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Washington State Ferry Biodiesel Project (Task II B)

Report of WSF Fuel System Environmental Process and Compatibility Evaluation

Submitted by

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Summary

The physical, chemical, and biological environments of the Washington State Ferry (WSF) fuel system may impact biodiesel fuel quality. This report will specify the fuel quality requirement in terms of important environmental parameters, procedures, and assessment results regarding compatibility of the vessel environment with respect to these parameters. The environmental parameters were identified and measured conditions to which biodiesel fuel is subjected aboard WSF vessels. Physical parameters include temperature, moisture level, storage time; chemical parameters include exposure to oxygen, tank materials, possible deposition at the fuel tank surface and at the tank bottom, quality of hose and other materials in the fuel line system; and biological parameters include bacterial and mold growth.

The material compatibility survey is intended to determine whether the WSF test vessel(s) fuel systems are compatible with extended operation on biodiesel and blended biodiesel fuels. The

survey includes an assessment of hoses, equipment and equipment components for materials incompatible with biodiesel or biodiesel blends. It also identifies equipment and equipment components that may experience accelerated wear, especially at higher biodiesel blend ratios.

1. Environmental Parameters inside the WSF test Vessel Fuel Systems

The extreme ranges of temperature, humidity and pressure in the fuel system were examined. The section below summarizes the findings for each parameter as well as other important environmental parameters.

1.1. Temperature influence

Fuel temperature varies in the WSF system, which may affect the biodiesel properties and quality. Some impurities in B20 biodiesel, such as plant sterols, could become insoluble due to their low solubility at low temperature. On the other hand, biodiesel could be oxidative at high temperatures, leading to the formation of other insoluble species in the fuel. These insoluble species could lead to filter clogging. It is important to understand the temperatures which the biodiesel blended fuel is exposed to in the WSF fuel system, as described below.

a. Fuel storage. It is just as important to monitor the temperature of the ullage (air) space in the tank above the fuel as it is to monitor the temperature of the fuel itself. A time history of both parameters would be helpful in understanding how (or whether) condensation forms.
b. Bunkering event. There may be rapid cooling of the relatively warm fuel oil when it is transferred from the tank truck to the vessel storage tanks. It is interested in whether this rapid cooling might promote precipitation within the biodiesel formulation.
c. Fuel service. Not all fuel oil that is delivered to the engines is consumed. Some is returned as hot oil to the fuel oil day tank by way of a fuel oil cooler. The effect of this significant heating and cooling cycling of the fuel formulation should be understood.
d. Measurement.

    i. Access to fuel tanks is limited to fill tubes, sounding tubes, and fuel transfer connections, none of which may be suitable for taking accurate fuel temperature readings at different depths in the tank. This may require removal of a manhole to hang special instrumentation (explosion proof or spark ignition protected) for accurate readings.

ii. Ullage space temperature measurement would similarly require removal of a manhole to hang special instrumentation for accurate readings.

iii. Tank skin temperature can be measured with infrared heat guns, with compensation for opacity and material of the measured surface. Outside tank temperature measurement will be more difficult.

iv. Service piping temperature can be measured with standard temperature gauges or heat guns.

The fuel may see temperature extremes ranging from 40 °F to 120°F.

The lower temperature extreme represents the lower of seawater temperature in contact with the vessel's tank (46°F[1]) or the lowest ambient air temperature in the engine room, where the day tank is located (estimated to be 40°F).

The upper temperature extreme is the higher of the highest ambient air temperature in the engine room (105°F) or the temperature of the diesel fuel returning to the day tank from the engine (estimated to be 120°F).

Fuel temperatures were measured aboard ***M/V Tillikum*** in normal operation on September 17, 2008. Conditions would be similar for ***M/V Klahowya*** (sister vessel), but not necessarily for ***M/V Issaquah*** (different engines and fuel system design).

Conditions were as follows:

- Ambient air temperature: ~ 55°F,
- Engine room air temperature: ~92°F
- Day tank fuel temperature: ~95°F
- Fuel return temperature (off engine): ~105°F

[1] Source: NOAA/NOS Seawater Temperature data collected between 1993 and 2003 at Tacoma, Seattle, Port Townsend and Friday Harbor. Extreme low seawater temperatures were consistent among the four reporting stations.

