

Performance and Emissions of Diesel and Alternative Diesel Fuels in a Heavy-duty Industry-Standard Older Engine

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Manuch Nikanjam
Chevron Products Co.

James Rutherford
Chevron Corp

Kent Spreen
Southwest Research Institute

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ABSTRACT

Conventional diesel fuel has been in the market for decades and used successfully to run diesel engines of all sizes in many applications. In order to reduce emissions and to foster energy source diversity, new fuels such as alternative and renewable, as well as new fuel formulations have entered the market. These include biodiesel, gas-to-liquid, and alternative formulations by states such as California.

Performance variations in fuel economy, emissions, and compatibility for these fuels have been evaluated and debated. In some cases contradictory views have surfaced. “Sustainable”, “Renewable”, and “Clean” designations have been interchanged. Adding to the confusion, results from one fuel in one type of engine such as an older heavy-duty engine, is at times compared to that of another type such as a modern light-duty.

This study was an attempt to compare the performance of several fuels in an identical environment, using the same engine, for direct comparison.

Results of a large-scale fleet test and emissions test to evaluate the performance of several diesel fuels in a modern heavy-duty diesel (HDD) engine were presented in a recent technical paper.

This article is the second in this series and includes the use of a heavy-duty industry-standard older engine, DDC Series 60 on a stand, to evaluate emissions and fuel economy of a number of diesel fuels that cover a range of products being used in the North American market. EPA, California, Texas LED diesel, biodiesel, biodiesel blends, and gas-to-liquid fuel were tested in this program.

Federal Test Procedure (FTP) for HDD and the 13-Mode European Stationary Cycle (ESC) portion of the Supplemental Emissions Test (SET) were used for emissions testing.

This document will provide a detailed description of this project along with statistical analysis of test results for eight diesel fuels.¹

INTRODUCTION

After many years of utilizing only conventional diesel fuel [1], other fuel types are being developed and brought into the market. Different types of diesel fuel are surfacing because of crude oil opportunities, local regulations, and/or desire for sustainable, renewable, or clean energy. There is a worldwide effort to expand the sources of fuels beyond crude based ones to bio fuels and synthetic fuels. Performance, including fuel economy and trouble-free operations (e.g., emissions

¹Numbers in brackets [] designate references at the end of the paper.

Table 1. Test Fuels

	ASTM Method	EPA	CARB	Texas	GTL100	B100	B20EPA	B20CARB	B5CARB
Density @ 15.56 °C, g/mL	D4052	0.8580	0.8379	0.8504	0.7745	0.8844	0.8628	0.8466	0.8396
SFC Aromatics, Wt %	D5186	35.7	21.0	36.1	<1.0	NA	29.8	17.5	20.5
SFC PNAs, Wt %	D5186	7.3	3.6	5.8	<0.5	NA	8.4	3.8	4.3
Calculated Cetane Index, Proc. B	D4737	43.0	57.4	43.1	74.1	NA	43.9	56.4	56.6
Derived Cetane Number	D6890	41.6	55.6	43.0	80.8	50.6	45.5	55.2	54.5
Heat of Combustion, MJ/kg, Net	D240	42.4	43.0	41.4	43.7	37.1	41.4	41.7	42.7
Heat of Combustion, MJ/gallon, Net	D240	137.7	136.4	133.2	128.1	124.2	135.2	133.6	135.7
Viscosity, 40°C, cSt	D445	2.811	3.565	2.487	2.560	4.021	3.182	3.774	3.771
Sulfur, wppm	D5453	5.12	4.67	5.29	<1	<1	4.77	3.79	4.88
Nitrogen, wppm	D5762	3.11	<1	1.11	<0.1	4.0	4.1	0.8	0.3
Flash Point, PMCC, °C	D93	71	75	67	68	162	64	71	60
Distillation, °C	D86								
IBP		174	178	172	181	n/a	168	172	163
10%		220	240	207	213	n/a	222	247	238
50%		270	294	264	269	n/a	286	304	295
90%		323	331	325	338	n/a	333	334	331
95%		336	342	339	351	n/a	343	343	342
FBP		352	350	353	363	n/a	351	349	349

control system longevity), as well as criteria and greenhouse gas emissions, are two significant categories to be considered for the end user of the fuel.

There are scattered indications and perceptions related to performance and emissions benefits from some new forms of diesel fuel. Some have contradictory data and others come from dated studies using older conventional fuels [2].

Plans were made to conduct systematic determination and evaluation of the relative exhaust emissions and fuel economy benefits or disadvantages of several diesel fuel types in three phases to include modern and aged heavy-duty engines as well as new light-duty vehicles.

The initial study included the use of a modern heavy-duty engine utilized in 18 buses in the Alameda-Contra Costa Transit District. Results were provided in a previous SAE technical paper [3].

This paper summarizes the results of a second study using the same fuel types, but in an older industry-standard engine without any aftertreatment device.

Additional studies are being conducted to characterize these fuels in light-duty vehicles.

TEST FUELS

Eight fuels were selected to provide a practical range of application and properties for use in diesel engines. They all

met the sulfur requirement of less than 15 ppm. These fuels are designated as follows:

- **EPA**, the most common and widely used diesel fuel in the United States, meets ASTM D975 Grade No. 2-D S15 specification.
- **CARB**, similar to the EPA fuel with the additional requirements by the state of California for lower emissions.
- **Texas**, with a Low Emissions Diesel (LED) designation modeled after the California lower emission fuel.
- **GTL100**, a Fischer-Tropsch gas-to-liquid diesel with a very high cetane number and lacking aromatics and sulfur. The number 100 indicated that this fuel was not used in a blend. This fuel contained a lubricity additive.
- **B100**, a methyl-ester biodiesel (soy) meets the ASTM D6751 blend stock specification. This is not a finished fuel but is used to make blends such as B5 and B20. It was used in this program to accentuate the potential differences to establish trends.
- **B20CARB**, a blend of 20% B100 and 80% CARB fuel.
- **B20EPA**, a blend of 20% B100 and 80% EPA diesel.
- **B5CARB**, a blend of 5% B100 and 95% CARB diesel.

