

Appendix B: WSF 2004 Biodiesel Pilot Test Report

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Washington State Ferry Biodiesel Project (Task II A)

Report of Findings from 2004 WSF Biodiesel Pilot Test

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Summary

In the second half of 2004 and in the first quarter of 2005 Washington State Ferries ran three of its vessels with a biodiesel blend as part of its “Clean Fuel Initiative.” The trial was suspended in December 2004 because of “product quality issues” that manifested themselves as clogged fuel filters and purifiers. The trial was restarted in March 2005, only to be terminated again due to similar issues. Though not well documented, the WSF trial produced anecdotal evidence that biodiesel blends may not be a direct substitute for petroleum based diesel fuel in vessels.

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Timeline

July 17, 2004 – *Issaquah* takes first load of B20

August 16, 2004 – *Tillikum* takes first load of B20

August 17, 2004 – *Klahowya* takes first load of B20

Within the first 24 hours, each vessel experiences and reports fuel issues. Problems are thought to be related to start-up issues, “e.g., biodiesel cleaning the fuel lines, etc.”

- Milky white gelatinous substance discharge from fuel purifier
- Racor filters have black substance in them
- Racors need to be changed twice daily (normally 4 to 6 months between changes)
- On-engine fuel filter runs black when drained
- Boiler filter (no pre-centrifuging) is caked black between filter pleats

Vessel Reports

September 27, 2004 – Chief Engineer on *Tillikum* reports serious concerns over filter consumption. Suspects “bugs” (microbial action in the fuel). Treated tanks with “Biobore.” Found some water when he bottom drained tanks. [Note: *Tillikum* was out of service more than two weeks after taking on a fresh load of B20. Long “dwell time” was thought to have contributed to the issue.]

September 30, 2004 - Chief Engineer on *Tillikum* requests authority to run two loads of 100% low-sulfur diesel in an attempt to “clean up” his fuel system. Request appears to have been granted, but the results are not documented. Fuel supplier, Reinhard, notified.

December 9, 2004 – Problems continue aboard WSF vessels. Troubleshooting discussions begin between WSF, Pacific Northwest Energy (PNWE – the local distributor of biodiesel products), Reinhard Fuels (Reinhard – the transportation contractor).

December 10, 2004 – PNWE representative suggests that product quality from his supplier, West Central Soy (WCS) may be an issue. West Central is engaged in the troubleshooting discussion.

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Mid-December, 2004 – Biodiesel trial on WSF vessels suspended.

December 22, 2004 – Meeting onboard *Tillikum* including vessel's chief engineer, and representatives from PNWE and WCS. WCS representative took possession of a filter sample and purifier sludge sample.

January 2005 – Representatives of WCS and PNWE as well as independent experts and proponents of biodiesel fuels meet with WSF. Discussions on possible causes and solutions continue throughout the month. Blending of bio and petro emerges as a target for improvement. Decision made to use B20 blend again when trial recommences.

January 30 to February 2, 2005 – WSF representatives attend National Biodiesel Board annual conference. Sidebar meetings with concerned parties produced new "Quality Control Measures for Transporting, Handling and Blending Biodiesel."

March 1, 2005 – *Tillikum* takes first load of B20 with new procedures in place. By 10:00 the same morning, pressure differentials in filters are already increasing. Chief engineer reports that he expects to have to change filters within the next 6 or 7 hours.

March 3, 2005 – *Tillikum* takes second load of B20.

March 4, 2005 – 18 filter changes in the first three days. Filters are black as before. Fuel purifier shows signs of brown sludge, but not as bad as before.

March 10, 2005 – 30,000 gallons of B20 received in total on March 1st, 4th and 8th. 34 filters used in 8 days of operation. In 2 months during which the vessel operated on low sulfur diesel, no Racor filters were changed. The purifier does not seem to be as dirty as in the first trial.

March 22, 2005 – Filter change-outs continue at the rate of about 4 per day. Purifier requires service (cleaning) once every two days.

March 28, 2005 – Decision is made to terminate Biodiesel trial on *Tillikum*.

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Vessel Preparation

In preparation for the fuel trials, WSF maintenance personnel:

- Cleaned all vessel fuel storage and service tanks. The exact cleaning protocol that was used is not known. The cleaning process apparently used only pressurized water without organic solvents and then wipes down by hand before loading the fuel. It is also not known how much water was used per tank, nor were any observations and/or tests made after cleaning to determine the level of cleaning achieved.
- Inspected all fuel lines. Natural rubber components were replaced. It is not known what materials were used to replace them.

Conclusions & Recommendations

1. The cleaning methods and protocols should be documented and reviewed.
2. The materials that were used in place of natural rubber should be identified and reviewed for compatibility.