From discussions with the crew, likely temperature ranges would be:

- Ambient air temperature: ~ 40-85°F,
- Engine room air temperature: ~90-105°F (manually controlled ventilation rates)
- Day tank fuel temperature: ~95-110°F (~+5°F over compartment temperature)
- Fuel return temperature (off engine): ~105-120°F (~+15°F over compartment temperature – but a function of engine load)

Recommendation: No additional temperature measurements are required unless laboratory trials dictate otherwise.

1.2. Moisture levels

Higher levels of moisture in fuels may exist in marine ferry conditions than in land-based conditions. Moisture condensation in biodiesel fuel, particularly during rainy periods, may occur because biodiesel has an affinity to water. The biodiesel standard specification limits a certain level of water content. The biodiesel may be out of spec if high levels of condensed moisture are present in the fuel. Thus, the moisture is considered as a negative factor for biodiesel applications in marine conditions.

Moisture condensate eventually settles to the bottom of the fuel tank, and is typically drained by operating personnel to a slop tank. Fuel suction/delivery lines are purposely placed several inches above the bottom of the tank to minimize the amount of water delivered to the fuel system.

Water can also be introduced in the fuel at the air/oil interface. Biodiesel blends may have an affinity for absorbing free water at the oil/water interface. Thus condensation is likely to be a contributing factor to the increased moisture content. It is important to understand that marine vessel tanks “breathe.” They are open to the atmosphere through vent pipes. As the tanks are filled and emptied, they expand and contract due to the diurnal cycle, and fuel vapor and humid air are exchanged. As a result, the water vapor in the ullage space is constantly being replenished. Knowing the relative humidity of the air in the ullage space of the storage and day tanks as a function of time may be important in understanding the rate at which water vapor is absorbed by the fuel. Research shows that moisture absorption into biodiesel is a very fast process. High moisture levels may be absorbed by biodiesel at high temperatures and water would then precipitate out once the temperature drops.

As with temperature, humidity measurement in the ullage space would require removal of a manhole to install instrumentation.

Relative humidity will range up to 100%. Ambient temperatures of atmospheric air drawn into fuel tanks will range from 23°F to 85°F.[2]

The fuel tanks aboard WSF vessels are vented to the atmosphere. Because of the proximity of the tank vents to the seawater surface, the air in the ullage space above the fuel in all storage and day tanks can be expected to range close to 100% relative humidity. Air temperature in the ullage space can transit the dew point one or more times during a day's operation. Passing the dew point as temperature decreases will cause water vapor to condense inside the tank. This can be a localized phenomenon around steel boundaries in contact with cool seawater, or it can be more generalized, with the formation of "fog" in the ullage space.

Recommendation: No additional humidity monitoring is recommended unless laboratory trials dictate otherwise.

1.3. Pressure

Another parameter is pressure -- including pressure in both transfer and service systems. The pressure may change abruptly during operation. Another parameter is process kinetics, including centrifuge, pumping, and pipe turbulence impacts.

Fuel may experience pressures ranging from a 5 psi vacuum to 50 psi positive pressure.

[2] Source: ASHRAE 1997 Fundamentals, Outside Air Temperatures at 99.6 percentile

Fuel pressures in the storage tanks will be atmospheric. Fuel pressures in the piping will range from about a 5 psi vacuum on the suction side of the transfer pump (or engine fuel pump) up to about 50 psi on the discharge side of the transfer pump. These are the pressures likely to be seen by fuel returning to the tanks from the engine(s) or moved during transfer operations. Fuel pressures noted aboard ***Tillikum*** ranged up to 41 psi.

Recommendation: No additional pressure measurements are recommended unless laboratory trials dictate otherwise.

1.4. Storage time

Biodiesel is less stable than conventional diesel. For example, the National Biodiesel Board (NBB) recommends that B20 be used within six (6) months. As biodiesel ages in storage, the acid number tends to increase and then goes "out of spec". Under marine conditions (such as increased moisture level, temperature change, and exposure to oxygen, etc.) biodiesel may be less stable in a WSF vessel than neat biodiesel in land storage for production and transportation.