Selected fuel properties are listed in [Table 1](#).

TEST ENGINE

The test engine for this project was a 1991 Detroit Diesel Corporation (DDC) Series 60 in-line 6-cylinder, 4-stroke, direct injected, diesel engine with a 12.7 liter displacement. A listing of the DDC engine description and specifications is given in Table 2. This engine has been used in numerous fuel screening and qualification studies and has been the basis for most California Air Resources Board (CARB) alternative diesel fuel formulations in use in California [4].

Table 2. Test Engine Specifications

Engine Model Year	1991
Emissions Calibration	1991 Federal
Displacement	12.7 L
Cylinder Configuration	In-Line
Number of Cylinders	6
Induction System	Turbocharged with Charge Air Cooling
Fuel Injection System	Electronic Unit Injectors
Power Output	370 hp
Rated Speed	1,800 rpm
Nominal NO _x	5 g/hp-hr
Nominal PM	0.25 g/hp-hr

Federal emissions limits for s1991 heavy-duty diesel engines were HC=1.3 g/hp-hr, CO = 15.5 g/hp-hr, NO_x =5.0 g/hp-hr, and PM = 0.25 g/hp-hr. Emissions limit have been decreased to present levels of 0.20 g/hp-hr for NO_x and 0.01 g/hp-hr for PM, but HC and CO levels remain unchanged. Figure 1 demonstrated the evolution of the emissions regulations.

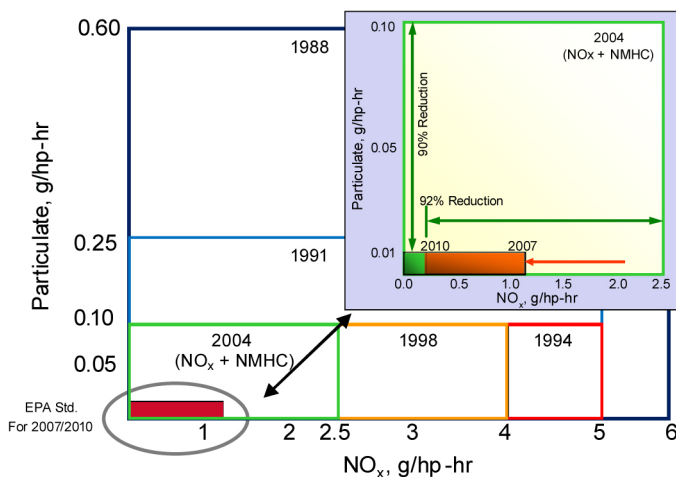


Figure 1. Heavy-duty Engine Emissions Regulations

TEST EQUIPMENT

The engine was installed in a test cell that is compliant to 40 CFR, Part 86, Subpart N [5]. Emissions were sampled and measured using a constant volume sampler (CVS) dilution tunnel that utilized a positive displacement pump (PDP). The total flow in the CVS was maintained at a nominal flow rate of 2,000 scfm. Separate sample probes for gaseous and PM emissions were connected to a common sample zone in the CVS. One probe for background air sampling was connected downstream of the dilution air inlet, but upstream of the mixing section of the CVS. A diagram of such a CVS and emissions sampling system is given in Figure 2.

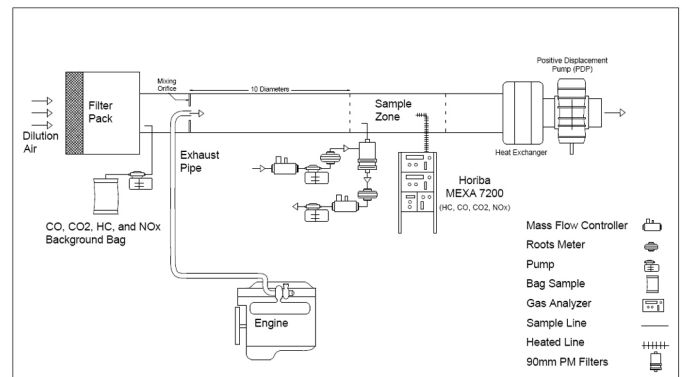


Figure 2. Schematic of Emissions Sampling System

EMISSIONS ANALYTICAL METHODS

Regulated emissions of hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), particulates (PM), along with carbon dioxide (CO₂) were measured for this project. Emissions of HC were continuously measured using a heated flame ionization detector (HFID). The entire HC sample system (sample probe, valves, tubing, and filters) were heated to maintain a sample gas temperature of 191°C (375°F). NO_x emissions were measured continuously on a dry basis using a heated chemiluminescent (CL) detector with a NO₂/NO converter. For this work emissions of CO and CO₂ were measured continuously using separate non-dispersive infrared (NDIR) analyzers.

Emissions of CO₂, HC, and CO were used to determine brake specific fuel consumption (BSFC) by a carbon balance method given in 40 CFR. Fuel flow was continuously measured using a Micromotion™ fuel meter and day tank arrangement. Gaseous emissions levels were corrected for dilution air background levels. Total particulate emissions were determined from the net weight gain of two 90 mm Pallflex® T60A20 media filters used in series. Filter face temperatures were maintained below the FTP-specified limit of 52°C (125°F) using double dilution.