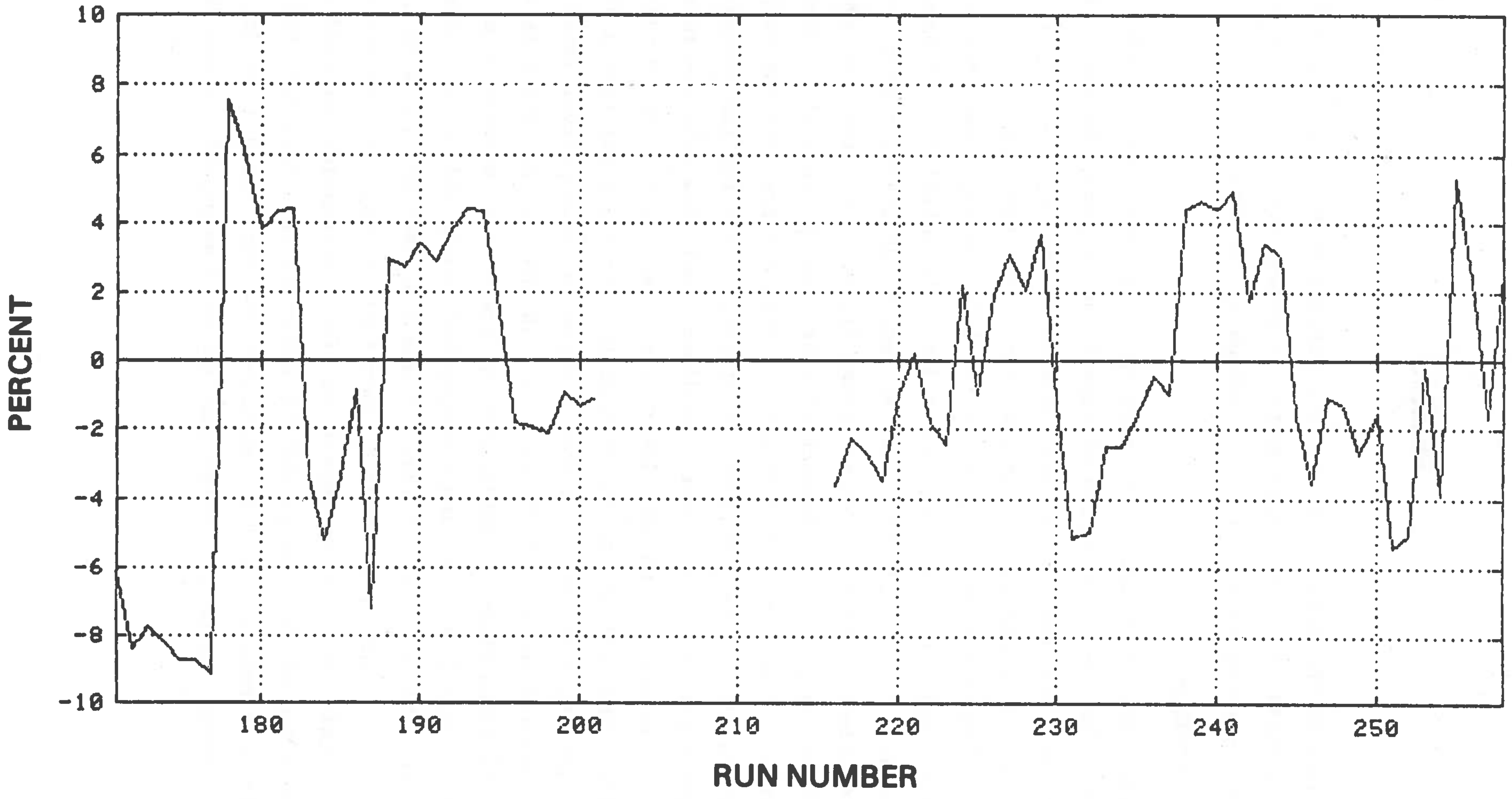


FIGURE 2-14. COMPARISON OF CARBON BALANCE AND MEASURED FUEL-AIR RATIO, CUMMINS ENGINE TESTS

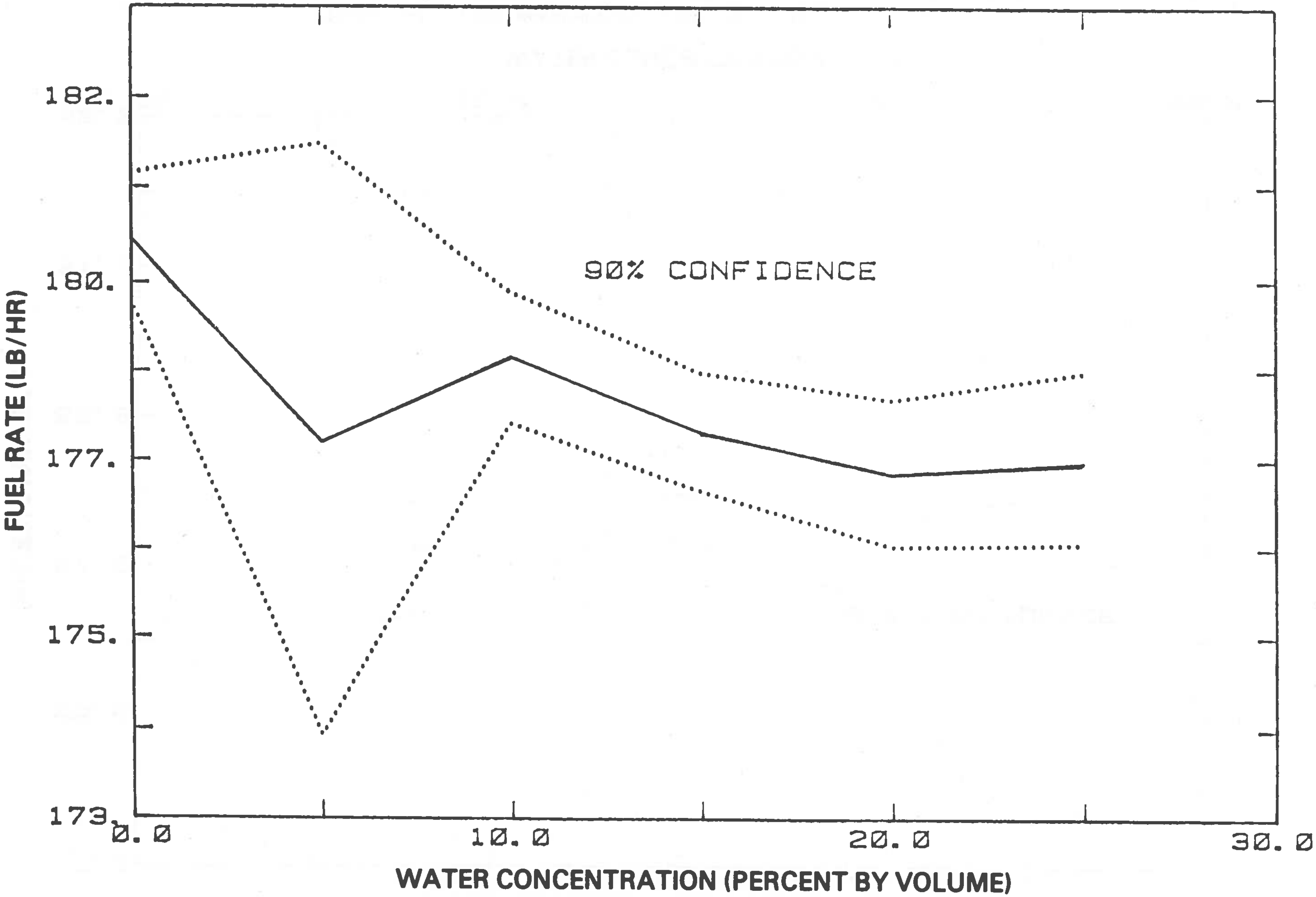


FIGURE 3-1. FUEL CONSUMPTION, CUMMINS ENGINE, 1800 RPM

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.

