Biodiesel Issues and Utilization for Marine Diesel Engines

Introduction

Pure biodiesel is defined as “A fuel compromised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats”. The fuel is obtained by reacting a parent vegetable oil or fat with alcohol, through a process called transesterification, in the presence of a catalyst to produce the mono-alkyl esters [1]. The primary advantages of biodiesel over conventional fossil fuels lie in environmental considerations Biodiesel reduces

hydrocarbon, particulate matter, and carbon monoxide emissions from the tailpipe, has a reduced CO2 life cycle by recycling CO2 in the atmosphere, and is non-toxic. Certain precautions must be taken to operate an engine on biodiesel due to the solvent properties of the fuel, the lower energy content, and poorer cold weather performance. Biodiesel can be produced by renewable farm-based crops such as soy, rapeseed, palm, and jatropha in addition to algae which can be grown away from farmlands and forest [2] and should produce an order of magnitude more fuel per acre than any of the other sources.

The preliminary evaluation of biodiesel fuels did not identify any ports worldwide which provided pure or blended biodiesel for mainline marine fueling. This is expected due to the state of the industry. Today the feedstocks are too expensive to lead to a competitive biodiesel market. At this time, only algae is in the running to be cost competitive. This is primarily because it is likely to produce oil at an annual rate that is a factor of ten greater than any of the competitors. Initial enthusiasm led to predictions approaching a factor of one hundred, but further experimentation has led to smaller and likely more realistic estimates. Biodiesel has been produced from algae, but the current production costs are estimated by the community to be $50 +/-$30 per gallon. Government and privately funded research and development are being conducted worldwide in an attempt to drive down the cost. While impressive advances are being made, it is yet clear that they will be sufficient to preserve the industry.

Environmental Benefits

Biodiesel is generally cleaner burning than petroleum diesel and reduces most regulated emissions. Compared to conventional diesel, biodiesel reduces particulate matter (PM) by 47%, carbon monoxide (CO) by 48%, and unburned hydrocarbons (HC) by 67%. According to the National Biodiesel Board, NOx emissions with pure biodiesel can increase by 10%, but research articles have shown that increases in NOx may be load dependent and a minor number of articles have actually reported a decrease in NOx emissions [3]. Overall, the lack of sulphur in biodiesel allows NOx control technologies that cannot be used with conventional diesel engines [4, 5]. In addition to the regulated emissions, biodiesel also decreases non-regulated emissions such as sulfates, polycyclic aromatic hydrocarbons (PAH), nitrated PAHs, and ozone generating hydrocarbons. These components have been identified as potential cancer-causing compounds [5].

Biodiesel is non-toxic and does not contain hazardous materials. Compared to petroleum diesel, the effects of inhalation, eye contact, and skin contact are minimal, which makes the fuel safer to handle. In the event of a spill (e.g., during fuel transfer), biodiesel degrades about two to four times faster than petroleum diesel [4, 6]. Investigations of blended biodiesel and petroleum diesel have shown that the biodiesel components, fatty acid methyl esters, will degrade first before the other hydrocarbon components from petroleum diesel in the event of a spill [7]. Further testing on impacts to larval fish has shown that biodiesel concentration levels of approximately 20 times those of petroleum diesel levels are required to have the same mortality effect on larvae [6]. Due to these environmental benefits, biodiesel offers a lower impact on sensitive marine ecosystems.
A very important environmental benefit from using biodiesel comes from the CO2 life cycle improvement. Through the photosynthesis process of growing the fuel feedstock, CO2 is recycled which helps to control greenhouse gases and fight global warming. A study sponsored by the US Department of Energy and US Department of Agriculture concluded that biodiesel decreases net CO2 emissions by 78.45% compared to mineral diesel due to the closed carbon cycle benefit [8]. Proper sources and methods must be used in the fuel production process to gain the CO2 benefits.

