PAT SMYTH – LECTURER IN ADVANCED BIOFUELS, MCGILL UNIVERSITY, CANADA

Block Micelles damage to generator injectors

Micelles are a major factor in emergency generator damage, yet traditional filters do not remove them efficiently. Pat Smyth, lecturer in advanced biofuels for BioFuelNet Canada, outlines a better solution

Micelles were recently recognised as the major factor in diesel corrosion and emergency generator damage. Micelles form when water droplets and surfactants bond together; the Micelles then settle to the storage tank bottom, forming a layer that is very conducive to microbial growth. Microbes create acids, which corrode components of backup generator engines, storage tanks (including fiberglass tanks), and piping. Micelles themselves are not efficiently removed by traditional filters, so they are ingested into engines, scouring injectors and greatly increasing the risk of backup generator failure.

There is one filtration standard that addresses Micelle removal, and that is SAE J1488 filtration.

Micelle formation

Water and surfactants are both polar molecules, which means they both have an electrical charge, so are attracted to each other; Micelles form when surfactants and water bond, and the water droplet becomes encapsulated by surfactants. The Micelles then settle to the storage tank bottom, forming a layer that is conducive to microbial growth, and also concentrate the water and surfactants on the bottom layer. Some examples of surfactants include biodiesel and ethanol; practically every additive to liquid fuels is a surfactant.

Figure 1 is a 3D illustration of a Micelle, the surfactant encapsulates the water droplet, forming a surfactant shell. Note that a traditional filter needs physical contact with the water to remove it; in a Micelle, the surfactant's fatty acid tail forms a barrier, isolating the water droplet from filter material, water tests, and fuel. Since the surfactant prevents contact between the filter and the water droplet, traditional filters cannot easily remove the water and most Micelles bypass the traditional filter.

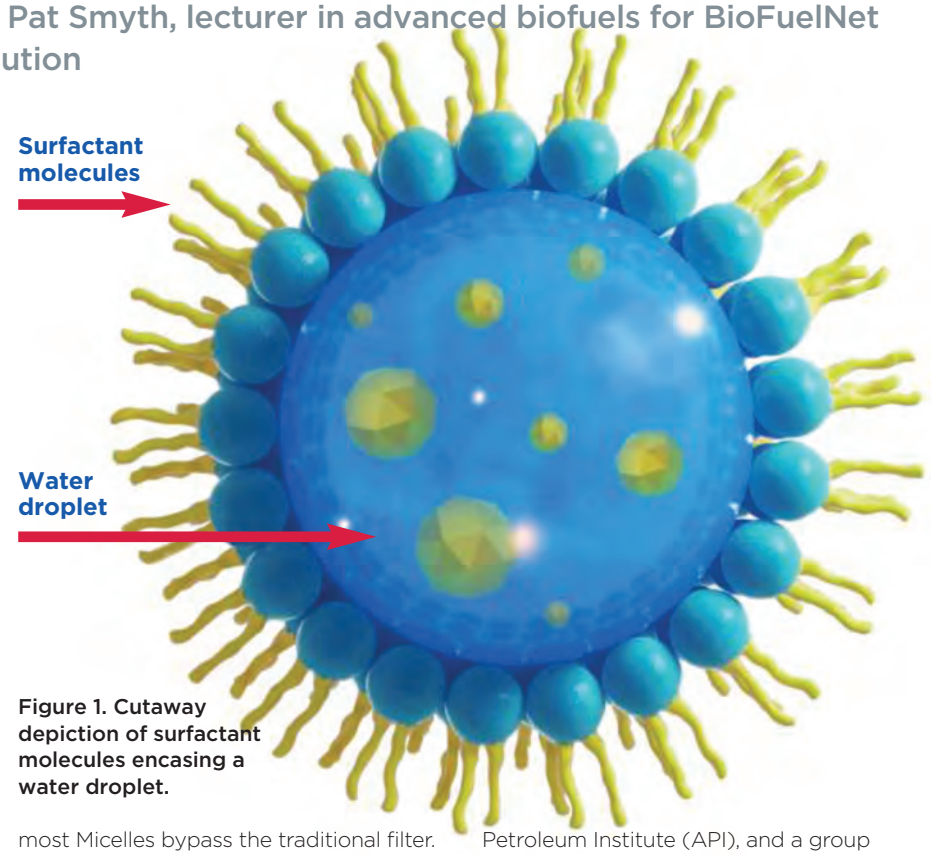

Figure 1. Cutaway depiction of surfactant molecules encasing a water droplet.