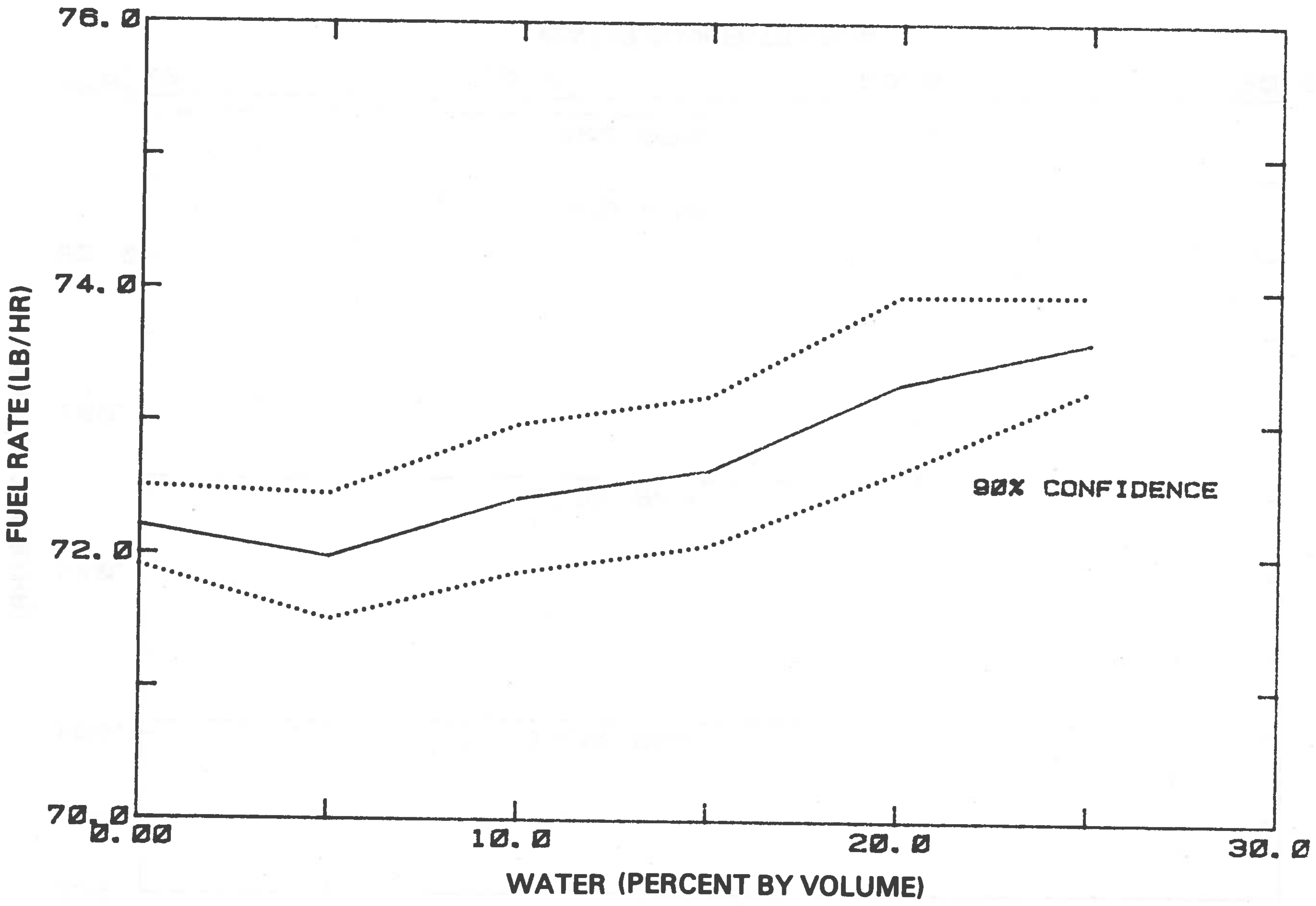


FIGURE 3-4. FUEL CONSUMPTION, DETROIT DIESEL ENGINE, 1000 RPM

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

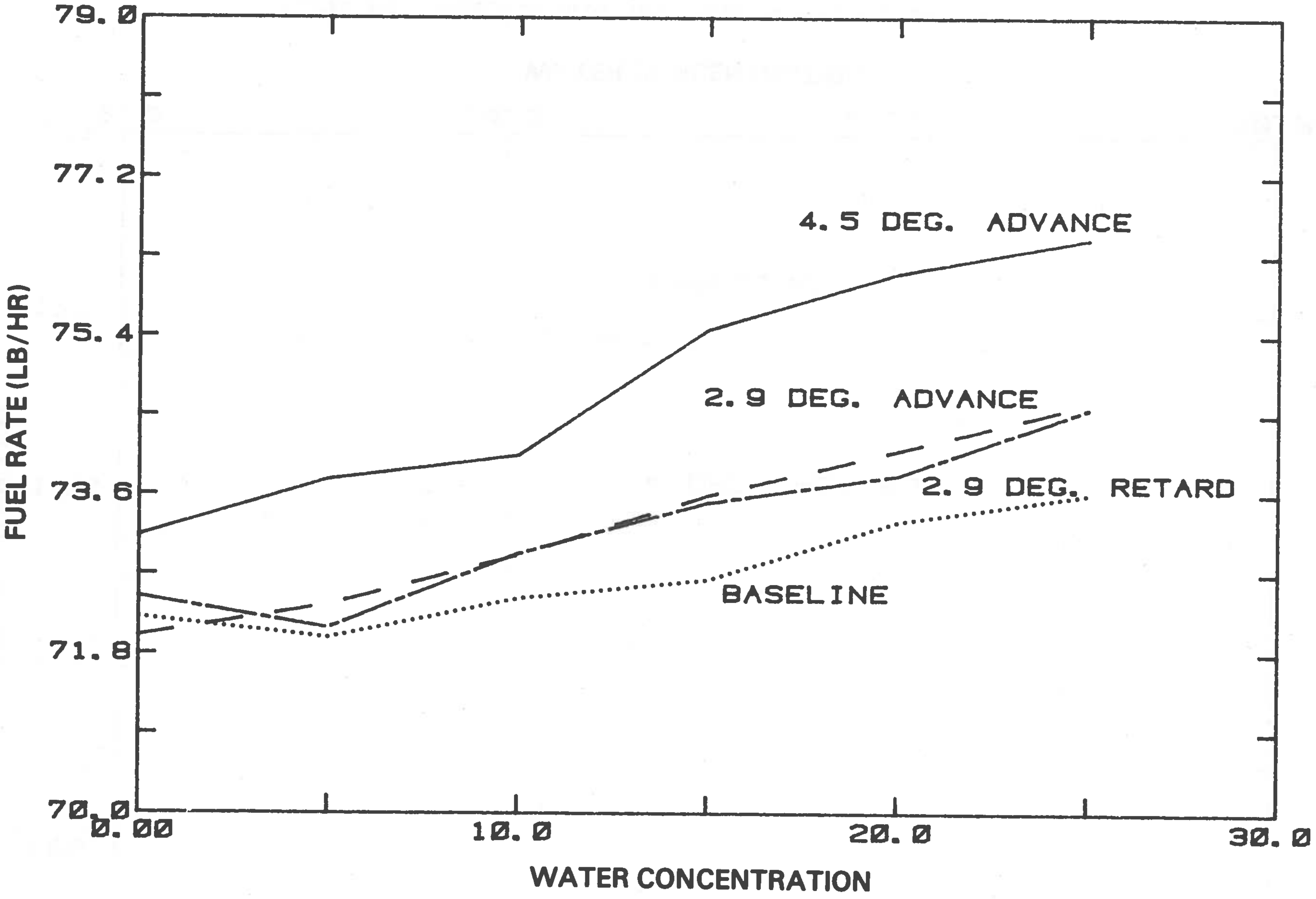


FIGURE 3-7. EFFECT OF INJECTION TIMING ON FUEL CONSUMPTION, DETROIT DIESEL ENGINE, 1000 RPM

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.

