AN ALTERNATIVE FUEL FOR URBAN BUSES - BIODIESEL BLENDS

Leon G. Schumacher, J. Alan Weber, and Mark D. Russell, Juergen G. Krahl,

Abstract

Qualitative and quantitative biodiesel fueling performance and operational data have been collected from urban mass transit buses at Bi-State Development Agency in St. Louis Missouri. A total of 10 vehicles were selected for fueling; 5 - 6V92 TA Detroit Diesel engines have been fueled with a 20/80 biodiesel/diesel fuel blend and 5 - 6V92 TA Detroit Diesel control vehicles have been fueled on petroleum based low sulfur diesel fuel (LSD). The real-world impact of a biodiesel blend on maintenance, reliability, cost, fuel economy and safety compared to LSD will be presented. In addition, engine exhaust emissions data collected by the University of West Virginia Department of Energy (DOE) sponsored mobile emissions laboratory will be presented. Operational data from Bi-State Development Agency is collected by the University of Missouri and quality control procedures are performed prior to placing the data in the Alternative Fuels Data Center (AFDC). The AFDC is maintained by the National Renewable Energy Laboratory in Golden, Colorado. This effort, which enables transit operators to review a real-world comparison of biodiesel and LSD, has been funded by the National Biodiesel Board with funds provided by the United Soybean Board with national checkoff dollars and the National Renewable Energy Laboratory.

Introduction

The testing of biodiesel as a fuel for diesel powered transportation vehicles has been conducted in several locations across the United States since July, 1991. Little effort had been made to systematically, qualitatively, and quantitatively collect and record vehicle performance and operational characteristics. The collection of this information is essential to the commercialization of biodiesel in the United States.

Overview and Objectives

Vehicle performance, operation, and maintenance characteristics are used extensively during the commercialization of a transportation fuel. Information concerning the use of biodiesel as a transportation fuel is needed to provide legislators and agencies the knowledge to make informed decisions that will effect market development and impact the acceptance of biodiesel as a transportation fuel for diesel engines.

Specific objectives of the project included:

1. Establish cooperative relationships and collect qualitative and quantitative vehicle performance and operational data from a mass transit district.

2. Summarize retrieved information and format appropriately for the National Renewable Energy Laboratory (NREL) Alternative Fuels Data Center (AFDC) database.

3. Transfer data (ASCII format) electronically to NREL and place in the AFDC database (monthly).

Methods and Procedures

This project involved highly controlled data collection from one mass transit agency. Data were collected and compiled by researchers at the University of Missouri (MU). Data collected from the transit properties were compiled using Paradox, a relational database, and electronically transmitted using CCMAIL to the Alternative Fuels Data Center. The AFDC is an electronic database that is operated by NREL. The AFDC contains data collected from urban transit properties that are testing alternative fuels such as compressed natural gas (CNG), liquefied natural gas (LNG), methanol, ethanol, biodiesel, and in the very near future, propane.

Site Selection

As the managing agency of the AFDC, NREL has outlined several criteria that are to be used when selecting a mass transit agency to serve as a site for controlled data collection. The selected mass transit agency must be able to supply identical or comparable buses to ensure that good control vehicles are available. Characteristics that must be similar include length, engine model, mileage, transmission, weight, year, and chassis model. The mass transit agency should have an accurate, acceptable means of recording data. Finally, NREL site selection is based on the overall ability to collect reliable data on the part of the operators and the ability to implement in-house quality assurance programs.

Biodiesel Blend Selection

Research conducted by Fosseen Manufacturing and Development (1993) suggested that the most appropriate blend when fueling the Detroit Diesel Corporation (DDC) 6V92 TA heavy duty engine was a 20/80 blend of biodiesel/diesel fuel. Based on their research, a 20/80 (%) blend (B20) was selected as the fuel of choice for the urban buses involved in this project. In their research, substituting 20 percent of the petroleum diesel with biodiesel substantially reduced the emissions of the engine while minimizing the incremental increase in fuel costs associated with biodiesel fueling.

Information Collection Procedures

Bi-State Development Agency, the regional transit agency of St. Louis, was selected as the host site for this data collection project. A total of 10 vehicles were selected for fueling: 5 - 6V92 TA DDC engines were fueled with a B20 biodiesel/diesel fuel blend and 5 - 6V92 TA DDC engines were fueled with petroleum based low sulfur diesel fuel (control group).