In 2021, the Coordinating Research Council (CRC) released Project DP-07-16-01 *Identification of potential parameters causing corrosion of metallic components in diesel fuel underground storage tanks*.[1] CRC is a non-profit organisation that directs engineering and environmental studies on the interaction between automotive/other mobility equipment and petroleum products. The Sustaining Members of CRC are the American Petroleum Institute (API), and a group of automobile manufacturer members (Stellantis, Mercedes Benz, Ford, General Motors, Honda, Nissan, Toyota, and Volkswagen).

A key finding is Micelle formation (see Fig 2).

Corrosion mechanism

Details of corroded ULSD equipment are shown in Figure 3 and a UST system with steel tank with severe metal corrosion in Figure 4.

Before the 2006 introduction of ULSD (Ultra Low Sulfer Diesel) and surfactants (biodiesel), free-standing water accumulated on the tank bottom, and microbes only existed in a thin layer at the water/diesel interface. This thin layer of microbes has been described as the thickness of a sheet of

Pat Smyth

Pat Smyth has researched diesel corrosion control for over 12 years. In 2022 he was invited to present his findings to ASTM International (American Society for Testing Materials) and to SAE International (Society of Automotive Engineers), as well as to NACE (National Association Corrosion Engineers) (2018) and the EPA Office of Underground Storage Tanks (2016). Pat is a lecturer in BioFuelNet Canada's Advanced Biofuels course, hosted on McGill University's myCourses platform.

paper. Since there are few microbes, there was minimal acid created, so there was little corrosion.

With the introduction of surfactants, Micelle formation prevents the free-standing bottom layer of water from existing. Instead, the Micelles clump to form what is called an invert layer; this layer can be several inches thick. Microbes can grow all throughout this layer, as opposed to just at the thin layer at the water/diesel interface. This thick Micelle layer is very conducive to microbial growth. More microbes produce more acids.

To give an idea of how much more growth volume microbes now have, a package of paper for a home printer is approximately one inch thick and holds 200 sheets of paper. Each inch of Micelle layer provides 200 times the growth volume for microbes, compared to diesel before ULSD. There could be multiple inches of the Micelle layer. The microbial growth volume has dramatically increased; more microbes make more acids, greatly acidifying the diesel (see Fig 5).

Micelle damage to injectors

Injector damage has two vectors:

- Acidified fuel corrodes all injector metal components; needles, orifices, fuel quantity reservoir, as well as pistons and valves.
- Micelles bypass traditional filters; water droplets scour the injector orifice and needles at 35,000 + psi.

This injector damage greatly increases the risk of backup generator failure (see Fig 6).

The damage to orifices and needles disrupts the spray patterns into the cylinder, increasing emissions and fuel use, and reducing power.

Predicting levels of damage

There are two main factors that can help predict the amount of corrosion and Micelle damage caused to a storage tank and emergency backup engine: one, the length of time the fuel is stored (1 year, 5 years, 10 years, etc), and two, the concentration of the surfactant used (B4, B5, B10, B20, etc). B4 means the addition of four per cent by volume of biodiesel, and B20 is a 20 per cent addition of biodiesel by volume. The combined effect of these two factors is discussed below.

Surfactant concentrations

B4: Samples from field testing over 12 years show unfiltered B4 storage requires around five years for significant contamination of fuel to occur, and by 10 years the fuel has severe contamination, and is well above diesel storage limits for water (as measured by Karl Fisher titration, ASTM D6304), TAN (Total Acid Number as measured by ASTM D664), and particulate (as measured by ISO 4406). Fuel stored for 10+ years has shown water at 3,000 to 30,000 ppm (generator warranty 200 ppm), TAN of .29 (limits .08), and particulate counts of 25/23/18 (limits 18/16/13).