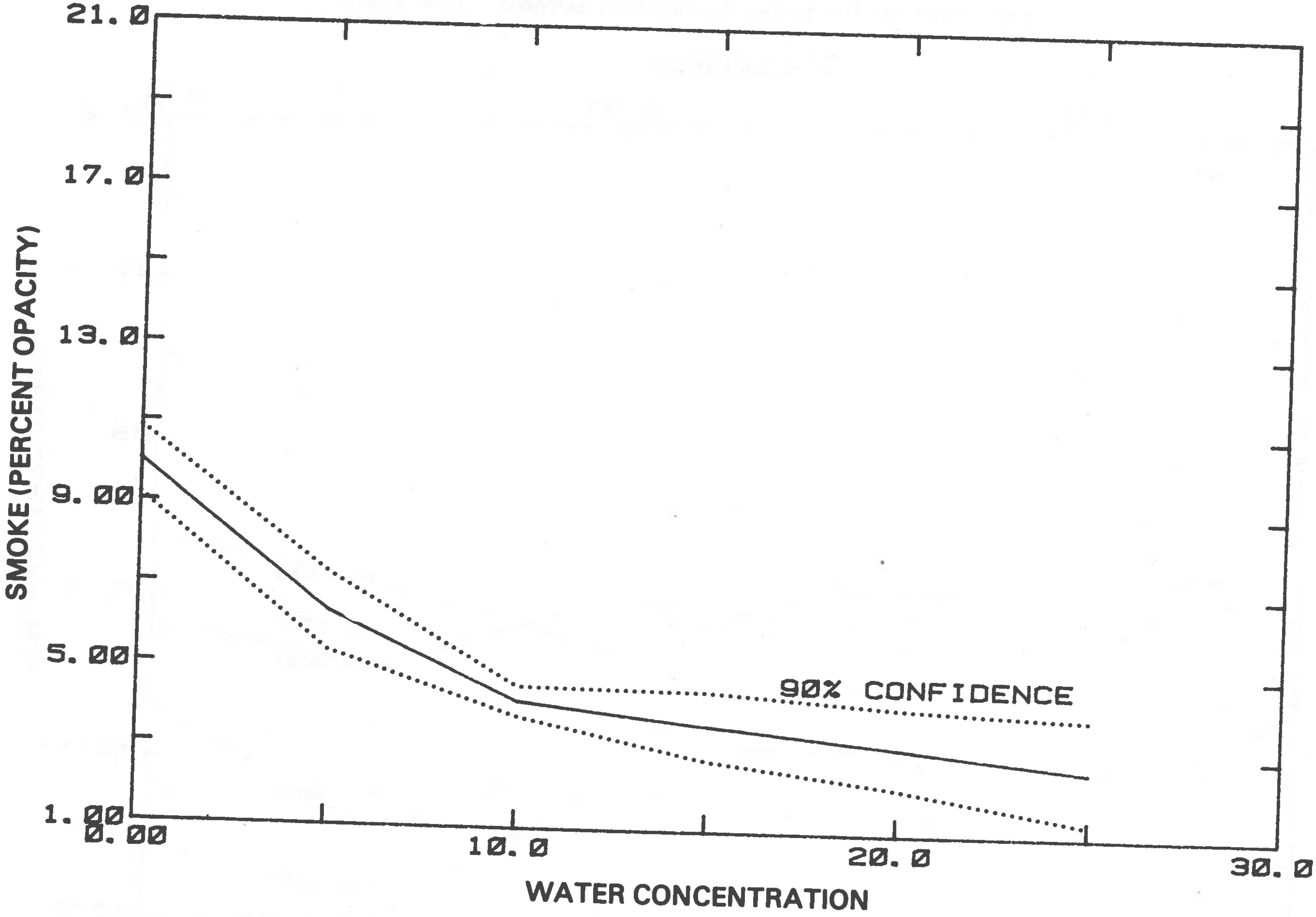


FIGURE 3-10. EXHAUST SMOKE, CUMMINS ENGINE, 1200 RPM

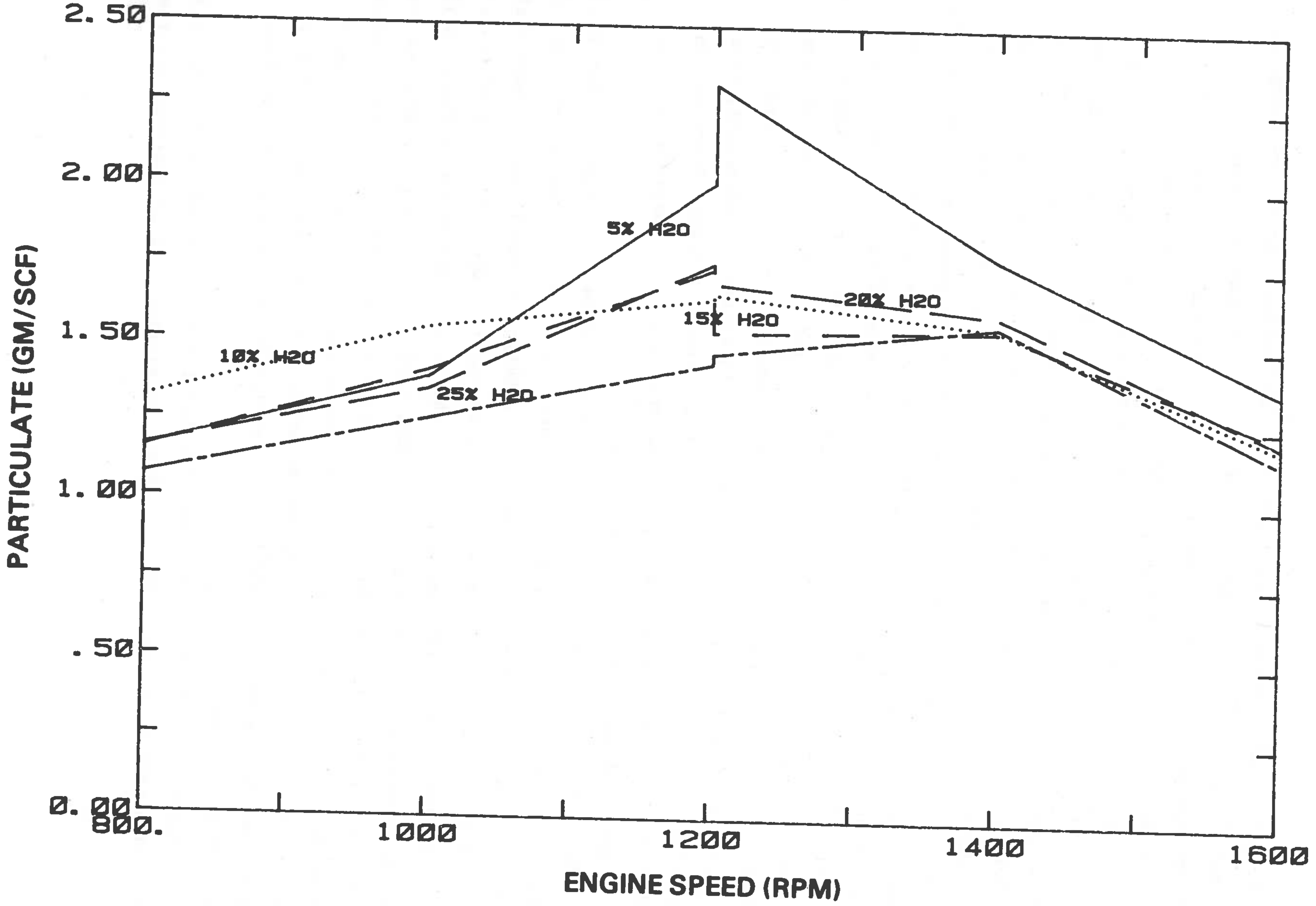


FIGURE 3-12. EXHAUST PARTICULATE EMISSIONS, DETROIT DIESEL ENGINE, BASELINE DATA 5, 10, 15, 20, AND 25 PERCENT WATER

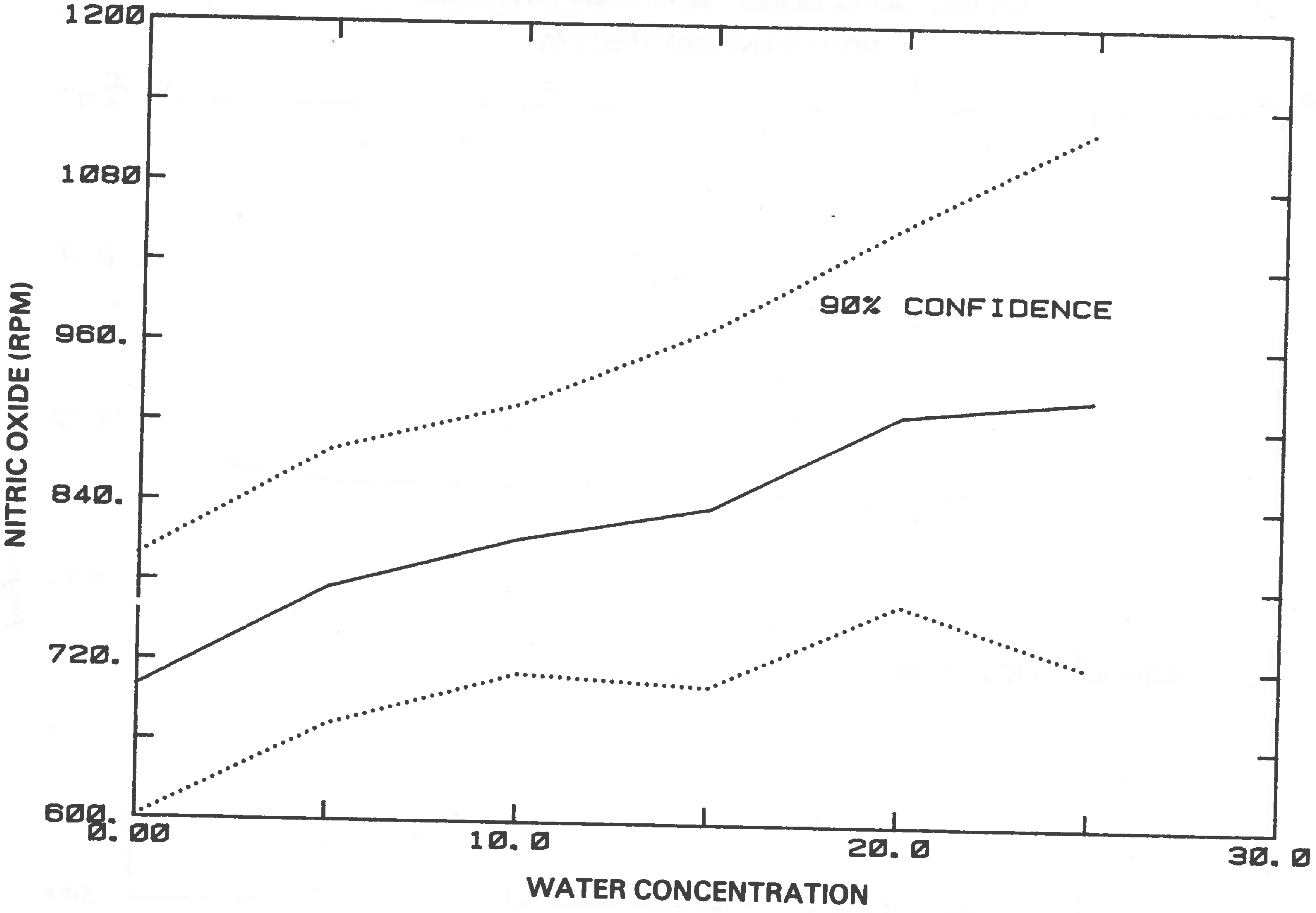
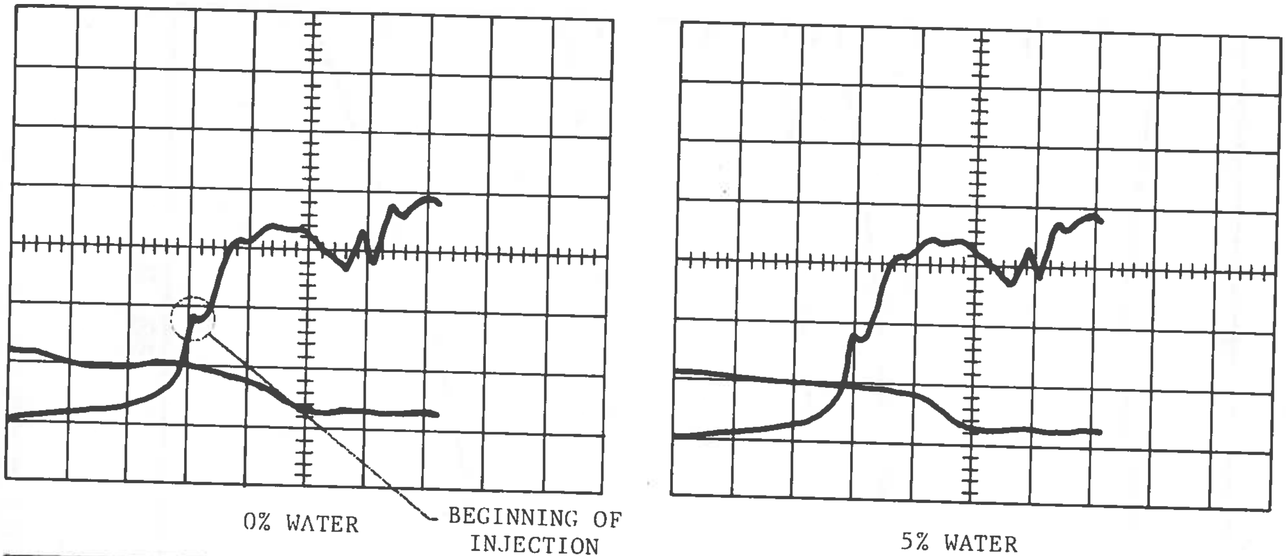
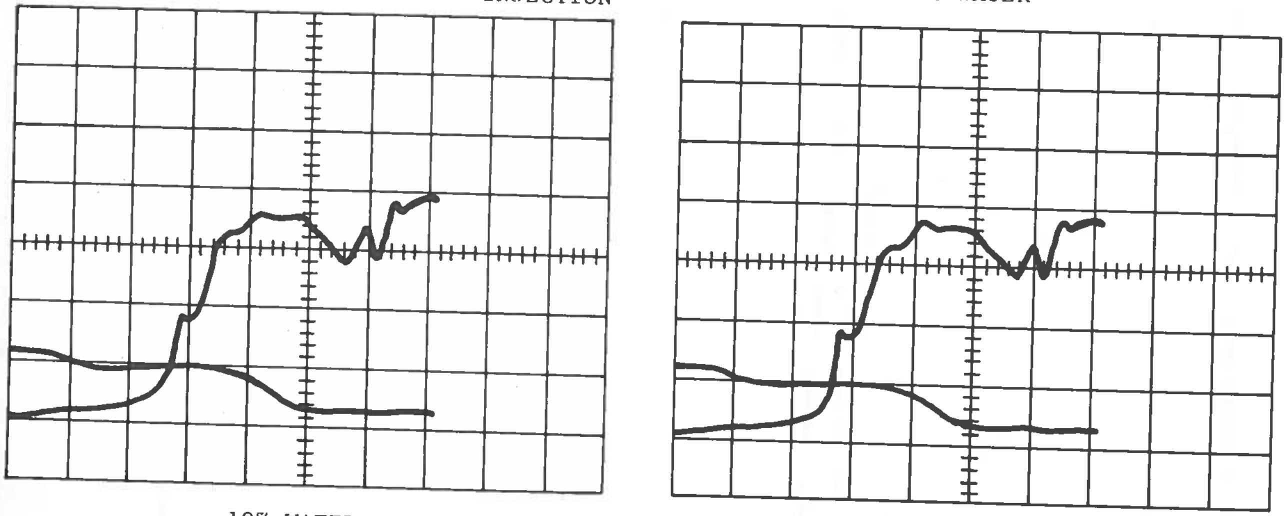


FIGURE 3-13. EMISSIONS OF NITRIC OXIDE, CUMMINS ENGINE, 1800 RPM



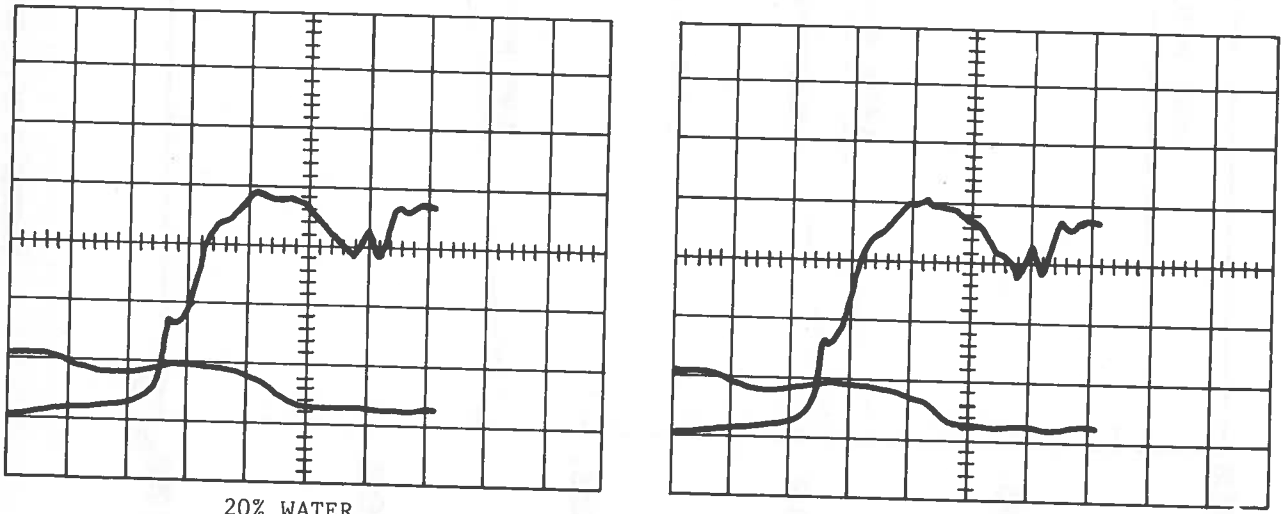
0% WATER

5% WATER



10% WATER

15% WATER



20% WATER

25% WATER

Note: Each major vertical division represents ten degrees.

