Final Report
Puget Sound Regional Fleet Biodiesel Fuel Study

Prepared for
Puget Sound Clean Air Agency

Prepared by
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1. Executive Summary

The Puget Sound Clean Air Agency (Agency) supports the use of biodiesel and biodiesel blends as one of several strategies aimed at reducing air pollution from mobile sources. Fleets of several local governments, including King County Metro, the City of Tacoma, and the City of Seattle currently use biodiesel blends in their vehicles. These fleets have mixed experiences with biodiesel, some reporting success with the fuel, and others reporting problems. Problems reported in 2005 include plugged fuel filters and fouled vehicle fuel pumps. These problems resulted in inoperative vehicles and required considerable financial resources and staff time.

In January 2006, the Agency contracted with Propel Biofuels (Propel) to evaluate these problems and provide high level recommendations to ensure successful use of biodiesel. Specifically, the Agency asked Propel to assess the topics of off-specification fuel, fuel contamination, and improper handling. Propel subcontracted with Washington Biodiesel to provide additional expertise to the investigation.

Propel worked with the Agency and peer reviewers to develop a process to evaluate the issues raised by three local fleets. Site visits were conducted to gather information about the fuel storage and dispensers. Fleet managers were interviewed to obtain information about fuel sourcing and distributors. Fleet facilities and fuel handling practices were assessed. Propel collected samples of fuel and fuel filters that were then sent to specified laboratories and analyzed for potential contaminants. Propel was unable to track fuel to the source (diesel or biodiesel blendstock), severely limiting our ability to determine the specific point of contamination. Because only blended fuel samples were available, this study was not able to determine if the biodiesel blendstock (B100) met ASTM specifications.

Propel evaluated three fleets in the Puget Sound area: King County Metro, the City of Seattle, and the City of Tacoma. Propel found the following:

- King County's Bellevue Base has not experienced problems in implementing and using B5 biodiesel blends. Fuel storage tanks were cleaned prior to implementing the use of biodiesel.
- King County's Ryerson Base reported problems related to B5 biodiesel blend use, including plugged dispenser and vehicle filters. Their current solution is to change filters more frequently. In contrast to King County Bellevue, Ryerson's fuel storage tanks were not cleaned prior to implementing biodiesel. Analysis of fuel and filters suggests that residual petroleum-associated sediment as well as biodiesel-associated material (glycerol, monoacylglycerols, and fatty acids) may be contributing to plugged filters.
- The B20 biodiesel blend used by the City of Seattle may have been subjected to conditions that resulted in its deterioration. Biodiesel oxidation is most commonly caused by extended residence time in an oxygenated environment, and/or exposure to high temperature. Components associated with biodiesel

(glycerol) may contribute to problems, but compounds not related to biodiesel (hydraulic fluid) may also be contributing to systemic problems.
- Problems at the City of Tacoma may be related to the introduction of a single off-specification or near-off-specification delivery of biodiesel.
- In general, fleet managers and distributors do not have a system in place to test, catalog, and archive fuel samples to allow the tracking and quality assurance of fuel from producer to end-user. Nor do they have in place a systematic approach to implementing biodiesel in their fleets.

2. Background

Biodiesel is a renewable fuel for diesel engines produced from domestically sourced natural oils like soybean, canola, other vegetable oil or animal tallow. With proper preparation, biodiesel can be blended in any concentration with petroleum diesel, and used in existing diesel engines with little or no modification. Pure biodiesel must meet the requirements of ASTM D6751. A biodiesel blend contains biodiesel fuel (meeting ASTM D6751) blended with petroleum-based diesel fuel. A biodiesel blend is designated BXX, where XX indicates the volume percentage of biodiesel fuel in the blend. Thus, B20 is a blend of 20% biodiesel and 80% petroleum diesel by volume. At present, only pure biodiesel (B100) has an ASTM specification; no specification exists for blends.

Since 2002, a number of fleets in the Puget Sound region have chosen to use biodiesel blends ranging from B5 to B20 to reduce diesel vehicle emissions. From late 2004 through 2005, operational problems arose in some fleets, including plugged fuel filters and other fuel-related issues.