Engine Performance

Biodiesel is used in conventional diesel engines either neat (100% biodiesel) or, more commonly blended with petroleum based diesel. Blends of biodiesel are usually referred to as BN, where N is number between 1 and 100 representing the percentage of biodiesel in the fuel. The National Biodiesel Board states that biodiesel blends up to 5 – 20% (B5 – B20) can be used in conventional diesel engines without voiding the warranties; however, users should check with the engine manufacturer first [9]. Pure biodiesel, B100, is a solvent and can degrade certain elastomers and natural or butyl rubber compounds. These materials must be replaced with compatible components, such as Viton. In addition to certain elastomers, contact with soft metals such as copper, brass, bonze, lead, tin, and zinc should be avoided. These materials should not be present in the storage tanks or fuel lines since they can accelerate oxidation of the fuel leading to corrosion and creation of sediment [10].

Biodiesel also has beneficial lubricity which can favorably reduce engine life cycle cost. A 2% mix of biodiesel can increase lubricity by 66% [4]. Pure biodiesel has an LHV (lower heating value) of 37.2 MJ/kg, which is about 12% less than the value for petroleum based diesel, 42.5 MJ/kg, but because biodiesel has a slightly higher density, the volumetric heating value is only reduced by 9.4%. Based on the reduced heating value of biodiesel, an 8-10% drop in power output would be expected, but various research papers have shown that engines can be operated on biodiesel without a significant loss in power output. These papers have cited the higher viscosity of biodiesel and increased lubricity as methods for partial power recovery [3]. Fuel property comparisons are shown in Table 1.

Table 1: Fuel properties [3, 7]

	Petro Diesel	B20 - Petro/Bio Blend	B100 - Neat Biodiesel
Cetane Number	43.3	46.0	51.2
Density [kg/m^3]	856	862	886
Heating Value [MJ/kg]	42.5	41.3	37.2
Sulfur [%Wt]	0.048%	0.037%	0.000%
Oxygen [%Wt]	0.000%	2.100%	11.000%
Viscosity [cSt]	2.8	2.9	4.1

Cold Weather Properties

Pure biodiesel has a higher freezing point than conventional diesel, which requires consideration when operating in cold weather environments. Neither the ASTM specification for biodiesel, ASTM D-6751, nor the European EN 14214 specification state maximum or minimum requirements of fuel temperature properties. The parameters which define cold weather properties for fuel are the cloud point, cold filter plugging point, and pour point. The cloud point is the highest temperature and refers to the temperature at which crystals will first start to appear. Below the cloud point is the cold filter plugging point which is the temperature at which crystals have agglomerated in a sufficient amount to clog a test filter. The lowest fuel property temperature is the pour point, where the fuel gels and is no longer able to flow [11]. Archer Daniels Midland Company suggests that biodiesel should be stored 5 – 8°C above the cloud point, which can required insulated and heated fuel lines and storage tanks. They state that if pure biodiesel fuel approaches too closely to the cloud point, certain components, particularly saturated components begin to crystallize out of the solution and settle to the bottom [10].

The temperature properties of biodiesel are affected by the original feedstock for the fuel. Biodiesels from soy, canola, and rapeseed can have cloud points between 0°C and -7°C, while fuel produced from grease, palm, and tallow can have cloud points that range between 8°C and 16°C. Blended biodiesel will exhibit better cold weather properties than B100. Lower percentage blends of biodiesel will have cold temperature properties close to the primary conventional diesel used in the blend. B20 blends of biodiesel will have a cold-filter plugging point of only 1.5 – 3°C higher than pure petroleum diesel. For cold weather operation, the cloud point or cold filter plugging point of the fuel should be tested to meet the service conditions [10, 11].

Worldwide Availability of Biodiesel

Member countries of the OECD (Organization for Economic Cooperation and Development) have lead the way in biodiesel production objectives. Currently, 95% of biodiesel production occurs in the United States and the European Union. Unfortunately, these regions do not possess the natural resources to maximize sustainable biodiesel production; nonetheless, enormous potential exists for the creation of a world biodiesel market [12]. Current large scale commercial biodiesel processing facilities have been launched over the last few years [13]; however, current global biodiesel capacity is 10.3 million tonnes with an annual production of 5-6 million tonnes. This can be compared to standard petroleum diesel's annual production of 470 million tonnes showing that the biodiesel market is just over 1% of the diesel fuel market [14]. Moreover, much of the biodiesel capacity is no longer being used as the products produced were not sufficiently low cost to attract a stable market.