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

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

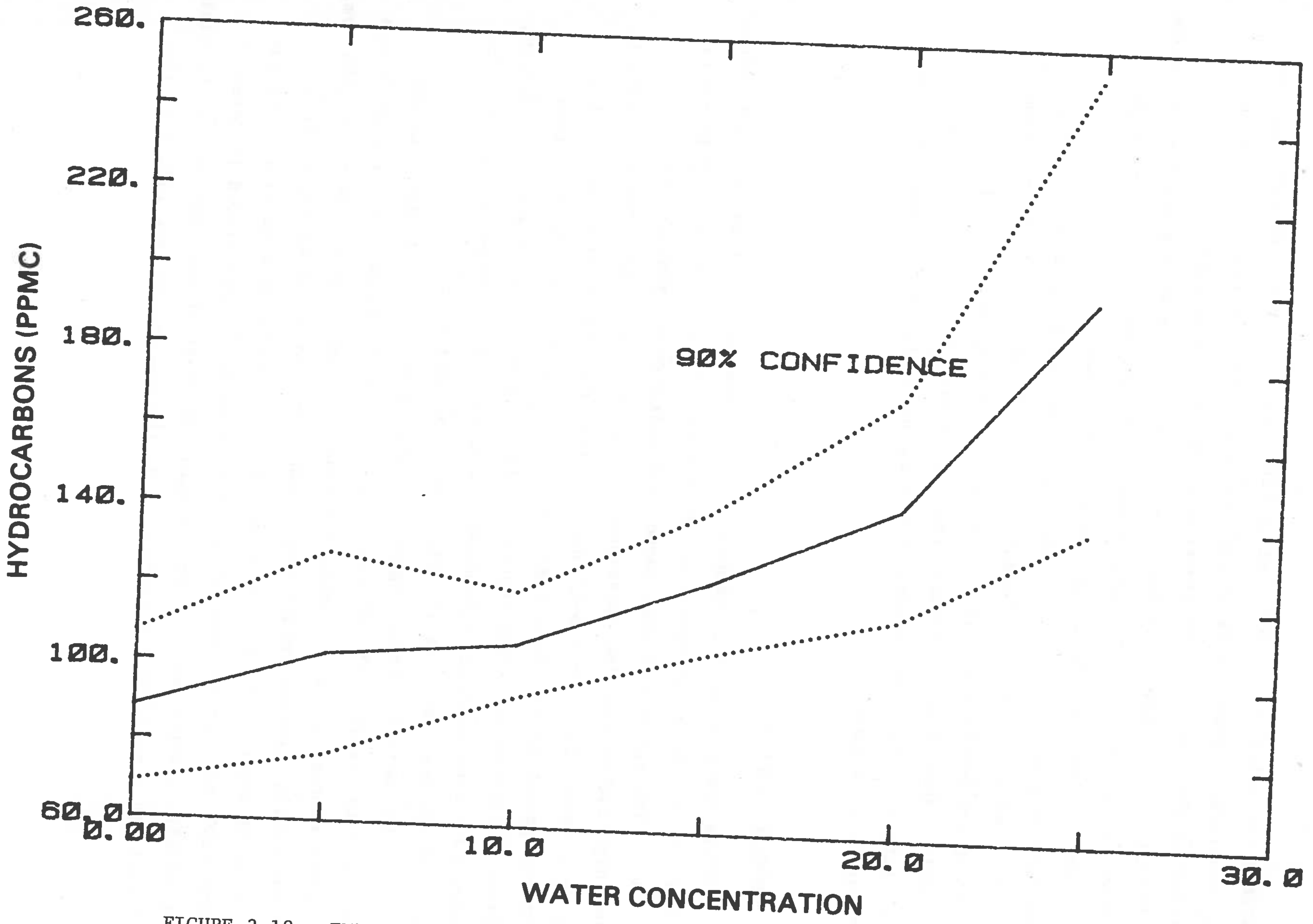


FIGURE 3-18. EMISSIONS OF UNBURNED HYDROCARBONS, CUMMINS ENGINE, 1200 RPM

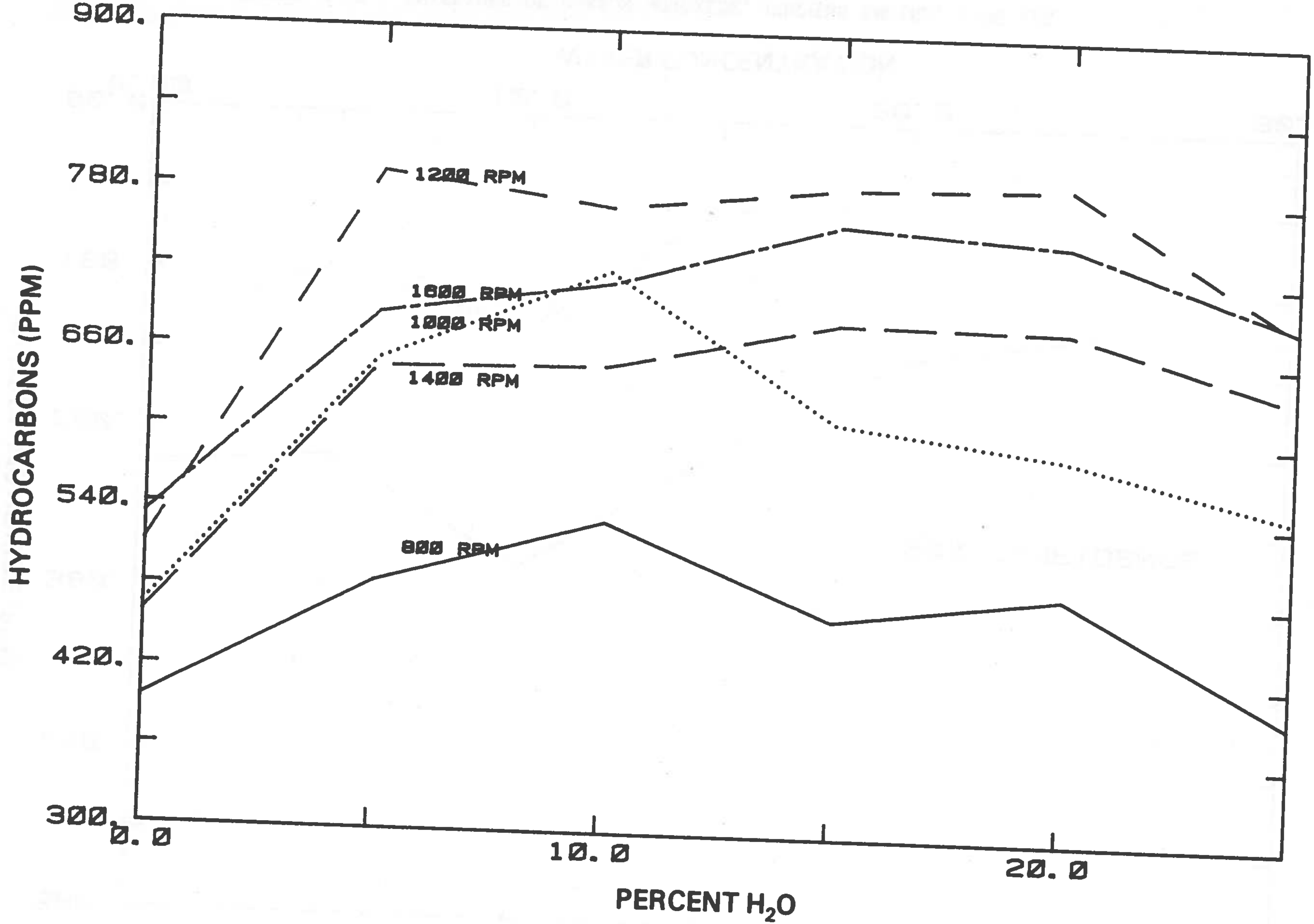


FIGURE 3-19. EMISSIONS OF UNBURNED HYDROCARBONS, DETROIT DIESEL ENGINE, FIVE SPEEDS

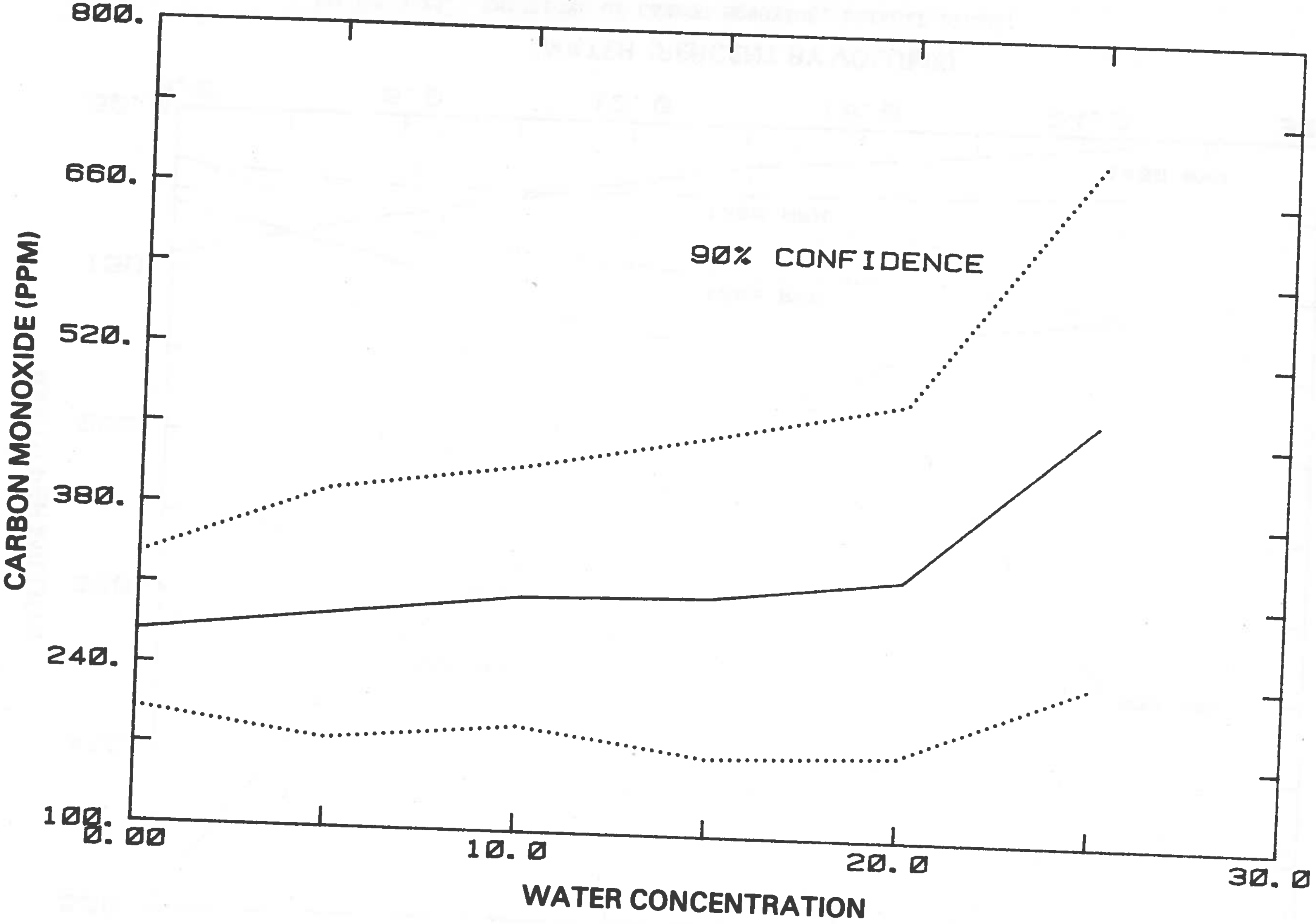


FIGURE 3-21. EMISSIONS OF CARBON MONOXIDE, CUMMINS ENGINE, 1200 RPM

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.