About two-thirds of public fleet operators in the Puget Sound region have reported plugged filters or other problems that have forced vehicles out of service. Fleet operators have incurred increased maintenance costs, including those associated with changing filters more frequently. In response to these problems, the Agency considered methods to evaluate biodiesel issues with local transit managers. The Agency also consulted the National Biodiesel Board, the Clean Cities Coalition, and biodiesel producers and representatives from the Washington State University Energy Program. Fleet managers provided information about their fleet characteristics and suspected fuel problems. This information is presented in tabular format (*Appendix A: Puget Sound Fleet Biodiesel Experience Summary*).

This study focuses on three fleets within the Agency's jurisdiction: King County Metro (Ryerson and Bellevue bases), the City of Seattle, and the City of Tacoma. These fleets experienced similar implementation problems such as filter plugging and black slime in filter media.

3. Description of Operational Problems

In fall 2005, multiple fleets in the Puget Sound region experienced filter-plugging problems associated with biodiesel blends. Filter plugging was not occurring with

petroleum diesel fueled vehicles. Initial investigation by fleet managers, however, revealed no obvious single point of fuel contamination. Fleet managers described substances plugging fuel filters in the following ways:

- Black/dark brown slime
- Black particles
- Waxy substance
- Vaseline-like substance

Previous studies and Propel's applied experience suggest a variety of potential causes, including:

- Microbial growth in storage tanks which manifests as aerobic, anaerobic, and/or filamentous organisms
- Oxidative degradation of biodiesel
- Mono- or di-glyceride residues resulting in Vaseline-like substance in filters
- Exotic fatty acid components resulting in white precipitant at temperatures below 60˚F
- Glycerol levels exceeding ASTM D6751
- Dissolved sediments from fuel tanks and/or storage tanks due to biodiesel "cleaning effect"
- Water from tank condensation and/or out of specification fuel

4. Investigative Strategy

4.1 Overview

To document problems experienced by the three identified fleets, Propel developed an investigative strategy that addressed fuel quality, handling, and storage. This strategy provided documentation and narrative from key individuals associated directly with these issues, and consisted of:

1. Conducting site visits to evaluate fueling infrastructure, which includes storage and dispensing equipment.
2. Interviewing fleet/facility managers to obtain fuel handling and dispensing protocols and to catalog implementation problems.
3. Collecting, cataloging, and analyzing fuel samples and fuel filters associated with operational problems.

4.2 Fueling Infrastructure Evaluation

Of the four fleet facilities included in this evaluation, only three maintain on-site fueling infrastructure. Propel assessed these three sites: City of Seattle, King County Ryerson Base, and King County Bellevue Base. The City of Tacoma does not currently maintain on-site fueling infrastructure. Fueling sites were examined for points of contamination in the fuel dispenser filter system, associated dispensing equipment, and fuel storage tanks.

The equipment evaluation was conducted with a fleet representative. In each case, Propel disassembled the fuel dispenser filtration system, and examined the inner filter materials for contamination. If contamination was observed, a swab was collected into a sterile container. Propel also collected contaminated fuel dispenser filters in clean heavy plastic bags.

Please see *Appendix B: Site Evaluation and Sample Photos* and *Appendix C: Fuel and Filter Samples Index* for detailed information.

4.3 Fleet Manager Interviews

Propel interviewed fleet managers from City of Seattle, King County Metro, and City of Tacoma, obtained descriptions of fuel handling and dispensing protocols, and cataloged implementation problems. These interviews were targeted at identifying improper fuel handling procedures. Propel asked fleet managers a series of questions in the following categories:

- Biodiesel Program Description
- Fuel Supply Information
- Problem Description

Please see *Appendix D: Fleet Manager Interviews* for detailed information.

4.4 Fuel and Fuel Filter Analysis

Where possible, Propel collected fuel samples and fuel filters from affected vehicles and fuel dispenser pumps, and fuel samples from storage tanks. The fuel and filter samples were visually examined and characterized (see *Appendix C: Fuel and Filter Samples Index*). Laboratory work focused on three modalities: microbiological, qualitative, and quantitative.