Public policy appears to be the driver of OECD member country biodiesel production. The OECD has expressed an interest in promoting biodiesel as have many governments in developed countries [15]. Currently over 40 countries are implementing biofuel policies, including member countries of the European Union, United States, Australia, Brazil, and much of East Asia; many of these countries are mandating minimal amounts of biodiesel be added to all diesel sold (often 2-5%) [16, 17]. Current pipeline and distribution systems have not adopted biodiesel because of its relatively small scale. If biodiesel is proven to be sustainable from certain feedstock, many underdeveloped countries with extensive sustainable biodiesel ingredients will likely produce and thus develop a global market.

Case Investigation: Biodiesel Use for Caterpillar Diesel Engines

Today's primary benefits for using biodiesel in marine applications will be environmental benefits and its renewable origins. The fuel can reduce ship exhaust emissions, compared to petroleum diesel, and is non-toxic and safer to handle. Another very important benefit is that biodiesel's "well to wheels" carbon life-cycle production is reduced, but only if proper sources and methods are used to produce the fuel. Biodiesel can be used as a pure fuel, or as an additive to conventional diesel fuel, which will still improve emissions. Another advantage of biodiesel is lubricity, which can decrease engine wear and maintenance cost.

Presented next is a summary of Caterpillar's recommendation for biodiesel use for their 3500 series diesel engines, which are in-use for ship propulsion. The Caterpillar document "Caterpillar Machine Fluids Recommendations" [18] provides the following information for use of biodiesel including the 3500 series Caterpillar diesel engines. *Recommendations for the Use of Biodiesel in Caterpillar Engines* – "For the 3500 series engines, biodiesel that meets the requirements that are listed in the "Caterpillar Specification for Biodiesel Fuel, ASTM D6751, or EN 14214 are acceptable blendstocks. Biodiesel may be blended in amounts up to a maximum of 30 percent (B30) with an acceptable diesel fuel. This blend is acceptable provided that the biodiesel constituent meets the requirements that are outlined in Table 20 prior to blending. In addition, the final blend must meet the requirements for the distillate diesel fuel that are listed in the "Caterpillar Specification for Distillate Diesel Fuel for Off-Highway Diesel Engines: Table 18". Further stated is that for blends above 30 percent, a Caterpillar dealer must be contacted for guidance.

It is important to note is that another Caterpillar document, "Caterpillar Commercial Diesel Engine Fluids Recommendations" [19], contradicts the information above by stating that the 3500 series diesel engine may use blended biodiesel up to a maximum of 20 percent (B20). Before converting Caterpillar engines to biodiesel use, Caterpillar should be contacted to fully understand the maximum blending percentage of biodiesel and also some of following topics:

- Impact on warranty with use of biodiesel or blends of biodiesel
- Acceptable blends and feedstock for biodiesel fuels
- Ability for engines to switch between petroleum diesel to pure biodiesel or blends of biodiesel
- Required precautions when using biodiesel after petroleum diesel use
- Biodiesel fuel storage requirements to maintain fuel above the cloud point, oxidation stability for long-term storage, and anti-microbial additives to prevent fuel contamination
- Fuel injector operation with biodiesel and possible requirements for heated fuel injectors
- Biodiesel and blended fuel effects on power and fuel consumption

Today, most diesel manufacturers are using standards as a barrier to entry into the market for biodiesel. This is not likely due to any bias against biodiesel. Rather it is likely prudent business practice. In general, diesel engine manufacturers insist that biodiesel must meet standards that were optimized for the current fuel type and engine design. Until it becomes clear that biodiesel will become a competitive fuel, it does not make economic sense to fund the testing needed to re-optimize an engine for a new fuel type.

The gas turbine engine manufacturers will probably be the leaders in biofuel adoption. Because air travel will likely require a bio-based fuel to meet carbon standards, work is being done to attain the most efficient use of biofuels in aircraft. If this succeeds, it will motivate diesel engine manufacturers to follow suit.

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