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

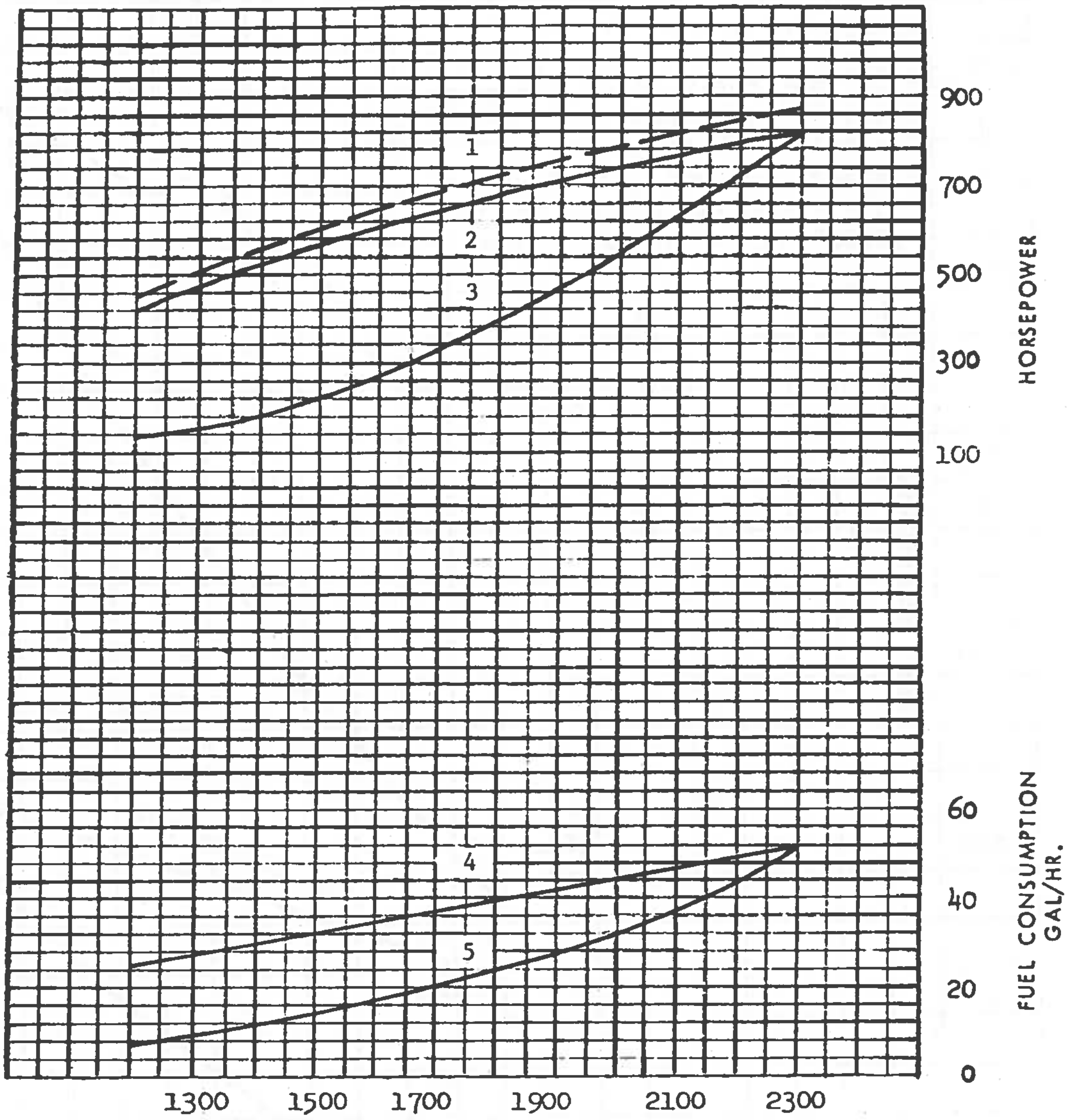
Both the data obtained during this study and the results reported by other investigators indicate that the effect of water-in-fuel emulsions on engine performance is dependent upon the engine system configuration. Although inferences can be drawn from the body of accumulated information, it is not possible, 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.

APPENDIX A

FUEL PROPERTIES AND ENGINE DATA

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).

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]

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

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, 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_2O	13.9
Exhaust Pressure (Right)	Inches - Hg	0.2
Exhaust Pressure (Left)	Inches - Hg	0.5
Pressure Drop, LFE Filter	In. H_2O	5.40
Pressure Drop, Laminar Flow Element	In. H_2O	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

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

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

$$P_{WB} = 3168.62 \text{ pascals (at } 298.15°\text{K)}$$

$$P_{DB} = 4382.41 \text{ pascals (at } 303.71°\text{K)}.$$

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

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

where P_V = vapor pressure, pascals
T_{DB} = dry bulb temperature, °K
T_{WB} = wet bulb temperature, °K
P_{BARO} = barometric pressure, 98307.2 pascals.

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:

TABLE B-2. WATER FLOWMETER CURVE COEFFICIENTS

	Meter 1 Glass Float	Meter 1 Stainless Steel Float	Meter 2 Stainless Steel Float
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	$-0.6943106 \times 10^{-8}$	$-0.1340098 \times 10^{-7}$	$-0.2025536 \times 10^{-7}$

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

$$P_{B,\ DRY} = P_{BARO} - \frac{P_V}{K_P} = 28.20 \text{ in. Hg}, \tag{9}$$

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

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

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

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

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]

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

where TCF = temperature correction factor

T_i = 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

ρs = 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,

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

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	1	2	3	4
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:

$$\mathrm{BSFC} = \frac{F}{\mathrm{CBHP}} = 0.3939 \text{ pounds fuel per brake horsepower hour.} \tag{17}$$

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

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

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 3[15] to determine the specific gravity of the fuel; for the test case, the specific garvity of the fuel at 60°F compared to water at 60°F was:

$$SG_{60/60} = 0.8483,$$

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

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:

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

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,

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

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

then,

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

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

and

calculation was for the stoichiometric fuel-air ratio:

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

The equivalence ratio was then calculated from

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

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

CO_2 = measured carbon dioxide concentration, percent.

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

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

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

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:

$$K_{NO_x} = \frac{1}{1 + A(G - 75) + B(T - 85)} = 1.19, \qquad (36)$$

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

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

G = humidity in grains per pound dry air

= (7000)(H')

T = inlet air temperature, °F ,

then

$$DNO = (NO)(K_{NO_x}) , \qquad (37)$$

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:

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:

$$S_{HC} = \frac{W_{HC}}{CBHP} = 0.14 \tag{42}$$

$$S_{CO} = \frac{W_{CO}}{CBHP} + 0.69 \tag{43}$$

$$S_{NO_x} = \frac{W_{NO_x}}{CBHP} = 6.59 , \tag{44}$$

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

$$\bar{X} = \frac{1}{\eta} \sum_{i=i}^{\eta} X , \tag{45}$$

where $\bar{X}$ = sample mean

η = 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:

$$S = \sqrt{\frac{\Sigma X^2 - \frac{(\Sigma X)^2}{\eta}}{\eta - 1}}, \qquad (46)$$

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

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

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:

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

where η = sample size
S = sample standard deviation ,

then

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

and

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

now, if

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

or

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

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.

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.	90.	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	.5	.5	.5	.5	.5	.5	.5
BOOST (L)	PSI	1.0	.9	1.0	1.5	1.5	1.5	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
FUEL 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-3. ENGINE TEST RESULTS, CUMMINS ENGINE, 900 RPM, 10% WATER

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

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	7.0	7.0	7.0	7.0
BOOST (R)	PSI	.5	.5	.5	.5
BOOST (L)	PSI	1.2	1.0	1.5	1.5
INLET VAC. (R)	IN-H2O	2.3	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	50.	60.	60.	60.

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

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

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	67.	68.	66.
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.	113.
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	.5	.5	.5
BOOST (L)	PSI	.9	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-7. ENGINE TEST RESULTS, CUMMINS ENGINE, 1200 RPM, BASELINE

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

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		.0691	.0691	.0691	.0691	.0691	.0691	.0691	.0691	.0691
MEAS. F/A		.0237	.0242	.0243	.0250	.0249	.0245	.0252	.0253	.0250
CALC. F/A		.0256	.0248	.0250	.0246	.0245	.0250	.0255	.0235	.0252
% DIFF.	PCT	8.07	2.37	2.74	-1.67	-1.80	2.07	1.18	-7.14	.61
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.	655.	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.	640.
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.	690.	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.	620.
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	15.0	15.0	15.0	15.0	15.0	15.0	15.0
BOOST (R)	PSI	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
BOOST (L)	PSI	2.6	2.5	2.5	2.5	2.6	2.5	2.5	2.4	2.0
INLET VAC. (R)	IN-H2O	3.6	3.8	3.9	4.2	4.3	4.5	4.8	5.0	5.4
EXH. PRESS. (R)	PSI	.1	.1	.1	0.0	0.0	0.0	0.0	0.0	.1
EXH. PRESS. (L)	PSI	.1	.1	.1	.1	.1	1.0	1.0	.1	.2
TURB. IN. (R)	IN-HG	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
TURB. IN. (L)	IN-HG	1.4	1.4	1.5	1.5	1.5	1.4	1.5	1.5	1.5
FUEL PRESS.	PSI	18.	21.	20.	20.	20.	20.	20.	20.	22.
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.	288.	263.	213.	229.	217.	239.	174.	225.
NITROGEN OXIDES	PPM	355.	313.	288.	234.	251.	230.	258.	190.	240.
CARBON DIOXIDE	PCT	5.4	5.3	5.3	5.3	5.2	5.3	5.5	5.0	5.4
OXYGEN	PCT	14.3	15.8	15.8	11.6	9.9	13.9	15.6	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	62.050	58.433	56.697	37.212	29.219
CO MASS	GM-HR	446.11	203.00	475.09	268.15	192.15	218.68	223.13	244.86	221.67
NOX MASS	GM-HR	521.20	535.94	484.32	431.38	441.54	404.88	419.61	383.03	427.38
BSHC	GM/BHP-HR	.3955	.2294	.3459	.3191	.5174	.4878	.4662	.3116	.2480
BSCO	GM/BHP-HR	3.8642	1.7475	4.0426	2.2558	1.6023	1.8255	1.8348	2.0501	1.8813
BSNO	GM/BHP-HR	4.5146	4.6137	4.1211	3.6290	3.6818	3.3799	3.4504	3.2069	3.6272

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

DYNAMOMETER CONSTANT: 3000 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	29.05	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. %	PCT.	9.3	9.3	9.2	9.2	9.1
BSFC	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		.0691	.0691	.0691	.0691	.0691
MEAS. F/A		.0240	.0236	.0245	.0246	.0250
CALC. F/A		.0249	.0242	.0240	.0252	.0235
% 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 SUMP	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.	99.	104.	109.	102.
FUEL COOLER	DEG F	96.	93.	96.	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.	170.	170.
CHARGE AIR (R)	DEG F	169.	169.	172.	171.	172.
EXH. STACK (R)	DEG F	568.	575.	587.	573.	583.
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.	690.
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.	623.	640.
EXHAUST 6R	DEG F	675.	680.	698.	677.	693.
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	15.2	15.2	17.0	15.0	16.0
BOOST (R)	PSI	1.8	1.8	1.7	1.7	1.6
BOOST (L)	PSI	2.8	2.5	2.5	2.5	2.3
INLET VAC. (R)	IN-H2O	3.7	3.8	4.2	4.6	5.3
EXH. PRESS. (R)	PSI	.1	.1	0.0	0.0	.1
EXH. PRESS. (L)	PSI	.1	.1	.1	.1	.2
TURB. IN. (R)	IN-HG	2.7	2.5	2.5	2.5	2.3
TURB. IN. (L)	IN-HG	1.2	1.4	1.3	1.4	1.7
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	PPM	298.	508.	274.	222.	222.
NITRIC OXIDE	PPM	320.	275.	200.	205.	215.
NITROGEN OXIDES	PPM	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	50.255
CO MASS	GM-HR	275.89	483.12	266.69	204.08	223.53
NOX MASS	GM-HR	557.52	496.37	450.12	419.09	516.01
BSHC	GM/BHP-HR	.4077	.3927	.5077	.4861	.4200
BSCO	GM/BHP-HR	2.3754	4.1595	2.2513	1.6923	1.8683
BSNO	GM/BHP-HR	4.8002	4.2736	3.7997	3.4753	4.3130