Microbiological Evaluation

Under the direction of Propel, National Tribology Services (NTS) performed microbial analysis. NTS has extensive experience in oil field work and biodiesel analysis. NTS performed biological testing of the substance collected from one filter canister (Sample FS 13), obtained from the fuel dispenser at King County Ryerson Base.

Qualitative Analysis (Unknown Material Analysis)

Qualitative analysis determines the chemical composition and identity of an unknown material. Qualitative analysis was performed on materials that had separated from fuel samples, solid materials recovered from fuel filters, and on selected fuel filters.

Propel selected Chemir Analytical Services of Maryland Heights, MO, to conduct material analyses. Chemir performed identification analyses by obtaining the infrared

spectrum of the material using Fourier Transform Infrared Spectroscopy (FTIR). FTIR is an analytical technique often used to identify organic materials. The spectrum of the unknown material is searched through in-house computer-based spectral libraries, and followed by interpretation and comparison with authentic spectra. The samples were also analyzed by Gas Chromatography-Mass Spectroscopy (GC-MS). GC-MS combines two analytical techniques to identify a combination of compounds. After the components of each material were identified using these two techniques, Propel deduced the likely origin of each identified compound. After examining an identified compound's known physical properties, Propel concluded whether the material was likely to cause or contribute to filter plugging. Four fuel samples and four fuel filters were subjected to Qualitative Analysis.

Based upon preliminary discussions with Chemir, it was determined that the qualitative analysis of one sample would be difficult due to its physical nature. Therefore, the sample (FS-7) was also sent to Intertek Caleb Brett in Houston, TX for analysis.

Quantitative Analysis

Under the direction of Propel, NTS conducted quantitative analytical testing of the fuel samples. Propel selected analyses based upon the following criteria:

- Indicative of off-specification fuel or contamination.
- Applicability to biodiesel blends. Certain analyses specified by D6751 are specific only to pure B100, and are not applicable to blends.

Table 1 presents and describes analyses executed.

Table 1: Quantitative Analyses and Descriptions

Analysis	Description
Biodiesel Content	This test measures the biodiesel content as a percentage of total volume. It serves to indicate whether the fuel blending was performed accurately.
Total Acid Number (TAN)	The acid number in a biodiesel blend is used to indicate the level of free fatty acids, processing acids or degradation by-products not normally found in a petroleum-derived diesel. High acid numbers in a biodiesel blend have been shown to increase fueling system deposits and may increase the likelihood of corrosion. Increased temperatures of fuel may accelerate degradation, which could result in high acid number and increased filter plugging potential.
Moisture by Karl Fisher (KFW)	This test determines the amount of water present in the sample. Water in fuels can cause corrosion of tanks and equipment, and if detergent is present, the water can cause emulsions or a hazy appearance. Significant amounts of emulsions may contribute to filter clogging.

Cloud Point (CP)	This test determines the temperature at which small solid crystals are first visible as the fuel is cooled. CP is a conservative measurement of the limits of cold flow performance. The cold filter plug point (CFPP), the temperature at which the crystals begin clogging fuel filters, is generally more than 10^{o} lower than the CP.

TAN, KFW, and CP are all indicators as to whether B100 blendstock was within ASTM D6751 specifications. The quality of the B100 blendstock can be extrapolated from the values of the blended fuel. If these parameters are outside specification, it cannot be determined whether the fuel was produced outside specifications or whether it was mishandled during shipment, storage, or blending. Five fuel samples were subjected to these analyses. Free and total glycerin is a parameter of concern, but the test for free and total glycerin cannot be performed on blended fuels.

Please see *Appendix E: Laboratory Reports and Results* for detailed information.