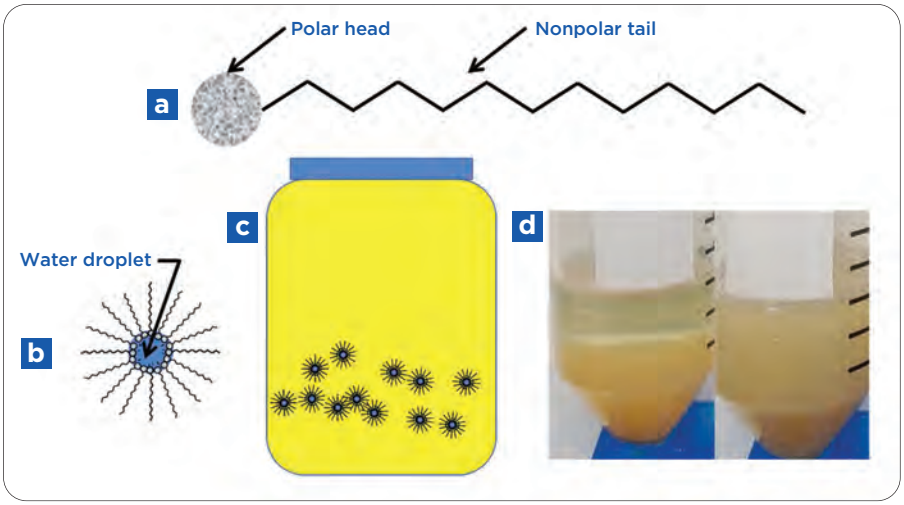

Figure 2. Surfactants: a) schematic of surfactant molecule showing polar head and nonpolar tail; b) schematic of invert-emulsion Micelle encapsulating water droplet and nonpolar tails extending into the medium (i.e., fuel); c) schematic of invert emulsion Micelles dispersed in fuel; d) photo of 10 mL each fuel and water – left: before shaking; right: 24h after shaking (note stability of invert emulsion).

B20: In 2020, the United States Air Force (USAF) commissioned a yearlong study of B20 storage: *In situ linkage of fungal and bacterial proliferation to microbiologically influenced corrosion.*[4]

According to the study, one tank was pulled after only nine months:

"... tank SE 3, which was removed from the study after nine months due to severe microbiological contamination that required mitigation." (p2)

From the report's conclusions:

Injector damage greatly increases the risk of backup generator failure

"... Together, they illustrate the susceptibility of fuels containing biodiesel to microbial proliferation (fouling), fuel biodegradation, and MIC of associated infrastructure. Here though, we were able to directly link the presence and prevalence of biofilms to pitting corrosion in actively operating B20 storage tanks." (p10)

Effect of time of storage

B20 has severe contamination after one year. B4 has severe contamination after 10 years. Other blends (B5, B10) will show severe contamination between these ranges; B10 can be expected to have severe contamination after two years, and B5 after eight years.

Micelle control, SAE J1488 Filtration

The Society for Automotive Engineering International (SAE) sets many international standards, such as for engine oil (example SAE 10W40), and for diesel filtration. In 2010, SAE updated their filtration standard for diesel filtration, J1488, to be suitable for testing filtration of biodiesel blends, to address Micelle

Figure 3. Corroded ULSD equipment: Corroded carbon steel submersible turbine pump (STP) shaft removed from pump housing, CA-1 (left); brass ball float extractor cage plug, NY-2 (middle); aluminium drop tube, NC-1 (right).[2]

Figure 4. UST system with steel tank with severe metal corrosion (43-MD-ST: [installed 1992; age of filter unknown). From left: fill pipe opening; STP shaft; tank top showing manway; ATG probe and STP shaft.[3]

formation. Note the J1488 standard is in the process of being updated in 2023.

The SAE J1488 test procedure[5] focuses on the prevention of damage to diesel engines. From the Forward:

"Water in fuels is one of the major causes of diesel engine maintenance problems. The effects of water in fuel are characterised by corrosion of fuel system parts, plugging of filters and orifices and, in some cases, failure of fuel injection equipment. Water in fuel often dissolves sulfur compounds, becomes acidic, and enhances corrosion in fuel injection systems as well as in the engine itself. The presence of water also encourages microbiological growth, which generates orifice and filter restricting sludge. Further, due to displacement of fuel lubrication in close tolerance injector parts, and rapid expansion of heated water at the fuel injector tip, galling, and more serious failure may also occur."

J1488 Test Procedure

The J1488 test procedure has two phases: 2500 ppm water is added to fuel samples in each test phase and is mixed using a 3500 rpm pump to emulate a fuel loading pump.

The 1st phase uses pure diesel with no surfactants, this phase tests for free water filtration.