Visits were made to the cooperating mass transit agency to perform an initial vehicle inspection and explain both the importance of and how to accurately collect this information. All test buses are being used in normal daily service. Data were collected to determine the actual impact of a biodiesel blend on maintenance, cost, fuel economy and safety (In-service Data Collection, Table 1).

Several steps were taken to increase the quality and reliability of the information generated from this project. Unit injectors for fuel in each of the ten test buses were replaced with new unit injectors in April, 1994. At the close of the demonstration in September, 1995, selected unit injectors will be returned to DDC for examination by their analytical laboratory. Injectors were replaced to ensure that any problems that occurred could be attributed to the test conditions. In addition, each of the ten test buses were placed in Bi-State's warranty program. This in-house program allowed MU researchers to track every event that happened to the test buses. In addition, Bi-State designated one employee to oversee the implementation of the data collection program.

Data are currently being collected using Bi-State's existing operating, dispatching, maintenance, and fueling systems. The data are collected, reported weekly and forwarded to the University of Missouri Agricultural Engineering Department. Maintenance data are being coded by MU researchers according to type; scheduled, unscheduled, or road call. The work performed and parts replaced are coded using the American Trucking Association format to facilitate data entry and to allow the researchers to compare data from fleets that are testing other alternative fuels. Vehicle performance problems, route information, and safety data are being monitored by Bi-State and forwarded to MU.

Table 1. In-service data collection variables for mass transit buses recorded in the Alternative Fuels Data Center database, National Renewable Energy Laboratory, Golden, CO.

Type of Data	Frequency Recorded	Data Items
Maintenance Data	For Each Work Order	Shop Order Number
		Repair Description
		Type of Maintenance
		-scheduled
		-unscheduled
		-road call
		Labor Hours
		Date of Repair

		Odometer Reading
		Parts Replaced
		Parts Cost
		Work Done
		Removed From Service
		Date Returned to Service
Fuel Data	Each Time a Bus is Fueled	Type and Amount of Fuel
		Odometer Reading
		Date
	Each Time the Bulk Fuel Storage is Refilled	One Sample of Biodiesel and Diesel Fuel Analyzed
Oil Data	Each Time Oil is Added	Make, Type, Viscosity of Oil
		Amount of Oil
		Odometer Reading
	Each Time Oil is Changed	Make, Type, Viscosity of Oil
		Amount of Oil
		Odometer Reading
		Oil Sample
Vehicle Deficiency Report	At Each Problem Occurrence	Standard Reporting
Bus Route and Operating Cycle Data	Each Day	Daily Route Assignments for Each Bus
Safety Data	As Needed	Number and Nature of Each Accident

Fuel has been sampled and will be analyzed by Analysts, Inc. after each new shipment of biodiesel and low sulfur diesel fuel has been delivered. Engine oil samples were taken using the approved sampling methodology. The oil samples were analyzed by an analytical laboratory and recorded by MU technicians.

Vehicle operating costs, maintenance costs, initial purchase price and vehicle salvage value is being monitored for each vehicle. These data provide an accurate assessment of the vehicle operating costs in actual fleet conditions and allows comparisons with other alternative fuels.

Treatment of Data

MU researchers have utilized macros within the Paradox relational database to check discrepancies within the data. Bi-State has been consulted when any discrepancies and/or inaccurate data has been noted.

Progress of Project

Although start-up for this project was planned for November, 1993, the actual start date was delayed until April 14, 1994 (the anticipated end date is September 15, 1995). The facility selection and the selection of the test buses were made in concert with DDC and NREL. Table 2 reports the buses that were selected for fueling.

Table 2. Bi-State Development Agency bus number, fuel, and mileage after rebuild for the NREL data collection sponsored by the National Biodiesel Board and the National Renewable Energy Laboratory.

Bus Number	Fuel	Mileage after Rebuild	Kilometers after Rebuild
8441	B20	37,155	59,795
8443	B20	33,600	54,074
8452	B20	13,959	22,465
8447	B20	20,546	33,066
8449	B20	10,938	17,603
8446	LSD	33,140	53,334
8450	LSD	12,175	19,594
8451	LSD	36,830	59,272
8455	LSD	29,653	47,722
8529	LSD	57,522	92,573

Each bus selected was powered with a DDC 6V92 TA two stroke engine utilizing a turbocharger and a blower. Nine of the engines were manufactured in 1988. One engine was manufactured in 1989. Each engine was rated at 277Hp at 2100 rpm and developed 880 ft-lbs of torque at 1200 rpm. Each bus had an Allison V731 transmission, was 40' in length, had a curb weight of 27,500 pounds and a GVWR of 39,500 pounds. Each bus engine had been rebuilt and had less than 93,300 kilometers (58,000 miles) on the engine rebuild. New unit injectors were installed in all ten of the bus engines. The change-out of these injectors was done at the request of DDC. Each vehicle selected has been tracked via Bi-State Development's maintenance tracking program. Previous maintenance records have been noted and recorded for comparison purposes. The mean number of km on the buses after rebuild was 45,950 km.