5. Results and Key Findings

Investigative results presented below are organized by fleet. Results and key findings are presented in the following structure:

- Overview
- Site Information
- Fuel Information
- Preventative Maintenance
- Sampling
- Fuel and Fuel Filter Analytical Results
- Recommendations

5.1 King County Metro – Bellevue Base

Overview

Propel visited the King County-Bellevue (KCB) base on January 12, 2006, and met with Bill Kipp-Young - Chief of Vehicle Maintenance, and Mark Quenzer - Vehicle Maintenance Supervisor.

KCB began fueling transit buses with B5 in July 2005. KCB experienced no fuel filter plugging events on their transit buses when implementing B5. However, KCB also experienced some fuel filter plugging events prior to biodiesel adoption, during their conversion to Ultra Low Sulfur Diesel (ULSD).

Site Information

KCB stores fuel in XERXES double-walled fiberglass tanks. The tanks were installed in 1996, and contain small amounts of yellow metals in the siphon system. Tanks are serviced annually for leakage and overall performance. Fuel is filtered at the dispenser via centrifuge and a 5-micron filter. The filter is equipped with a flow gauge, allowing the fleet technician to monitor filter performance.

Currently, KCB's transit buses are on a regularly scheduled 12,000-mile fuel filter change schedule and are not experiencing problems.

Fuel Information

Associated Petroleum Products (APP) delivers pre-blended B5 to KCB. According to their most recent purchase order, APP is splash-blending ULSD with pre-blended B50. They are not using additives in their fuel. Propel contacted APP with a detailed questionnaire regarding their blending practices, and is still awaiting their response.

Preventative Maintenance

KCB cleans their fuel system according to the manufacturers scheduled maintenance. Accordingly, the underground tanks are not checked for debris, nor are they emptied and cleaned regularly. They do not use fuel additives to prevent microbial growth and water accumulation. They do not take random fuel samples from the delivery truck for testing. KCB reported that the fuel storage tanks were thoroughly cleaned in July 2004, prior to the introduction of biodiesel blended fuel.

Sampling

Propel inspected all refueling equipment, but did not observe any microbial growth or other abnormalities. Fuel samples were obtained from two different dispensers, and the 5-micron dispenser fuel filter was removed and packaged for analysis. The inside of the fuel filter canister was clean with no obvious debris. Mr. Quenzer also supplied two unused fuel filters and collected fuel samples from two transit buses. These samples were collected in order to compare results with King County Ryerson location.

Analytical Results

Analytical results for the fuel sample obtained from KCB (FS-1), for TAN, KFW, and CP did not suggest that the B100 biodiesel blendstock was outside specifications. Biodiesel content analysis indicated the sample was B10. This is in contrast to the information provided by King County, which indicated the sample was B5. This discrepancy is not a major concern, as the biodiesel content analysis is relatively inaccurate at blends below B10. This could, however, indicate a problem with the blending of the fuel. Since the amount of biodiesel in a B5 blend is small, however, a large variation in biodiesel content would require a major mishap in the blending process.

Recommendations

KCB in not experiencing biodiesel-related problems. Therefore, the following top level recommendations are preventative in nature and of the "best practices" category. Propel

recommends biodiesel distributors and users institute a fuel quality control program. Components of this program should include:

- Vehicle and storage equipment compatibility checklist
- Fuel testing and certificate of analysis from producer to user
- Fuel cataloging and archiving system

5.2 King County Metro – Ryerson Base

Overview

Propel visited the King County-Ryerson (KCR) base on January 17, 2006. Scott Conyne - Vehicle Maintenance Supervisor, and Mark Quenzer from KCB attended the site visit.

KCR has been fueling their transit buses with B5 since October 2004, and began experiencing fuel filter plugging in January 2005. KCR utilizes the same fuel storage/dispensing equipment as KCB, and both are supplied by the same fuel distributor. Vehicle fuel filters and dispenser filters have exhibited different problems. The vehicle fuel filters were plugged with a black particulate; the dispenser filters were plugged with an amber Vaseline-like substance. Propel examined the dispenser fuel systems, and collected samples from each.

KCR could not supply archived fuel samples or filters associated with prior problems.