Storage or dwell time aboard the ferries may be retrievable from the fuel logs, if they are still available. Consideration should also be given to the expected level of mixing of "fresh bunkers" which are loaded into "remaining bunkers." The vessel can inform the team of typical ratios of fresh bunkers to remaining bunkers.

1.4. Exposure to oxygen (air)

Biodiesel oxidation can lead to high acid number, high viscosity, and the formation of gums and sediments resulting in filter clogging. In biodiesel, the higher the level of unsaturated fatty acids, the more likely it is that fuel will be oxidized. The points of unsaturation on the biodiesel molecule can react with oxygen, forming peroxides that break down into acids, sediments, and gums.

Keep in mind that "tank breathing" as described above may be constantly replenishing the oxygen supply. Therefore the biodiesel blended fuels are constantly exposed to oxygen in the WSF fuel system.

Measuring oxygen content in the ullage space as a function of time can provide information on the rate of oxidation.

1.5. Biological Parameters

Bacteria and mold may grow if condensed water accumulates in the bottom of the WSF fuel tank. This bacteria and mold may use biodiesel and diesel hydrocarbons as a food source. They then may grow as film or slime in the tank, and accumulate as sediment. These hydrocarbon-degrading microbes often have a reddish orange color and tend to form mats. The slime and sediment might break loose and accumulate in the fuel filter, resulting in the clogging problem. The bacteria and mold can be detected if the samples are available.

Biocides may kill the bacteria and molds growing in the fuel tank without interfering with the engine operation. The biocides can also inhibit the growth of microbes over long periods of time in very low concentrations. It is noted that biocide products typically are very toxic.

Additional consideration:

1. After years of use with petroleum oil there is expected to be significant deposits in the fuel tanks. Biodiesel users have noted significant fallout of these deposits due to the aggressive natural solvent properties of the biodiesel.
2. Iron oxide or rust can also have a catalytic effect on the oxidation of the biodiesel.
3. If the biodiesel contained large amounts of water or was not properly separated in the wash stage of the production process it would increase the risk of emulsion in the fuel tanks.
4. Because of the biodiesel’s affinity to water it is not necessary to see free water in the fuel before forming emulsions. The fuel must be tested regularly to determine water content.

It is noted that biodiesel fuel is not simply stored in a tank on a marine vessel. It is transferred into a storage tank -- in the case of WSF, from a tanker truck. It is therefore subject to sloshing while in the storage tank. It is then transferred from the storage tanks into fuel oil day tanks through purifiers, pumps, and filters. It is pumped at pressure through service piping through filters, hoses and engine equipment, with some fuel returning to the fuel oils day tanks. In this way, environmental conditions under which the biodiesel is used in the ship are not simply weather dependant, but are also impacted by the processes inherent with marine vessel operations.

2. Material Compatibility

Biodiesel may have adversely impacted natural and nitrile rubber seals in the WSF vessel fuel system. In addition, brass, bronze, copper, etc., may be oxidized due to contact with biodiesel, thereby creating metal sediments.

Material compatibility is also significantly affected by other conditions such as flow temperature, contact time (i.e., when passing through a pipe or hose at velocity), flow turbulence, flow pressure and electrical bonding.

2.1. Fuel Storage Tank Materials

The fuel storage tanks and fuel day tanks on all three vessels under consideration for this test program have uncoated mild steel fuel tanks. The tanks are likely original steel, and therefore at least 25 years old (*M/V Issaquah*) to 50 years old (*M/V Tillikum/Klahowya*). Biodiesel is known to have good solvent properties, which will likely remove anything left on the bulkheads of the fuel tanks. Any substances removed from the tank bulkheads will end up passing through the purifiers and filters, likely requiring accelerated purifier cleaning intervals and increased filter replacements due to clogging.

Recommendation: The fuel tanks should be thoroughly decontaminated prior to introducing biodiesel into the vessels. Tank cleaning protocols will be developed as part of the ongoing work.

2.2. Fuel System Piping Materials

The majority of the fuel system piping materials on all three vessels is as follows:

- Piping - ASTM A53 or A106 carbon steel, uncoated.
- Pipe Fittings – ASTM A234 carbon steel and/or ASTM A197 malleable iron.
- Valves – ASTM A395 nodular iron, ASTM A126 cast nodular iron and/or ASTM A216 cast steel.