Fuel economy for the buses can be observed in Table 3. The overall average fuel economy is slightly lower for the biodiesel fueled buses. The total miles driven by the diesel powered buses is approximately 18 percent higher. The biodiesel powered buses have not been driven on the week-ends and consequently have traveled fewer miles.

Table 3. Fuel economy and total miles by bus number for the National Biodiesel Board and National Renewable Energy Laboratory sponsored bus data collection at Bi-State Development Agency (1/27/95).

		Avg Fuel Economy in k/L (mpg)	
Bus Number	Blend	4/14/94-1/27/95	Total Miles
8441	B20	1.46 (3.52)	60,400 (37,539)
8443	B20	1.48 (3.56)	57,910 (35,991)
8452	B20	1.66 (3.99)	60,161 (37,390)
8449	B20	1.45 (3.49)	57,789 (35,916)
8449	B20	1.54 (3.70)	56,794 (35,298)
Total miles driven			293,054 (182,134)
Average fuel economy in k/L (mpg)			1.51 (3.65)
8446	LSD	1.56 (3.76)	74,576 (46,349)
8450	LSD	1.53 (3.69)	47,816 (29,718)
8451	LSD	1.72 (4.14)	79,859 (49,633)

8455 8529	LSD LSD	1.63 (3.93) 1.59 (3.84)	73,327 (45,573) 71,528 (44,455)
Total miles driven Average fuel economy in k/L (mpg)			347,106 (215,728) 1.61 (3.87)

The actual maintenance costs can be found in Table 4. The total costs associated with maintaining the diesel powered buses are lower than the buses that have been fueled with B20. The researchers anticipated that differences in maintenances costs could surface during the investigation. Maintenance costs, however, should be interpreted with caution due to the fact that these costs have varied much during the data collection.

Table 4. The maintenance costs for buses fueled for forty-two weeks on a twenty percent blend of biodiesel and petroleum diesel fuel. (4/15/94 -1/27/95).

Blend	Cost	Total Kilometers (Miles)	Cost/Kilometers (miles)	Cost/Month
B20	$11,661.25	293,054 (182,134)	$0.039 ($0.064)	$1,203.14
LSD	$12,177.11	347,106 (215,728)	$0.035 (0.057)	$1,256.37

Emissions Testing

In order to collect all of the data requested by NREL for this project, chassis dynamometer testing of the buses was conducted. The DOE Mobile Emissions Laboratory coordinated by West Virginia University was utilized to collect these data. Emissions tests were conducted during June of 1994 and during March of 1995. Wheel horsepower and fuel rate were recorded at rated and peak torque speed during the chassis dynamometer tests. The Central Business District (CBD) test cycle was used when collecting the data. Test results were recorded in grams per mile for the following: hydrocarbons, carbon monoxide, carbon dioxide, nitrogen oxides, and particulates. The results for the testing conducted on June 6, 1994 are reported in Table 5.

An examination of the emissions data yielded unexpected results. The PM levels did not change and the emissions of nitrogen oxides were nearly 10 percent lower when fueled on a B20 blend. If one examines the data without the data reported for bus number 8441 however, the data were more similar to data reported in the literature (Schumacher, et al, 1993). Examining the data without bus 8441 reveals a 2 percent increase in oxides of nitrogen and a 29 percent reduction in total particulate (PM).

Table 5. Mobil Emissions Testing Conducted at St. Louis, MO, June 6, 1994 as a part of the NREL - NBB - DOE funded Biodiesel data collection project. Data were collected by West Virginia University using the CBD Test Cycle.