Site Information

KCR stores fuel in XERXES double walled fiberglass tanks. The tanks were installed roughly 10 years ago, and last tested in January 1999. KCR has conducted tests on their storage tanks during high problem periods, but test results were negative for microbial growth or contamination. Fuel tanks at KCR were not cleaned prior to the introduction of B5. Fuel is filtered at the dispenser via centrifuge and a 5-micron filter. The filter is equipped with a flow gauge, allowing the fleet technician to monitor filter performance. KCR is replacing fuel filters at twice the recommended rate (every 6,000 miles vs. 12,000 miles).

Fuel Information

APP delivers pre-blended B5 to KCB. According to their most recent purchase order, APP is splash-blending ULSD with pre-blended B50. They are not using additives in their fuel. Propel contacted APP with a detailed questionnaire regarding their blending practices, and is still awaiting their response.

Preventative Maintenance

KCR does not regularly clean their fuel system outside the manufacturer's recommended schedule. For example, the underground tanks are not checked for ground level debris, nor are they emptied and cleaned. They do not regularly use fuel additives to prevent microbial growth and water accumulation. They do not take random fuel samples from the delivery truck or test for blend content accuracy. KCR has conducted infrared tests in

the past through their fuel distributor and Spectra Laboratories. The results were negative for bacteria, and positive for glycerol.

Sampling

Propel collected three fuel samples from each stage in the fuel dispenser process: fuel drained from the centrifuge, fuel drained from the filter, and fuel from the dispenser. Propel also removed the fuel filter from the canister and found a Vaseline-like substance on the filtration paper, and a reddish Vaseline-like substance at the bottom of the canister with black flaky particulates. A sample was swabbed from the canister and the filter was retained for analysis.

Fuel filters were obtained from two transit buses that experienced a loss of power with about 6,000 miles on each filter. Propel submitted these filters to the lab for analysis.

Analytical Results

Analytical results for KCR are summarized in Table 2. Comprehensive numerical results are included in Appendix E.

Table 2: Analytical Results at KCR

Sample #	Sample Location	Observations and Results
FS-12	Fuel sample: KCR Dispenser filter	This dispenser filter fuel sample contained a small amount of a fine black particulate. TAN, KFW, and CP analyses of the fuel from this filter did not suggest that the B100 blendstock was outside specifications. Biodiesel content analysis indicated the sample was B10. As with the KCB fuel sample, this in contrast to the information provided by King County, which indicated the sample was B5. This discrepancy is not a major concern, as the biodiesel content analysis is relatively inaccurate at blends below B10. This could, however, indicate a problem with the blending of the fuel. Since the amount of biodiesel in a B5 blend is small, however, a large variation in biodiesel content would require a major mishap in the blending process. The composition of the particulate in this fuel was not identified.
FS-13	Material Sample: KCR fuel dispenser	This sample was black sludge scraped from a fuel dispenser filter canister. NTS tested the sample for biological material but did not find any microbial growth.
FS-15	Material sample: Vehicle fuel filter swab	This sample was a semi-solid material swabbed from inside a paper fuel filter, supplied by KCR (sampling date unknown). Qualitative analysis determined this material was primarily monoacylglycerol, with typical diesel hydrocarbons and fatty acid methyl esters (FAMEs, biodiesel). The monoacylglycerol could

		contribute to or cause filter plugging. There are no samples of the B100 fuel archived, so we cannot determine if or when an off-specification fuel sample was delivered.
FS-16	Vehicle fuel filter	This sample was a transit bus fuel filter used for approximately 6,150 miles. Analysis of an extract of the filter revealed a mixture of hydrocarbons and FAMEs (biodiesel). The hydrocarbons were typical diesel fuel components and, due to their melting point, the FAMEs were not expected to cause filter plugging. A black particulate material of petroleum origin is the suspected cause of fuel filter plugging. (See Chemir Report.)
FS-22	Fuel sample: Vehicle fuel filter	This sample was obtained from the residual fuel inside a vehicle fuel filter canister. The sample separated into a clear upper layer that appeared to be blended fuel and a lower opaque black viscous layer. The black layer was determined to contain primarily glycerol (free glycerin), some FAMEs, and a relatively large amount of a large molecular weight fatty acid. The glycerol and the fatty acid could contribute to or cause filter plugging, especially in combination with particulates.