Fuel Acquisition and Blending

Procurement

WSF worked with the Office of State Procurement to write specifications for biodiesel and procure it through existing state fuel contracts. The basis of the biodiesel specification was ASTM Standard D-6751-02, the Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels. It should be noted that including the suffix “-02” in the specification is inappropriate. It indicates the year of the revision to the Standard. This standard, in particular, has undergone several updates since its introduction as a product specification in 1999 and as a standard specification in 2002. The procurement specification should instead refer to “the most recent revision of ASTM Standard D-6751.”

Blending

Initially, it was reported that blending took place onboard the vessels. Reportedly, B100 was loaded onto the vessel in the approximate quantity necessary to produce a B20 blend. Diesel fuel was then loaded on top. The initial blending procedure was modified after problems were

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reported, and fuel was blended in delivery trucks. Beginning in October 2004, trucks were loaded first with biodiesel, then with low-sulfur petrodiesel at a fairly high flow rate (400 GPM bottom loading) to encourage mixing. The two constituents were added in the quantities necessary to produce a B20 blend.

Based on B100 product quality concerns, a “cold-filtering” step as rail cars were being loaded may have been added before the trials recommenced in early 2005. Details of this process are unclear.

B100 blend stock (100% virgin soy) was purchased from a supplier in Iowa, West Central Soy. It was loaded at (100 degrees F) onto 25,000-gallon rail cars belonging to the supplier. Cars were reportedly “cleaned with biodiesel prior to loading.” No specific information was presented on whether the tank cars were insulated. It is presumed that the cars were not insulated, since it was reported that, upon arrival at the distributor’s facility in Tacoma, “rail car is unloaded to shoreside tank. Tank is heated to 100 degrees F.”

Additional Discussions and Troubleshooting

A round table discussion took place during a biodiesel conference in early 2005 by the entire team. The results were summarized as follows:

- The blended fuel seen onboard may not have been B20. There is a suspicion that at times, mixtures as high as B60 may have been passing through the vessel’s fuel system.
- Sterols may have been precipitating out during rail transportation of B100 from the Midwest. The process is believed to occur when temperatures drop below 45 or 50 degrees F. Precipitates will not re-dissolve even when heated.
- Results of laboratory analysis of samples from the WSF fuel purifiers were not available.
- Issues of incompatibility of biodiesel and “yellow metals” may have been overstated. Yellow metals are presumably brasses and bronzes.

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Conclusions & Recommendations

1. Revise the biodiesel fuel specification to drop the suffix and invoke the most recent revision.
2. Design laboratory blending tests that can identify any propensity of the fuels to separate or stratify after blending, particularly when subjected to temperature changes or mechanical purifiers (see additional discussion in “Filter/Purifier Problems” section).
3. Establish whether the precipitation of sterols at cold temperatures is a reversible process, either through literature searches or laboratory experiments.
4. Document and evaluate the effectiveness of cold filtering process. If the process removes anti-oxidant characteristics of the blend, determine how this can affect storage and use aboard vessels.

Filter/Purifier Problems

During the onboard trials, both spin-on filters (presumably of the paper element type) and mechanical separators (centrifugal and coalescing style) became clogged with contaminants described alternately as:

- Milky white gelatinous substance
- Butterscotch pudding
- Black grainy material with a grease-like texture

It is difficult to believe that these three descriptions could apply to the same substance. While the first two could describe an oil-in-water emulsion, the last one does not. There is an indication that one or more of the substances found clogging filters was subjected to laboratory analysis. An unsigned document dated May 12, 2005, titled “Analysis results for samples sent by Tina Stolz from fuel separators on Washington State Ferries” was reviewed. It indicated that the black grainy substance, believed to have been collected from a centrifugal separator, exhibited high water content and high iron content reported by the University of Idaho.

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The centrifugal separator (purifier) is designed to separate water and solid contaminants from the fuel by relying on differences in densities and centrifugal force (up to 10,000 times that of gravity). It is unclear whether such a device could create unintended effects, such as:

- Emulsification (rather than separation) of free water with the biodiesel component (due to its higher hygroscopic nature than diesel), or
- Separation of insoluble components from the blend fuel.

Conclusions & Recommendations:

1. The theory of operation of the centrifugal separator must be better understood before concluding that the water content is high. Gross separation of water and oil occurs in the purifier bowl, where the sample was extracted. It is better to know how or when separated water is ejected from the purifier bowl.
2. The accelerated separation effects caused by the centrifugal separator must be taken into account when identifying any propensity of the constituents of B20 to separate or stratify after blending.
3. The possibility that the purifier could be inadvertently adding the mixing energy necessary to create hard emulsions of biodiesel and water should be investigated.
4. The high iron content may indicate that the corrosive and solvent behavior of biodiesel is effectively “leaching” the iron out of the steel tanks. Evaluate the effect of biodiesel blends on uncoated steel. The effect of varying amounts of sterols in solution should also be investigated.