		Grams per kilometer (mile)			
Bus Number	Blend	CO	NOx	HC	PM
8441	B20	18.3 (29.4)	9.7 (15.6)	1.0 (1.6)	1.92 (3.09)
8443	B20	7.5 (12.1)	24.5 (39.5)	1.0 (1.6)	0.40 (0.65)
8452	B20	18.3 (29.4)	23.1 (37.2)	1.1 (1.7)	0.86 (1.38)
8447	B20	14.6 (23.5)	27.0 (43.5)	1.1 (1.7)	0.54 (0.87)
8449	B20	14.1 (22.7)	24.2 (38.9)	1.2 (2.0)	0.72 (1.16)
8446	LSD	14.5 (23.3)	23.8 (38.3)	2.0 (3.2)	1.93 (3.10)
8450	LSD	21.8 (35.0)	24.7 (39.8)	1.0 (1.6)	0.80 (1.28)
8451	LSD	26.2 (42.2)	26.4 (42.5)	1.1 (1.8)	0.77 (1.24)
8455	LSD	16.5 (26.5)	25.7 (41.3)	1.4 (2.2)	0.68 (1.09)
8529	LSD	9.0 (14.5)	20.4 (32.9)	1.1 (1.7)	0.27 (0.44)
Average LSD		17.6 (28.3)	24.9 (40.0)	1.3 (2.1)	0.87 (1.4)
Average B20		14.5 (23.4)	21.7 (34.9)	1.1 (1.7)	0.87 (1.4)
% Change		-17.2	-10.3	-18.1	0.0

Engine Lubrication Oil Analysis

The used lubrication engine oil analysis data were summarized for all diesel control and B20 fueled buses. The samples were taken when each engine was serviced. Approximately 12,000 miles of operation were placed on each oil sample. The oil analysis data are shown in Table 6.

Table 6. Averaged lubricating oil analysis results of the NREL - NBB - DOE funded Biodiesel data collection project.

Category	B20	LSD	Relative Change

			from LSD (LSD=100%
Iron (ppm)	147.0	89.0	165
Chromium (ppm)	4.8	3.5	137
Lead (ppm)	14.5	19.5	74
Copper (ppm)	32.9	28.5	115
Tin (ppm)	5.9	4.0	148
Aluminum (ppm)	1.0	0.1	1000
Silicon (ppm)	17.4	19.0	92
Boron (ppm)	19.8	17.3	115
Sodium (ppm)	25.7	69.8	37
Magnesium (ppm)	555.0	559.2	99
Calcium (ppm)	995.0	1030.0	97
Barium (ppm)	3.0	3.3	91
Phosphorous (ppm)	1047.0	1053.3	99
Zinc (ppm)	1150.0	1197.5	96
Molybdenum (ppm)	1.1	1.2	92
Vanadium (ppm)	4.7	49.9	9
Viscosity at 1000 C	16.7	15.1	111
Solids % by wt.	0.7	0.7	100
Total Base Number	6.9	7.4	

Please note: The data are presented in whole numbers, the averages presented have been rounded to the tenth decimal point for comparison purposes.

Summary

The National Biodiesel Board and the National Renewable Energy Laboratory together with the University of Missouri Agricultural Engineering Department are collecting real world data that will be placed in the Alternative Fuels Data Center.

Bi-State Development Agency of St. Louis was selected as the site for a highly controlled data collection activity. Vehicles were selected and fueling began April 14, 1994. Fueling is scheduled to conclude September 15, 1995. NREL and DDC were actively involved in the site and vehicle selection process.

The buses have experienced small but observable differences in fuel economy and maintenance costs. Emergency road calls were few in number for both B20 and diesel fuel control buses. An analysis of the engine lubricating oil indicated that the wear metals normally found in the B20 fueled buses were mostly quite similar to the diesel control buses.

The emissions data collected by West Virginia University were quite similar to that found in the literature Fosseen and Goetz (1993) after examining the data without the B20 outlier. The unmodified DDC 6V92TA engines produced lower levels of carbon monoxide, hydrocarbons, and particulate matter. Slightly higher levels of nitrogen oxides were noted, however, the increase was not different from the emissions that were recorded for the diesel control buses.

Bibliography

Fosseen, D. and Goetz, W. (1993). Methyl soyate evaluation of various diesel blends in a DDC 6V-92. Fosseen Manufacturing and Development. Radcliffe, IA. (Report prepared for National Biodiesel Board, Jefferson City, MO)

Schumacher, L. G., S.C. Borgelt, and W.G. Hires. (1993). Fueling a 7200 John Deere tractor with blends of methyl ester soybean oil and petroleum diesel fuel. Proceedings of the Mid Central Conference Meeting. St. Joseph, MO. Paper #MC94-109. (40)