While the presence of glycerol, acylglycerols, and fatty acids in fuel is undesirable, small quantities of these materials can occur in biodiesel (B100) blendstock that meets ASTM D6751. Propel was unable to obtain archived samples to verify the specifications of the blendstock used by King County. The presence of these materials in fuel and filters could be the result of residual material that entered the fuel tanks from a single delivery of off-specification fuel and is persisting in the fuel system. However, while there is some information on the solubility of these compounds in B100, there is little or no data in the literature on the solubility of these compounds in blends. Consequently, we cannot say definitively what concentration of these compounds in B100 is acceptable when that fuel is used to make variable blends with diesel fuel.

The temperature of the underground storage tanks could impact the solubility of the glycerol, monoacylglcyerols, and fatty acids in the blended fuel. Lower temperatures results in decreased solubility and may result in precipitation of compounds from the fuel blend. Since KCB receives the same fuel as KCR, but is not experiencing similar problems, a significantly lower storage tank temperature at KCR could be contributing to filter clogging and explain the different experiences of the two sites.

The presence of particulates of petroleum origin in several of the fuel and filter samples suggests that the KCR fuel system contains considerable residual particulate material that was not removed during cleaning and is being mobilized by the solvent properties of

biodiesel blends. Particulate could also be introduced through unfiltered storage tank vents.

Recommendations

The fuel system, including all tanks, delivery hoses, and dispensers should be thoroughly cleaned of all petroleum residues. Particulates appeared to contribute to filter plugging, and considerable particulate material was observed in the fuel dispensing system. Therefore, it is likely that the origin of this material is the fuel storage system, and less likely that the vehicle fuel system is involved. Cleaning of the fuel system should also remove any residual contaminants (glycerol, monoacylglycerols, fatty acids) that may be present from the delivery of any off-specification biodiesel blended fuel.

To further investigate potential causes for the presence of glycerol, monoacylglycerols, and fatty acids in the samples, the temperature of the underground storage tanks should be examined. Fuel samples should be experimentally maintained at the temperature of the tanks to determine if precipitates form from the fuel.

A recent conversation with Mark Quenzer revealed that vents to the storage tanks are open to the environment and allow unrestricted airflow into the tanks during pumping. The air entering the tanks should be filtered and desiccated to prevent particulates and moisture from entering the tanks.

5.3 City of Seattle

Overview

Propel visited the City of Seattle's Charles Street (SEC) base on January 12, 2006. Alan Brittenham - City of Seattle Fleet Manager, was contacted via email, but was unable to attend the site visit.

SEC uses B20 in a range of non-emergency vehicles from light trucks to heavy machinery. SEC reported biodiesel-related problems in several different vehicles. Mr. Brittenham collected a number of samples beginning in September 2005. The samples consisted of fuel and fuel filters from vehicles that had experienced problems.

Site Information

SEC dispenses B20 biodiesel from the Charles Street and Ken Station fueling depots. Both sites have 20,000 gallon below ground storage tanks feeding multiple dispensers. Dispensers use a 10-micron filter. Each site receives weekly inspections by City of Seattle employees.

Fuel Information

APP delivers pre-blended B20 to SEC. According to a recent purchase order, APP splash-blends ULSD with pre-blended B50. Propel was unable to obtain purchase orders specific to the delivery of the problematic fuel.

Preventative Maintenance

SEC cleans their fuel system according to the manufacturers scheduled maintenance. Accordingly, the underground tanks are not checked for debris, nor are they emptied and cleaned regularly. They do not use fuel additives to prevent microbial growth and water accumulation. They do not take random fuel samples from the delivery truck for testing.

Fuel and Filter Analysis Results

Analytical results for SEC are summarized in Table 3. Comprehensive results are included in Appendix E.