- Valve trim – bronze (ASTM B61), aluminum and/or stainless steel (ASTM A312).
- Gasket material – unknown – assumed to be Cloth Inserted Neoprene.

As discussed above, biodiesel is known to have good solvent properties which will likely remove anything on the interior of the piping. Any substances removed from the piping will end up passing through the purifiers and filters, likely requiring accelerated purifier cleaning intervals and increased filter replacements due to clogging. Biodiesel also increases the rate of oxidation, and could cause accelerated wastage in piping.

Recommendation: Increase monitoring of the differential pressure gages at the filters indicating clogging, and decrease purifier cleaning intervals until foreign particle presence is diminished. The frequency of inspection and thickness gauging of fuel piping may have to be increased if biodiesel blends are adopted on a fulltime basis.

2.3. Fuel Transfer Pump Materials

The fuel transfer pumps are primarily cast iron construction with elastomer-based seals. As discussed above, biodiesel is known to have good solvent properties, which will likely remove anything on the interior of the pumps. Any substances removed from the pumps will end up passing through the purifiers and filters, likely requiring accelerated purifier cleaning intervals and increased filter replacements due to clogging.

Recommendation: Increase monitoring of the differential pressure gages at the filters indicating clogging, and decrease purifier cleaning intervals until foreign particle presence is diminished. Check transfer pump seals regularly.

2.4. Main Engines – Electro Motive Diesel (EMD) – M/V Tillikum/Klahowya

EMD representatives have an internal presentation for their sales staff discussing the use of biodiesel in the EMD 12V645 F7B main engines. That presentation is included as an attachment to this report (please note the proprietary nature of these materials). The report is developed for the locomotive industry (which is 95% of EMD's business), but is applicable to the WSF vessels.

Separately, WSF is reported to use Aeroquip FC234 hoses in the fuel systems on all engines. These hoses are not fully compatible with biodiesel and may experience premature failure. There is no known replacement for these hoses bearing U.S. Coast Guard (USCG) approval.

EMD concerns:

- Fuel water retention and stability when stored.
- Compatibility with elastomers (seals and hoses).
- Injector tip and injector pump wear.
- Plugged fuel filters.

Recommendation: Obtain EMD's assistance in monitoring engine performance and engine component performance during the duration of the test.

EMD recommends:

- Inspect seals and hoses regularly – replace as necessary.
- Monitor lube oil condition.
- Monitor fuel and lube oil filter condition closely.

2.5. Main Engines – General Electric (M/V Issaquah)

The local General Electric diesel engine representatives have been contacted repeatedly, but have not yet responded with manufacturer's published information on the compatibility of the GE FDM12 main engines with biodiesel and biodiesel blends. The GE engines serve the same primary locomotive industry as does EMD. It is likely these engines face similar concerns and issues. Until we receive other information, our recommendations will be the same as for the EMD engines.

Separately, WSF is reported to use Aeroquip FC234 hoses in the fuel systems on all engines. These hoses are not fully compatible with biodiesel and may experience premature failure.

Recommendation: Until other information is received, recommendations will be the same as for the EMD engines.

- Inspect seals and hoses regularly.

- Monitor lube oil condition.
- Monitor fuel and lube oil filter condition closely.

2.6. Auxiliary Engines – Detroit Diesel (all three vessels)

The local Detroit Diesel engine representatives have been contacted and supplied Reference 5 with information on the compatibility of the Series 60 auxiliary diesel engines (ship service generator engines) with biodiesel and biodiesel blends. Detroit Diesel does not approve the Series 60 engine for biodiesel blends of over B5. In discussing modifications/conversions for biodiesel operation at higher blend ratios, among the most significant measures is to check engine lube oil for compatibility with biodiesel. In addition, the engines should also be expected to produce approximately 8-10% less output than on petro-diesel.

Separately, WSF is reported to use Aeroquip FC234 hoses in the fuel systems on all engines. These hoses are not fully compatible with biodiesel and may experience premature failure.

Recommendation:

- Check engine lube oil for compatibility with manufacturer's recommendations – change lube oil type if necessary.
- Monitor engine load to make sure engines are not overloaded.
- Inspect seals and hoses regularly.
- Monitor lube oil condition.
- Monitor fuel and lube oil filter condition closely.