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. BMEP	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	99.	97.	96.	100.	95.
INTAKE AIR	DEG F	85.	76.	86.	95.	81.
TURB. INLET (L)	DEG F	601.	588.	596.	608.	596.
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.	556.	559.
EXH. STACK (L)	DEG F	551.	538.	546.	557.	546.
WATER INLET	DEG F	85.	81.	88.	95.	88.
CELL AIR	DEG F	84.	77.	86.	96.	83.
EXHAUST 1R	DEG F	634.	644.	665.	648.	655.
EXHAUST 2R	DEG F	542.	555.	567.	657.	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.	675.	648.	656.
EXHAUST 1L	DEG F	614.	609.	609.	625.	618.
EXHAUST 2L	DEG F	637.	614.	619.	654.	640.
EXHAUST 3L	DEG F	577.	572.	585.	586.	570.
EXHAUST 4L	DEG F	586.	581.	589.	588.	580.
EXHAUST 5L	DEG F	564.	613.	634.	656.	639.
EXHAUST 6L	DEG F	615.	604.	620.	628.	615.
OIL PRESSURE	PSI	65.	63.	64.	65.	64.
RAIL PRESSURE	PSI	15.5	15.8	20.0	18.0	19.0
BOOST (R)	PSI	1.6	1.8	1.6	1.5	1.5
BOOST (L)	PSI	2.7	2.5	2.5	2.5	2.4
INLET VAC. (R)	IN-H2O	3.7	3.8	4.2	4.6	5.3
EXH. PRESS. (R)	PSI	.1	.1	0.0	0.0	.1
EXH. PRESS. (L)	PSI	.1	.1	.1	.1	.2
TURB. IN. (R)	IN-HG	2.5	2.5	2.5	2.5	2.5
TURB. IN. (L)	IN-HG	1.2	1.2	1.2	1.2	1.3
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	175.	149.	149.	146.	95.
CARBON MONOXIDE	PPM	263.	613.	229.	263.	267.
NITRIC OXIDE	PPM	330.	275.	211.	215.	220.
NITROGEN OXIDES	PPM	360.	313.	248.	249.	250.
CARBON DIOXIDE	PCT	5.3	5.1	5.3	5.3	5.3
OXYGEN	PCT	13.6	16.0	9.3	15.4	15.6
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	212.32	242.91	250.79
NOX MASS	GM-HR	607.14	611.45	514.93	509.42	520.16
BSHC	GM/BHP-HR	.7212	.6198	.6019	.5788	.3934
BSCO	GM/BHP-HR	2.0906	4.9214	1.7802	2.0043	2.1223
BSNO	GM/BHP-HR	5.2097	5.2405	4.3176	4.2035	4.4018

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	.4171	.4056	.4073	.4761	.4109	.4151	.3986
AIR FLOW	LB/MIN	83.5	82.6	83.7	38.0	85.0	84.5	81.4
STOICH. F/A		.0691	.0691	.0691	.0691	.0691	.0691	.0691
MEAS. F/A		.0363	.0361	.0360	.0242	.0351	.0355	.0363
CALC. F/A		.0335	.0324	.0341	.0248	.0347	.0348	.0342
% 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.	188.	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.	106.	109.	90.	105.	105.	109.
INTAKE AIR	DEG F	83.	92.	84.	72.	79.	78.	91.
TURB. INLET (L)	DEG F	965.	969.	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	1.8	11.2	11.1	10.9
BOOST (L)	PSI	10.5	11.3	10.5	2.5	10.8	11.5	10.2
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
EXH. PRESS. (L)	PSI	.6	.6	.5	.1	.5	.5	.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
FUEL 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	863.	950.	880.	313.	838.	850.	750.
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 OPACITY	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
BSCO	GM/BHP-HR	1.6161	.8712	3.2248	1.7475	1.4113	2.7802	.6181
BSNO	GM/BHP-HR	8.0876	8.5787	8.3803	4.6137	7.7323	7.6960	6.6393

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

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

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.	94.	79.	80.	83.	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. %	PCT	4.8	5.1	4.9	4.9	4.8	4.8
BSFC	LB/BHP-HR	.4111	.3727	.4076	.4078	.4052	.4060
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
% DIFF.	PCT	-9.98	-.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.	93.	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.	82.	84.	91.
TURB. INLET (L)	DEG F	952.	958.	934.	937.	946.	962.
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.	186.	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.	803.	780.	782.	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.	929.	937.	948.
EXHAUST 1L	DEG F	995.	1001.	915.	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	11.0	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	.5	.5	.5	.6	.5	.5
TURB. IN. (R)	IN-HG	11.0	11.0	11.0	11.0	11.0	10.5
TURB. IN. (L)	IN-HG	9.8	9.8	9.8	10.0	9.8	9.5
FUEL PRESS.	PSI	22.	18.	20.	20.	20.	20.
EMULSION PRESS.	PSI	100.	150.	100.	100.	100.	100.
FUEL SUPPLY	PSI	2.	2.	2.	3.	2.	2.
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	925.	870.	850.	742.	625.	640.
NITROGEN OXIDES	PPM	875.	915.	875.	632.	645.	648.
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	1231.8	542.95	505.92	497.47	470.61
NOX MASS	GM-HR	3790.3	3869.4	3681.6	2606.0	2774.6	2584.7
BSHC	GM/BHP-HR	.3113	.3647	.2535	.1336	.1475	.2295
BSCO	GM/BHP-HR	1.4154	2.7169	1.2423	1.1573	1.1232	1.0537
BSNO	GM/BHP-HR	8.6618	8.5346	8.4237	5.9613	6.2647	5.7870

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

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

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	89.	100.	82.	86.	87.	95.
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. %	PCT.	14.9	15.0	15.2	15.2	14.6	14.8
BSFC	LB/BHP-HR	.4060	.3855	.4037	.4017	.3995	.3987
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
% 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.	96.
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.	802.
EXH. STACK (L)	DEG F	775.	782.	756.	768.	774.	790.
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.	996.
EXHAUST 5R	DEG F	902.	914.	886.	893.	895.	911.
EXHAUST 6R	DEG F	914.	928.	900.	906.	913.	923.
EXHAUST 1L	DEG F	968.	983.	946.	949.	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	88.0	90.0	90.0	88.0	90.0
BOOST (R)	PSI	10.3	10.2	10.3	10.4	10.2	10.0
BOOST (L)	PSI	10.9	10.8	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	.3	.3	.2	.2	.1	.2
EXH. PRESS. (L)	PSI	.5	.5	.5	.4	.5	.5
TURB. IN. (R)	IN-HG	10.5	10.3	10.5	10.4	10.2	10.0
TURB. IN. (L)	IN-HG	9.2	9.0	9.1	9.2	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.	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.	675.	695.	700.
NITROGEN OXIDES	PPM	983.	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	1222.3	1009.6	399.94	279.54	333.28
NOX MASS	GM-HR	4382.4	6479.9	4473.2	3662.0	3228.9	3051.5
BSHC	GM/BHP-HR	.1269	.3706	.2449	.1385	.1662	.1620
BSCO	GM/BHP-HR	1.1041	2.6425	2.3039	.9086	.6296	.7424
BSNO	GM/BHP-HR	9.9733	14.009	10.208	8.3195	7.2722	6.7974

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	.3998	.3963	.3981
AIR FLOW	LB/MIN	79.8	80.1	77.7	77.9	76.1
STOICH. F/A		.0691	.0691	.0691	.0691	.0691
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	892.	872.	881.	884.	909.
TURB. INLET (R)	DEG F	906.	886.	894.	900.	924.
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	769.	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.	90.	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.
RAIL 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-H20	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	88.8	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	PPMC	46.	100.	55.	55.	69.
CARBON MONOXIDE	PPM	163.	429.	148.	151.	148.
NITRIC OXIDE	PPM	1188.	1113.	770.	788.	748.
NITROGEN OXIDES	PPM	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	13.3	11.3
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	75.734
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	2.0613	.6982	.6989	.6743
BSNO	GM/BHP-HR	12.862	12.819	8.4027	9.0196	7.8030

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

DYNAMOMETER CONSTANT: **2000**. API GRAVITY OF DIESEL FUEL: 33.9 AT 60F
H/C RATIO: 1.82

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.	125.	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	.5	0.0	0.0	.5	.5
BOOST (RR)	PSI	1.0	0.0	0.0	.5	.5
BOOST (LF)	PSI	0.0	0.0	0.0	0.0	0.0
BOOST (LR)	PSI	1.0	0.0	0.0	.5	.5
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
EMULSION 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-22. ENGINE TEST RESULTS, DETROIT DIESEL ENGINE, 1000 RPM, BASELINE

DYNAMOMETER CONSTANT: **2000**.   API GRAVITY OF DIESEL FUEL: 33.9 AT 60F
H/C RATIO: 1.82

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.	79.	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.	452.
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-H20	1.6	1.7	1.5	1.6	1.6	1.5	1.5	1.5	1.4
INLET VAC. (RR)	IN-H20	1.7	1.7	1.6	1.7	1.5	1.5	1.5	1.6	1.6
INLET VAC. (LF)	IN-H20	3.9	3.8	4.0	4.0	3.9	3.9	4.0	4.0	4.0
INLET VAC. (LR)	IN-H20	3.8	3.8	3.9	3.9	3.9	3.8	3.9	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	3.2	3.1	3.1	3.0
TURB. IN. (RR)	IN-HG	0.0	.8	1.2	3.7	2.4	3.1	3.1	3.2	3.0
TURB. IN. (LF)	IN-HG	0.0	1.0	1.0	3.7	2.4	3.0	3.1	3.1	3.0
TURB. IN. (LR)	IN-HG	0.0	.8	1.2	3.7	2.4	3.2	3.3	3.2	3.2
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-24. ENGINE TEST RESULTS, DETROIT DIESEL ENGINE, 1000 RPM, 20, 25% WATER

DYNAMOMETER CONSTANT: 2000. API GRAVITY OF DIESEL FUEL: 33.9 AT 60F
H/C RATIO: 1.82

RUN NUMBER		23.	55.	69.	24.	56.	70.
NOM. WATER PCT.		20.	20.	20.	25.	25.	25.
ENGINE SPEED	RPM	1000.	1000.	1000.	1000.	1000.	1000.
OBS. TORQUE	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	3.8	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	3.3	3.1	3.1
TURB. IN. (RR)	IN-HG	3.1	3.1	3.0	3.3	3.1	3.0
TURB. IN. (LF)	IN-HG	2.9	3.1	3.1	3.3	3.1	3.0
TURB. IN. (LR)	IN-HG	2.9	3.2	3.1	3.3	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-26. ENGINE TEST RESULTS, DETROIT DIESEL ENGINE, 1000 RPM, FUEL INJECTION TIMING RETARDED 4.1 DEGREES