Table 3: Analytical Results at SEC

Sample #	Sample Location	Observations and Results
FS-3	Fuel sample: Vehicle TRK 33650	The fuel sample obtained from vehicle TRK 33650 has a relatively high TAN. If all of the acid in the blend were contributed by the biodiesel, the TAN for the B100 would have been 0.70 mg KOH/g. While this is within current ASTM specifications (0.80 mg KOH/g), it would not meet the recently passed specification (0.5 mg KOH/g) that should go into effect in the next few months. The high level of TAN could be the result of exposure of the fuel to environmental conditions that may have caused deterioration. KFW and CP gave no indication that the B100 sample was out of specification for these parameters. The biodiesel blend was determined to be B20, consistent with information provided by SEC.
FS-4	Fuel sample: Ken Station storage tank	TAN, KFW, and CP analyses of the fuel did not suggest that the B100 blendstock was outside specifications. The biodiesel blend was determined to be B20, consistent with information provided by SEC.
FS-5	Material sample: Vehicle fuel filter swab	This sample was a yellow liquid recovered from a vehicle fuel filter cartridge. Analysis determined that the material contained glycerol, FAMEs (biodiesel) and FAME oxidation products. Glycerol can contribute to or cause filter plugging. The presence of the FAME oxidation products suggests that the fuel was subjected to extreme environmental conditions that cause deterioration of the biodiesel fuel. FAME oxidation products can also contribute to or cause filter plugging.
FS-7	Material sample: Vehicle fuel filter	A white semi-solid removed from the filter of a vehicle was found to be a mixture of hydrocarbons

	swab	and FAMEs. The material also contains a diester (Bis ethylhexylhexandioate), a compound used as a plasticizer, as well as in hydraulic fluid.
FS-24	Fuel sample: Vehicle #06645	Analysis revealed a mixture of hydrocarbons and FAMEs (biodiesel) that is not suspected of causing filter plugging.

Recommendations

City of Seattle fuel and filter analysis revealed the presence of FAME oxidation products in a single fuel sample, and another fuel sample with high TAN. These results suggest that the biodiesel utilized by SEC may have been subjected to extreme environmental conditions that resulted in deterioration of the fuel. Biodiesel oxidation is most commonly caused by long residence time in an oxygenated environment, and/or exposure to high temperature. It is not possible to determine at what point in the fuel distribution or use chain the deterioration occurred or whether the deterioration occurred after the samples were obtained or during their storage. This fact supports the necessity of a system for sampling and sample retention by distributors to allow better tracking of potential problems.

The presence of possible hydraulic fluid in sample FS-7 is unexplained. Hydraulic fluid is not an ASTM certified diesel fuel. Further vehicle fuel system analysis is recommended.

Propel recommends City of Seattle institute a fuel quality control program. Components of this program should include:

- Vehicle and storage equipment compatibility checklist
- Securing and cataloging of the certificate of analysis from the B100 producer
- Field testing of delivered B100 (field tests are now available that allow for a rapid and relatively inexpensive testing for the most important fuel parameters)
- Institution and maintenance of a fuel cataloging and archiving system

In addition, the fuel system, including all tanks, delivery hoses, and dispensers should be thoroughly cleaned of all residues. The FAME oxidation products that appear to be contributing to filter clogging may be persistent in the system and will continue to contaminate until removed. Cleaning of the fuel system should also remove any other residual contaminants (glycerol, monacylglycerols, fatty acids) that may be present from the delivery of any off-specification biodiesel blended fuel.

5.4 City of Tacoma

Overview

Propel evaluated the City of Tacoma (TAC) service facility on January 19, 2006, with Senior Vehicle and Equipment Shop Supervisor Jon Edick.

TAC uses B20 in their solid waste truck fleet. TAC experienced biodiesel-related fuel filter plugging problems over the past 14 months, and as a result has accumulated more than $6,000 in unscheduled vehicle maintenance costs. At the onset of problems TAC began using 2-micron fuel filters. Although TAC has experienced a high frequency of problems, the majority of the fleet has not been impacted simultaneously.