Guidance Received from Bio Industry

WSF attended a biodiesel conference sponsored by the National Biodiesel Board during the winter of 2005. Much of the information gathered there, which included meetings with the Bio supplier in Iowa -- West Central Soy -- focused on the temperature extremes during transport. These led to the formulation of improved handling procedures that were invoked before the trial recommenced in March 2005.

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Corrective Measures Attempted

In addition to the improved blending techniques and the addition of cold-filtering as described above, the following additional corrective measures were undertaken during the trial.

- B100 was loaded at a higher temperature (110F vs. 100F) into insulated (vs. un-insulated) rail cars for transport to Tacoma. The first load shipped in this manner arrived at a temperature of 60 °F.
- Rigorous testing of B100 was invoked upon arrival of the rail car, including tests, "...for water and sediment, swirl test, spin test and acid number." The results from these tests must pass the requirements of the ASTM D6751 standard specification.
- Sampling of the B100 as it is loaded on the tank truck "will be retained for testing later as required." It is unclear if these samples have indeed been retained.
- A second filtering as B100 is loaded on the tank truck was considered. It is unclear whether this was actually done. This filtering step is required to assure B100 quality before blending.
- A sample of B20 was to be pulled from the middle of a truck compartment at random, and retained for future testing. It is unclear whether these samples were indeed retained and analyzed. Some discussion indicates that the delivery company failed to execute the sampling program. The delivery company seems not to have another filtering mechanism to remove any possible insoluble species produced during the fuel blending.

Conclusions & Recommendations:

1. Ascertain whether these improvements were undertaken. If they were, attempt to discern where and when.
2. Identify the B100 tests conducted upon arrival of the railcars in Tacoma and secure the reports therefrom. Determine whether the information so derived can provide an indication of the nature and source of the filter-clogging episodes.
3. Locate the B100 and B20 samples that were gathered, if any, and take possession of them for cataloguing and analysis.

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Fuel Tank Residues

In June 2005, several months after the second biodiesel trial onboard *Tillikum* was aborted, the opportunity presented itself to inspect the fuel tanks. “There was a brownish slime in way of the water contact area in the bottom turn of the bilge. The rest of the tank appeared clean with a slight rust bloom on the tank top.” This was alternately described as “a brown slime below the normal waterline and dry brown patina above.” These two descriptions are consistent with one another.

The deep fuel tanks on the ferries are “single skin tanks” meaning that a tank boundary is the hull of the ship. A part of that boundary is submerged in seawater, while another part is exposed to air, direct sunlight, and spray, leading to a very broad range of surface temperatures.

A sample of the brown slime scraped from the filters was delivered to the University of Idaho for analysis. The results exhibited high water content and high iron content in the sample.

Conclusions & Recommendations:

1. The results of the sludge analysis, if any, should be captured.
2. The range of surface temperatures should be established and reviewed as one environmental parameter affecting the properties of the fuel blend.
3. The “rust bloom” should be investigated and explained.

Guidance Received from Engine Manufacturers

The Detroit Diesel policy on the use of biodiesel blended fuels is vague. Their Engine Requirements document Paragraph 5.1.4 states, “Biodiesel meeting ASTM D 6751 specifications can be blended up to 20% maximum by volume in diesel fuel. The resulting mixture must meet the fuel properties listed [in a table describing the attributes of acceptable diesel fuel].” This statement would lead one to believe that B-20 is an acceptable fuel. Unfortunately, the statement

is immediately followed by the disclaimer, “Failures attributed to the use of biodiesel will not be covered by Detroit diesel product warranty.”

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They elaborate further by offering a quote from a document referred to as *World Wide Fuel Charter – Draft for Comments – June 2002, page 46*, “... for reference and guidance: ‘Based on the technical effects of FAME [Fatty Acid Methyl Esters], it is strongly advised that FAME content be restricted to less than 5%. As a pure fuel, or at higher levels in diesel fuel, the vehicles need to be adapted to the fuel, and particular care is needed to avoid problems.’”

So, it would appear that Detroit Diesel is acknowledging the existence of B-20 as a motor fuel, advocating the use of blends not greater than B-5, and accepting no responsibility for honoring engine warranties for engines burning biodiesel. However, engine manufacturers all have similar warranty statements relating to fuels. Since they do not sell fuels, they do not take responsibility for problems caused by the fuel – it doesn’t matter whether the fuel is diesel fuel or biodiesel. Engine manufacturers will also honor warranties for problems that relate to the parts and assembly of their engines. The fuel you use does not affect this unless the fuel is the cause of the problem – then it is the fuel supply problem. So, it is not reasonable to expect a statement from Detroit Diesel that they will honor their warranties on a specific fuel. The companies will make recommendations about fuels but this does not relate to warranties

Detroit Diesel’s former sister company, Electromotive (or EMD), takes a slightly different tack in its Maintenance Instruction on fuel recommendations. “EMD does not approve or prohibit the use of biodiesel fuels or biodiesel blends with distillate fuels.... If a failure arises as a result of using a specific fuel, it will be the responsibility of the fuel supplier and/or the customer to accept the costs incurred.” The instruction then goes on to offer some “recommendations” which appear to be more akin to warnings, “for those customers considering the use of biodiesel fuels.”