DYNAMOMETER CONSTANT: **2000.** API GRAVITY OF DIESEL FUEL: 33.9 AT 60F
H/C RATIO: 1.82

RUN NUMBER		79.	85.	80.	81.	82.	83.	84.
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	29.04	28.93	29.06	29.06	29.03	29.00	28.96
DRY BULB	DEG F	80.	94.	80.	83.	83.	84.	92.
WET BULB	DEG F	70.	70.	70.	71.	71.	71.	71.
REL. HUMIDITY	PCT	61.	30.	61.	56.	56.	53.	35.
CORR. BHP	HP	170.3	172.6	170.6	170.6	171.2	172.6	172.8
CORR. BMEP	PSI	37.7	38.2	37.8	37.8	37.9	38.2	38.3
FUEL FLOW	LB/HR	72.58	72.52	72.09	72.93	73.51	73.82	74.57
WATER FLOW	CC/MIN	0.0	0.0	33.8	69.7	108.0	154.4	211.7
CALC. VOL. %	PCT.	0.0	0.0	4.9	9.6	14.0	18.8	23.9
BSFC	LB/BHP-HR	.4263	.4201	.4226	.4275	.4293	.4276	.4315
AIR FLOW L	LB/MIN	39.3	39.6	39.1	39.1	40.7	38.0	39.6
AIR FLOW R	LB/MIN	40.4	39.5	39.8	39.8	39.7	39.5	39.5
COOLANT IN	DEG F	178.	177.	178.	177.	178.	177.	177.
COOLANT OUT	DEG F	184.	184.	184.	184.	184.	184.	184.
OIL SUMP	DEG F	197.	199.	198.	199.	200.	199.	200.
FUEL IN	DEG F	104.	108.	105.	107.	107.	105.	104.
FUEL RETURN	DEG F	123.	127.	124.	125.	124.	122.	121.
FUEL SUPPLY	DEG F	95.	108.	97.	99.	101.	103.	104.
FUEL COOLER	DEG F	103.	106.	105.	106.	106.	104.	104.
INTAKE AIR (RF)	DEG F	89.	100.	92.	95.	95.	100.	101.
INTAKE AIR (RR)	DEG F	89.	100.	92.	95.	95.	100.	101.
INTAKE AIR (LF)	DEG F	85.	100.	86.	88.	93.	95.	96.
INTAKE AIR (LR)	DEG F	85.	100.	86.	88.	93.	96.	97.
HP AIR (RF)	DEG F	109.	120.	112.	114.	113.	118.	120.
HP AIR (RR)	DEG F	109.	121.	112.	115.	114.	119.	120.
HP AIR (LF)	DEG F	109.	124.	110.	111.	116.	120.	119.
HP AIR (LR)	DEG F	106.	121.	108.	109.	114.	116.	117.
EXH. STACK	DEG F	493.	504.	492.	483.	480.	473.	469.
WATER INLET	DEG F	82.	99.	83.	88.	92.	95.	94.
CELL AIR	DEG F	84.	96.	86.	86.	88.	94.	96.
EXHAUST 1R	DEG F	500.	505.	494.	490.	484.	482.	479.
EXHAUST 2R	DEG F	477.	480.	468.	463.	464.	464.	464.
EXHAUST 3R	DEG F	467.	472.	463.	457.	451.	451.	453.
EXHAUST 4R	DEG F	484.	487.	480.	470.	465.	464.	464.
EXHAUST 5R	DEG F	466.	469.	461.	456.	453.	450.	450.
EXHAUST 6R	DEG F	473.	476.	467.	461.	453.	450.	452.
EXHAUST 1L	DEG F	544.	552.	542.	536.	530.	523.	520.
EXHAUST 2L	DEG F	549.	554.	544.	539.	533.	523.	518.
EXHAUST 3L	DEG F	522.	525.	513.	505.	502.	496.	489.
EXHAUST 4L	DEG F	547.	548.	542.	533.	528.	518.	512.
EXHAUST 5L	DEG F	572.	578.	567.	554.	547.	537.	530.
EXHAUST 6L	DEG F	584.	592.	579.	566.	558.	549.	543.
OIL PRESSURE	PSI	35.0	35.0	35.0	35.0	35.0	35.0	35.0
FUEL SPILL	PSI	35.0	35.0	35.0	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
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	2.0	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	3.0	3.0	3.0	3.0	3.0	3.0	3.0
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	PSI	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-28. ENGINE TEST RESULTS, DETROIT DIESEL ENGINE, 1000 RPM, FUEL INJECTION TIMING ADVANCED 5.5 DEGREES

DYNAMOMETER CONSTANT: **2000.**   API GRAVITY OF DIESEL FUEL: 33.9 AT 60F
H/C RATIO: 1.82

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. %	PCT.	0.0	0.0	4.6	9.3	14.2	19.0	23.8
BSFC	LB/BHP-HR	.4333	.4247	.4334	.4357	.4419	.4460	.4474
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.	445.	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	1.6
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	30.0	3.0	3.2	3.4	3.5
WATER PRESS.	PSI	0.	0.	50.	50.	50.	50.	50.

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

DYNAMOMETER CONSTANT: 2000. API GRAVITY OF DIESEL FUEL: 33.9 AT 60F
H/C RATIO: 1.82

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.	515.	567.	561.
EXHAUST 2R	DEG F	575.	563.	554.	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-H20	2.6	2.6	2.6	2.5	2.5
INLET VAC. (RR)	IN-H20	2.7	2.7	2.7	2.6	2.6
INLET VAC. (LF)	IN-H20	5.7	5.6	5.7	5.7	5.7
INLET VAC. (LR)	IN-H20	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	4.0	4.2
WATER PRESS.	PSI	50.	50.	50.	50.	50.

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

DYNAMOMETER CONSTANT: **2000**.   API GRAVITY OF DIESEL FUEL: 33.9 AT 60F
H/C RATIO: 1.82

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	68.8
FUEL FLOW	LB/HR	175.30	177.80	176.64	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	.4006	.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.	164.	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.	655.
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	8.5	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	0.0	.1	0.0	.1	0.0	.1	0.0
EXH. PRESS. (L)	PSI	0.0	.1	0.0	.1	0.0	.1	0.0	.1	0.0
TURB. IN. (RF)	IN-HG	9.9	9.6	9.8	9.5	9.8	9.5	9.7	9.4	9.7
TURB. IN. (RR)	IN-HG	9.8	9.5	9.7	9.4	9.7	9.4	9.6	9.3	9.6
TURB. IN. (LF)	IN-HG	9.8	9.4	9.7	9.4	9.5	9.4	9.5	9.2	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-34. ENGINE TEST RESULTS, DETROIT DIESEL ENGINE, 1600 RPM, BASELINE

DYNAMOMETER CONSTANT: 2000.   API GRAVITY OF DIESEL FUEL: 33.9 AT 60F
H/C RATIO: 1.82

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	.4001	.3940	.3941
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	8.5
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	.3	.3
EXH. PRESS. (L)	PSI	.2	.3	.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-36. PERFORMANCE AND EMISSION TEST RESULTS, DETROIT DIESEL ENGINE, 800 RPM

DYNAMOMETER CONSTANT: 3000 API GRAVITY OF DIESEL FUEL: 33.9 AT 60F
H/C RATIO: 1.82

RUN NUMBER		114.	120.	115.	116.	117.	118.	119.
NOM. WATER PCT.		0.	0.	5.	10.	15.	20.	25.
ENGINE SPEED	RPM	800.	800.	800.	800.	800.	800.	800.
OBS. TORQUE	LB-FT	592.	592.	592.	592.	592.	592.	592.
BAR. PRESS.	IN-HG	29.22	29.14	29.22	29.21	29.21	29.19	29.18
DRY BULB	DEG F	88.	99.	89.	91.	92.	95.	99.
WET BULB	DEG F	77.	78.	77.	78.	78.	78.	78.
REL. HUMIDITY	PCT	61.	39.	58.	56.	54.	47.	39.
CORR. BHP	HP	92.4	93.8	92.6	92.9	93.1	93.5	93.9
CORR. BMEP	PSI	25.6	26.0	25.6	25.7	25.8	25.9	26.0
FUEL FLOW	LB/HR	42.95	43.25	43.18	43.69	43.80	44.10	44.81
WATER FLOW	CC/MIN	0.0	0.0	17.3	46.5	61.4	94.0	124.5
CALC. VOL. %	PCT.	0.0	0.0	4.3	10.5	13.4	19.1	23.5
BSFC	LB/BHP-HR	.4650	.4612	.4665	.4702	.4704	.4715	.4773
AIR FLOW L	LB/MIN	31.0	30.9	30.8	30.4	30.4	30.2	30.2
AIR FLOW R	LB/MIN	30.9	30.6	30.9	30.8	30.7	30.6	30.5
STOICH. F/A		.0689	.0689	.0689	.0689	.0689	.0689	.0689
MEAS. F/A		.0116	.0117	.0117	.0119	.0119	.0121	.0123
CALC. F/A		.0101	.0100	.0102	.0102	.0103	.0103	.0104
% DIFF.	PCT	-12.64	-14.39	-13.02	-13.97	-14.05	-14.35	-15.23
COOLANT IN	DEG F	168.	163.	174.	183.	173.	181.	168.
COOLANT OUT	DEG F	178.	174.	181.	189.	186.	187.	177.
OIL SUMP	DEG F	193.	187.	193.	200.	194.	200.	192.
FUEL IN	DEG F	105.	106.	106.	108.	106.	106.	104.
FUEL RETURN	DEG F	125.	124.	125.	127.	123.	125.	120.
FUEL SUPPLY	DEG F	110.	117.	111.	113.	114.	116.	115.
FUEL COOLER	DEG F	104.	103.	104.	107.	104.	104.	102.
INTAKE AIR (RF)	DEG F	97.	110.	98.	102.	103.	107.	107.
INTAKE AIR (RR)	DEG F	92.	107.	95.	97.	99.	104.	104.
INTAKE AIR (LF)	DEG F	90.	105.	92.	95.	98.	103.	102.
INTAKE AIR (LR)	DEG F	89.	105.	91.	94.	97.	102.	102.
HP AIR (RF)	DEG F	102.	117.	105.	107.	109.	114.	114.
HP AIR (RR)	DEG F	102.	118.	105.	108.	110.	114.	115.
HP AIR (LF)	DEG F	104.	119.	106.	19.	111.	116.	115.
HP AIR (LR)	DEG F	101.	116.	104.	106.	109.	113.	113.
EXH. STACK	DEG F	381.	381.	380.	383.	374.	376.	366.
WATER INLET	DEG F	88.	102.	89.	92.	95.	96.	95.
CELL AIR	DEG F	88.	100.	90.	92.	94.	98.	102.
EXHAUST 1R	DEG F	379.	375.	376.	382.	375.	377.	366.
EXHAUST 2R	DEG F	360.	354.	357.	364.	358.	362.	352.
EXHAUST 3R	DEG F	342.	335.	341.	346.	340.	346.	339.
EXHAUST 4R	DEG F	356.	352.	355.	360.	354.	359.	350.
EXHAUST 5R	DEG F	346.	341.	344.	347.	342.	349.	339.
EXHAUST 6R	DEG F	342.	337.	341.	345.	360.	345.	339.
EXHAUST 1L	DEG F	429.	423.	422.	425.	414.	413.	402.
EXHAUST 2L	DEG F	406.	401.	401.	403.	392.	396.	484.
EXHAUST 3L	DEG F	397.	390.	393.	397.	388.	389.	378.
EXHAUST 4L	DEG F	426.	420.	419.	420.	410.	410.	400.
EXHAUST 5L	DEG F	423.	418.	417.	420.	412.	413.	401.
EXHAUST 6L	DEG F	441.	436.	435.	433.	422.	420.	407.
OIL PRESSURE	PSI	26.0	27.0	26.0	25.0	25.0	25.0	26.0
FUEL SPILL	PSI	25.0	25.0	25.0	25.0	26.0	26.0	25.0
BOOST (RF)	PSI	.5	.5	.5	.5	.5	.5	.5
BOOST (RR)	PSI	.7	1.0	.8	.8	.8	.8	.9
BOOST (LF)	PSI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BOOST (LR)	PSI	.8	.7	.4	.5	.7	.6	.7
AIR BOX	PSI	1.5	1.3	1.3	1.3	1.3	1.3	1.3
INLET VAC. (RF)	IN-H2O	.8	.8	.8	.8	2.8	2.8	.8
INLET VAC. (RR)	IN-H2O	.8	.9	.8	.8	2.8	2.8	.8
INLET VAC. (LF)	IN-H2O	2.8	2.8	2.8	2.7	.8	.8	2.8
INLET VAC. (LR)	IN-H2O	2.7	2.8	2.7	2.7	.8	.8	2.8
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	1.6	1.6	1.6	1.6	1.6	1.6	1.7
TURB. IN. (RR)	IN-HG	1.5	1.5	1.5	1.5	1.5	1.5	1.5
TURB. IN. (LF)	IN-HG	1.5	1.6	1.5	1.5	1.5	1.5	1.5
TURB. IN. (LR)	IN-HG	1.7	1.6	1.7	1.7	1.7	1.6	1.6
FUEL PRESS.	PSI	28.0	29.0	28.0	28.0	28.0	28.0	28.0
EMULSION PRESS.	PSI	100.	100.	100.	100.	100.	100.	100.
FUEL SUPPLY	PSI	3.3	3.2	3.3	3.3	3.3	3.3	3.3
WATER PRESS.	PSI	0.	0.	50.	50.	50.	50.	50.
HYDROCARBONS	PPMC	414.	376.	485.	532.	463.	484.	393.
CARBON MONOXIDE	PPM	108.	108.	136.	172.	193.	252.	401.
NITRIC OXIDE	PPM	405.	428.	385.	345.	376.	328.	236.
NITROGEN OXIDES	PPM	446.	469.	439.	403.	453.	398.	299.
CARBON DIOXIDE	PCT	2.1	2.1	2.1	2.1	2.1	2.1	2.1
OXYGEN	PCT	16.8	16.7	16.0	15.8	18.0	16.7	17.2
PARTICULATE	MG/SCF	1.0	1.0	1.2	1.3	1.2	1.2	1.1
HC MASS	GM-HR	388.	356.	455.	500.	436.	455.	373.
CO MASS	GM-HR	199.	202.	252.	320.	359.	466.	750.
NOX MASS	GM-HR	1588.	1541.	1572.	1492.	1685.	1474.	1101.
BSHC	GM/BHP-HR	4.30	3.95	5.04	5.55	4.83	5.05	4.14
BSCO	GM/BHP-HR	2.21	2.24	2.79	3.55	3.98	5.18	8.32
BSNO	GM/BHP-HR	17.61	17.09	17.44	16.55	18.70	16.35	12.22