The 2nd phase a standard surfactant monoolein is added to emulate a B20 blend, this phase tests Micelle filtration.

J1488 Test Results

In the 1st phase of filtration of free water, all filters are approximately 100 per cent efficient; all water is removed.

In the 2nd phase of filtration of Micelle: traditional filters cannot contact the water encapsulated in Micelles, and filters have low efficiency at removing Micelles.

Only two filter manufacturers have released their J1488 test results showing high efficiency in removing Micelles. These filters can keep water content below the 200 ppm water warranty level required by emergency generator manufacturers. This means a minimum 92 per cent filtration efficiency: 2500 ppm water added * (1 – 0.92 per cent) = 200 ppm water remaining.

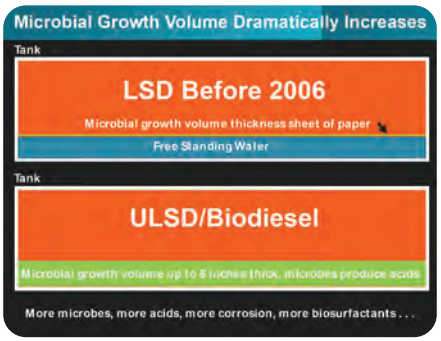

Figure 5.

The testing organisation provides a J1488 test certification report to the filtration company detailing the test results. Ask for this test report when considering a fuel filter.

Summary

There are, then, two damage vectors: corrosion and Micelles.

Surfactants are added to all liquid fuels, such as diesel (biodiesel) and gasoline (ethanol). Surfactants encase water droplets to form Micelles, which settle to the tank bottom, forming a layer that is very conducive to microbial growth.

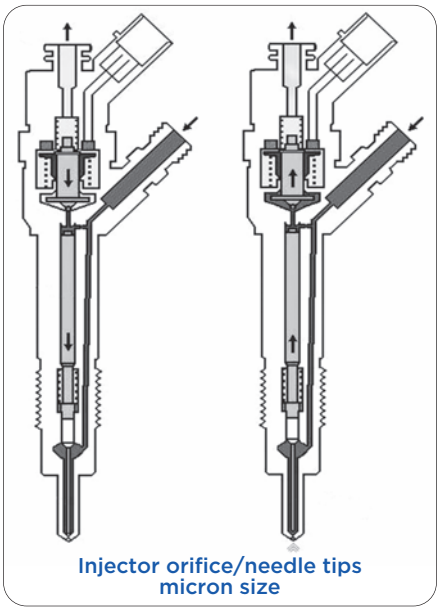

Figure 6.

Microbes produce acids, which corrodes critical backup generator and storage tank components.

Traditional filtration is not very efficient in removing Micelles, so Micelles bypass the filters and scour injector components, greatly increasing maintenance costs and risk of backup generator failure.

Two factors that can provide a prediction as to the amount of corrosion and Micelle damage caused to a storage tank and emergency backup engine: the length of time the fuel is stored (1 year, 5 years, 10 years, etc), and the concentration of the surfactant used (B4, B5, B10, B20, etc). Biodiesel is mandated in most jurisdictions; United States at B5, EU at B5 - B7.5, Canada at B4.

B20 diesel will show major issues after one year of storage, B4 after 10 years, and B5 after eight years.

Micelle and corrosion control

SAE J1488 is the only filtration standard designed to test the efficiency of filters in removing Micelles. The filters on fuel polishing systems and backup generators should be tested against SAE J1488 and have a filtration efficiency of at least 92 per cent in order to keep water in Micelles below 200 ppm, the warranty standard for most backup generators. **IFHE**

References

1 Passman FJ. CRC Project DP-07-16-01. Identification of potential parameters causing corrosion of metallic components in diesel fuel underground storage tanks. p102. 2021.

2 Battelle Report. Corrosion in systems storing and dispensing ultra-low sulfur diesel (ULSD), hypotheses investigation. p3. 2012.

3 U.S. Environmental Protection Agency Office of Underground Storage Tanks. Investigation of corrosion-influencing factors in underground storage tanks with diesel service. p29. 2016.

4 Stamps BW, Bojanowski CL, Drake CA *et al.* In situ linkage of fungal and bacterial proliferation to microbiologically influenced corrosion. pp2, 10. 2020.

5 SAE International (2010) Emulsified water/fuel separation test procedure [https://www.sae.org/standards/content/j1488_201010].