They point out that biodiesel may have:

- Lower energy content (BTU/unit)
- Hygroscopic characteristics
- Poor lubricity
- Poor stability
- High viscosity at low temperatures
- Varying compatibility with elastomers in use in vessel fuel systems
- A tendency to encourage microbial growth

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Advice received by WSF from GE Transportation quotes from the Engine Manufacturers Association guidance: “Though similar to conventional diesel fuel, biodiesel and biodiesel blends can cause engine performance problems such as injector tip plugging, severe coking, piston ring sticking, or catastrophic engine lubrication degradation.”

It should be noted that all engine warranties only cover hardware and never cover damage caused by fuel. Also, it should be noted that the information presented as guidance available at the time of the trials is outdated and in some cases inaccurate. Any conclusions being drawn at this point in time for use going forward should take into consideration the most current statements of the original engine manufacturer.

Anecdotal Results of Marine Trials

Despite all the negativity surrounding the engine manufacturers’ company line, a distributor chose to forward a testimonial to WSF from American River Transport Company (ARTCO), who ran a trial in one of its boats over a 14-month period in 2002-03. The boat was equipped with EMD main engines and a Detroit Diesel auxiliary. The only difficulty encountered during the ARTCO trial was a plugged “spin-on filter” that had to be changed shortly after the start of the test. This was attributed to the solvent properties of the biofuel.

Detroit Diesel also chose to share some information from a trial at the Channel Islands National Park. The conclusions were that oil change intervals had to be shortened and that fuel lines “deteriorate in 10-12 months from the inside out.”

Conclusions & Recommendations:

1. The engine manufacturers of most interest to WSF have NOT approved the use of biodiesel blends for fuel. Engine manufacturers don’t approve or disapprove fuels. All fuels are used at the vessel owner’s and the fuel supplier’s risk. The engine manufacturer is only responsible for the hardware. The use of biodiesel blends will be at the vessel owner’s risk. This may become an issue in any new building or repowering programs that WSF may undertake.

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2. There is no information in either of the trials (for which engine manufacturers offered anecdotal performance data) that fuel systems included mechanical fuel purifiers, such as centrifugal separators or plate coalescers. The absence of mechanical purifiers should be confirmed.

Speculations as to Possible Reasons for the Clogging Problems

A combination of factors may have contributed to formation of clogging materials resulting in the clogging problems in the 2004 test. The possible factors for the problems are discussed below. The following discussions, however, remain speculative.

- *High impurity contents in the B20 blend*

The impurities in biodiesel, such as glycerin, glucosides, sterols, and monoglycerides, at high levels may form precipitates when biodiesel blends with petroleum diesel, resulting in filter clogging problems. In addition, low temperatures in the marine environment could enhance the formation of the clogging precipitates.

- *High water content in the B20 blend*

Biodiesel has more polar property than diesel because of the presence of 11% wt oxygen. During its operation process, the polar B20 may absorb moisture under the marine environment through condensation, causing the B20 blend to be “out of spec” for water content. Excess water in the biodiesel or B20 blend in a metal storage tank may lead to corrosion and high sediment levels having high metal content, causing filter clogging.

- *Biodiesel oxidation*

Oxidation stability is one of the most important properties of biodiesel. Because of its chemical structure, biodiesel is sensitive to oxidative degradation which results in the formation of corrosive acids and deposits. The oxidative reaction could have occurred during the 2004 WSF test due to the Northwest environmental conditions and the WSF vessel structure. High temperatures during the operation could enhance the biodiesel oxidation.

- *Incomplete tank cleaning*

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Pure biodiesel and biodiesel blends have excellent solvent properties. The use of petrodiesel, especially #2 petrodiesel, leaves over time a deposit in the bottom of fuel lines, tanks, and delivery systems. Biodiesel could loosen or partially dissolve these sediments, and thus lead to the need to change filters more frequently when first using biodiesel until the entire system has been cleaned of these sediment deposits. In the 2004 fuel test, incomplete cleaning could have occurred since only water was apparently used during the cleaning process. As previously discussed, there seem not to have been any criteria and/or tests to ensure completed cleaning during the 2004 test.