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	290.8	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	115.06	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	185.	179.	186.	179.	181.	177.	184.	178.
OIL SUMP	DEG F	204.	199.	204.	201.	204.	196.	205.	201.
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	106.	109.	107.	109.	109.	108.	111.	116.
INTAKE AIR (RF)	DEG F	103.	111.	111.	114.	102.	120.	105.	115.
INTAKE AIR (RR)	DEG F	92.	104.	99.	108.	94.	109.	96.	112.
INTAKE AIR (LF)	DEG F	95.	108.	103.	111.	97.	106.	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.	103.
CELL AIR	DEG F	91.	104.	98.	107.	94.	102.	95.	105.
EXHAUST 1R	DEG F	590.	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	582.	579.	587.	584.	572.	570.	566.	573.
EXHAUST 5R	DEG F	557.	548.	559.	553.	550.	546.	547.	552.
EXHAUST 6R	DEG F	546.	544.	552.	548.	541.	540.	534.	541.
EXHAUST 1L	DEG F	637.	632.	642.	638.	623.	617.	616.	618.
EXHAUST 2L	DEG F	653.	646.	649.	655.	638.	637.	627.	636.
EXHAUST 3L	DEG F	610.	610.	620.	617.	598.	595.	589.	591.
EXHAUST 4L	DEG F	653.	645.	656.	651.	638.	637.	629.	633.
EXHAUST 5L	DEG F	644.	645.	657.	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	43.0	42.0	44.0	41.8	43.0
FUEL SPILL	PSI	41.0	44.0	44.8	45.0	43.0	44.0	42.0	44.0
BOOST (RF)	PSI	2.0	2.0	2.0	2.0	2.0	1.9	2.0	1.9
BOOST (RR)	PSI	2.1	2.8	2.2	2.5	2.2	1.9	2.3	2.2
BOOST (LF)	PSI	1.1	1.1	1.2	1.2	1.4	1.0	1.3	1.1
BOOST (LR)	PSI	2.1	2.1	2.2	2.5	2.1	2.1	2.1	2.1
AIR BOX	PSI	3.0	3.2	3.8	3.0	3.0	3.5	3.2	4.0
INLET VAC. (RF)	IN-H2O	2.4	2.5	2.4	2.6	2.5	2.5	2.5	2.5
INLET VAC. (RR)	IN-H2O	2.4	2.7	2.5	2.7	2.5	2.6	2.6	2.6
INLET VAC. (LF)	IN-H2O	5.7	6.0	5.9	6.1	5.7	5.9	5.8	6.0
INLET VAC. (LR)	IN-H2O	5.6	5.9	5.8	6.0	5.6	6.0	5.7	5.9
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	5.3	5.4	5.2	5.3	5.2	5.3
TURB. IN. (RR)	IN-HG	5.1	5.3	5.3	5.3	5.3	5.2	5.3	5.3
TURB. IN. (LF)	IN-HG	5.1	5.3	5.2	5.3	5.1	5.2	5.1	5.2
TURB. IN. (LR)	IN-HG	5.2	5.4	5.4	5.2	5.1	5.3	5.2	5.3
FUEL PRESS.	PSI	28.0	27.5	20.5	20.0	29.0	21.0	28.0	21.0
EMULSION PRESS.	PSI	100.	100.	100.	100.	100.	100.	100.	100.
FUEL SUPPLY	PSI	2.0	3.0	2.8	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.	560.	522.	791.	774.	768.	758.
CARBON MONOXIDE	PPM	83.	83.	81.	84.	99.	88.	98.	94.
NITRIC OXIDE	PPM	674.	681.	728.	756.	648.	727.	644.	763.
NITROGEN OXIDES	PPM	692.	714.	752.	775.	676.	764.	685.	796.
CARBON DIOXIDE	PCT	3.7	3.7	3.6	3.6	3.7	3.6	3.7	3.7
OXYGEN	PCT	15.0	16.0	15.8	15.8	15.2	14.8	15.5	15.2
PARTICULATE	MG/SCF	1.7	1.2	0.0	1.5	2.0	2.3	1.6	1.7
HC MASS	GM-HR	746.	755.	822.	779.	1154.	1139.	1123.	1109.
CO MASS	GM-HR	234.	239.	233.	246.	282.	252.	277.	269.
NOX MASS	GM-HR	3673.	3542.	3577.	3519.	3634.	3754.	3852.	4010.
BSHC	GM/BHP-HR	2.65	2.68	2.92	2.77	4.11	4.05	3.99	3.94
BSCO	GM/BHP-HR	.83	.85	.83	.87	1.00	.89	.99	.96
BSNO	GM/BHP-HR	13.06	12.60	12.72	12.51	12.92	13.35	13.70	14.26

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
H/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.
OBS. 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	DEG F	87.	102.	89.	94.	94.	94.	100.
WET BULB	DEG F	77.	76.	77.	78.	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. %	PCT	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/MIN	63.9	64.6	65.5	62.3	61.9	61.9	63.3
AIR FLOW R	LB/MIN	68.0	66.5	68.3	67.9	65.9	65.9	66.0
STOICH. F/A		.0689	.0689	.0689	.0689	.0689	.0689	.0689
MEAS. F/A		.0225	.0227	.0222	.0228	.0232	.0232	.0231
CALC. F/A		.0170	.0171	.0172	.0174	.0176	.0175	.0176
% DIFF.	PCT	-24.56	-24.57	-22.53	-23.35	-24.19	-24.53	-24.10
COOLANT IN	DEG F	169.	173.	169.	169.	169.	172.	172.
COOLANT OUT	DEG F	181.	183.	181.	181.	181.	183.	183.
OIL SUMP	DEG F	207.	209.	206.	207.	207.	209.	210.
FUEL IN	DEG F	112.	114.	112.	114.	112.	111.	109.
FUEL RETURN	DEG F	131.	135.	131.	132.	130.	128.	126.
FUEL SUPPLY	DEG F	95.	101.	95.	98.	98.	99.	100.
FUEL COOLER	DEG F	109.	109.	110.	112.	109.	108.	105.
INTAKE AIR (RF)	DEG F	103.	114.	102.	107.	109.	110.	112.
INTAKE AIR (RR)	DEG F	92.	105.	92.	99.	100.	102.	104.
INTAKE AIR (LF)	DEG F	95.	110.	95.	103.	104.	104.	106.
INTAKE AIR (LR)	DEG F	93.	109.	94.	100.	102.	103.	105.
HP AIR (RF)	DEG F	150.	165.	150.	156.	157.	157.	160.
HP AIR (RR)	DEG F	149.	163.	149.	155.	155.	157.	159.
HP AIR (LF)	DEG F	161.	177.	161.	167.	167.	168.	170.
HP AIR (LR)	DEG F	152.	170.	154.	158.	159.	160.	163.
EXH. STACK	DEG F	652.	672.	641.	644.	637.	632.	624.
WATER INLET	DEG F	86.	104.	95.	103.	103.	102.	100.
CELL AIR	DEG F	90.	104.	91.	98.	100.	100.	102.
EXHAUST 1R	DEG F	693.	712.	693.	697.	695.	686.	679.
EXHAUST 2R	DEG F	677.	690.	676.	673.	669.	660.	666.
EXHAUST 3R	DEG F	692.	715.	690.	695.	692.	686.	684.
EXHAUST 4R	DEG F	675.	699.	674.	674.	672.	669.	665.
EXHAUST 5R	DEG F	668.	686.	664.	666.	666.	662.	661.
EXHAUST 6R	DEG F	646.	667.	648.	649.	646.	646.	759.
EXHAUST 1L	DEG F	745.	771.	735.	736.	726.	720.	713.
EXHAUST 2L	DEG F	777.	797.	770.	767.	756.	745.	736.
EXHAUST 3L	DEG F	714.	736.	709.	710.	702.	698.	693.
EXHAUST 4L	DEG F	753.	776.	743.	741.	731.	722.	717.
EXHAUST 5L	DEG F	755.	776.	748.	746.	737.	729.	720.
EXHAUST 6L	DEG 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	47.0	47.0	46.0	46.0	45.0	45.0	45.0
BOOST (RF)	PSI	3.9	3.8	3.9	3.8	3.7	3.5	3.6
BOOST (RR)	PSI	4.7	3.0	2.5	3.2	3.0	3.0	3.1
BOOST (LF)	PSI	3.1	2.3	2.2	2.8	2.1	2.1	2.1
BOOST (LR)	PSI	4.1	4.0	4.1	4.0	3.8	3.8	3.8
AIR BOX	PSI	5.8	5.4	4.8	5.3	5.2	4.8	5.2
INLET VAC. (RF)	IN-H2O	4.3	4.2	4.4	4.3	8.4	4.1	4.2
INLET VAC. (RR)	IN-H2O	4.4	4.3	4.5	4.3	8.3	4.3	4.3
INLET VAC. (LF)	IN-H2O	8.5	8.7	8.6	8.5	4.2	8.5	8.4
INLET VAC. (LR)	IN-H2O	8.3	8.6	8.5	8.4	4.2	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	8.9	8.8	8.5	8.7
TURB. IN. (LR)	IN-HG	9.0	9.1	9.2	8.9	8.8	8.7	8.8
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	PPMC	420.	497.	646.	649.	684.	682.	633.
CARBON MONOXIDE	PPM	141.	136.	116.	96.	76.	67.	56.
NITRIC OXIDE	PPM	683.	764.	676.	689.	725.	706.	674.
NITROGEN OXIDES	PPM	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

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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