Site Information

TAC does not maintain a fueling infrastructure. Rather, fuel is delivered weekly to the vehicles using a method called wet-hosing. The term "wet-hosing" is commonly used to describe fueling vehicles directly from a tanker truck. This technique is employed to rapidly refuel vehicles while they are not in service (often overnight).

Fuel Information

Petro Card delivers pre-blended B20. Fuel is produced by West Central Soy of Ralston, Iowa.

Preventative Maintenance

TAC collects random samples upon fuel delivery. These samples are analyzed by the fuel distributor if problems arise. In the past, this analysis has confirmed off-spec B100 blendstock.

Sampling

Jon Edick supplied a fuel and fuel filter sample from a solid waste truck that stopped running January 19th, along with a sample of the same fuel from the distributor's delivery tank. The solid waste truck fuel sample contained a large amount of black sludge.

Analytical Results

Fuel sample FS-19 was obtained from a vehicle fuel tank. A black viscous layer settled to the bottom of the sample container. Analysis of the black viscous layer showed it to be primarily monoacylglycerol and a high molecular weight fatty acid (eicosanoic acid) with a small amount of FAMEs. Both the monoacylglycerol and the fatty acid have relatively high melting points (63–68^{o}C) and (74–76^{o}C) respectively, and could contribute to or cause filter plugging.

As in the case of King County, although monoacylglycerols and fatty acids are allowable components of biodiesel, their presence is undesirable. Whether the separation of these components from the blended fuel is the result of using off-specification B100, mishandling of fuel, inappropriate blending techniques, or a combination of these, cannot be determined from these analyses.

Follow-up conversations with TAC's fuel distributor indicated the problem was identified as a suspect batch of B100 and possible fuel filter element incompatibility.

Recommendations

The City of Tacoma is working closely with Vince McBroom of SC Fuels to identify potential fuel quality problems. Propel recommends TAC continue to work with their distributor to identify potential biodiesel issues.

Propel recommends City of Tacoma institute a fuel quality control program. Components of this program should include:

- Vehicle and storage equipment compatibility checklist
- Securing and cataloging of the certificate of analysis from the B100 producer
- Field testing of delivered B100 (field tests are now available that allow for a rapid and relatively inexpensive testing for the most important fuel parameters)
- Institution and maintenance of a fuel cataloging and archiving system

6. General Recommendations

1. Biodiesel distributors and fleet users should implement a systematic approach to biodiesel handling and use. Examples of best practices include the National Renewable Energy Lab's *Biodiesel Handling and Use Guidelines* and the National Biodiesel Board's BQ9000 standards for biodiesel manufacturers and distributors. Outside experts are available to implement these programs in partnership with fleets and their fuel suppliers. A comprehensive biodiesel program should include the following components:

- Biodiesel Users
    - Set biodiesel project baseline objectives and implementation benchmarks
    - Educate drivers, mechanics, and fleet managers
    - Evaluate all vehicles and fueling equipment prior to program start
    - Establish fuel supply that meets BQ9000 or equivalent standards
    - Monitor vehicles and fuel for common indicators of problems
    - Review results and compare to other biodiesel projects for keys to success

- Biodiesel Distributors
    - Adopt BQ9000 or equivalent handling processes
    - Implement a sampling and testing program at point of receipt
    - Purchase fuel from reputable biodiesel producer supplying a Certificate of Analysis
    - Ensure that storage and distribution tanks meet quality specifications
    - Retain samples of B100 biodiesel at points of distribution
    - Follow proper blending practices for biodiesel blends
    - Retain samples and test results for blended fuel

2. This study found several samples that contained glycerol, monoacylglycerols, and fatty acids. As mentioned previously, these are minor components of biodiesel and the amount of these components allowed in B100 is delineated in the ASTM specifications. Limited data are available, however, on the solubility of these

compounds in biodiesel blends. Consequently, levels that may be acceptable in B100 may not be appropriate for blended fuel. Since these compounds could contribute to implementation and use problems, Propel recommends that specific studies be undertaken to determine the allowable level of these compounds in biodiesel blends.

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