What Grows in the Darkness of Diesel

From taking samples and cleaning tanks to arming with biocides and/or biofilm dissolvers, here are strategies to help captains and service yards fight contaminated diesel.

Text and photographs by Nigel Calder

Above—*If primary fuel filters look anything like this, opening up the fuel tank and thoroughly cleaning it out is long overdue.*

Twice in recent years we have taken on board seriously contaminated fuel, both times at "high-end" marinas—one in Sweden and the other in the United Kingdom, the latter immediately after the marina had spent two weeks cleaning and flushing its fuel tanks and fuel-delivery systems. My experiences led me to do significant research into preventive measures to ensure that I don't get fouled again.

I found that fuel contamination is, unfortunately, not uncommon, possibly a casualty of changes in worldwide fuel supplies. These changes include the removal of sulfur from diesel, resulting in today's ultra low sulfur diesel (ULSD), and the increasingly common addition of a "bio" component to the fuel, including in the United States. In 2015 the Environmental Protection Agency's (EPA) limited sampling of diesel storage tanks across the nation found a biodiesel component in 70% of them. Note that biodiesel is added as a lubricity enhancer, typically in quantities of 1%, to make up for lubricity lost in the sulfur-removal process for producing ULSD.

Multiple Problems

Biodiesel is a solvent, much as ethanol in gasoline is a solvent. If added to an old tank in higher concentrations, biodiesel is likely to dissolve all kinds of gunk off tank walls and add it to the fuel supply (see "Biodiesel," *Professional BoatBuilder* No. 116). I suspect that the fuel we took on in Sweden was the marina's first batch of biodiesel that had been delivered to the marina (see the **sidebar** on page **xx**). It dissolved the gunk out of their tank and deposited it in ours, plugging not just our primary filter but also all the lines between the tank and filter. The fuel

Fuel in a primary filter should be absolutely crystal clear (although colors may differ according to diesel blends and added dyes). Any opaqueness is a sign of serious contamination that needs addressing.

system had to be disassembled and cleaned and the tank opened and flushed—no small task (more on this later).

Biodiesel also has the capacity to hold significant amounts of water in suspension; petrodiesel does not. The fuel we took on in the U.K. was saturated with water. During six days of sampling, small amounts of fresh water dropped out each day. Biodiesel is a surfactant (surface active agent), meaning it breaks up the water into tiny droplets, which are held in suspension within the fuel and small enough to pass through most water-separating filters. After six days spent dockside, we pumped the U.K. fuel out of our main tank, ran it through the marina's portable fuel-polishing system, and stored it in an auxiliary tank. I let it sit for two months and then sampled it for additional water that might have precipitated out. I pulled almost 2 gal (7.6 l) of water off the bottom of the 60 gal (227 l) of fuel in the tank (see the **sidebar** on page **xx**).

The author and his wife have at times taken on fuel from various potentially dubious sources. In this case, she's getting fuel from a lighthouse off the Yucatan coast of Mexico.

But perhaps the biggest problem with the combination of ULSD and biodiesel is the favorable environment it creates for microbial proliferation. ULSD removes a naturally occurring antimicrobial agent at the same time as the bio component promotes microbial growth. This growth can not only plug fuel systems and degrade fuel quality, but it can also foment microbiologically influenced corrosion (MIC) in metal tanks, including stainless steel tanks, and on metal components in the fuel system. (For more on diesel quality and chemistry, see "So You Think You Know Diesel," PBB No. 115.)

Although the microbes are primarily found in diesel and aviation fuel, they can also be in gasoline, especially with the increasing levels of ethanol and other biofuels.

Microbial Processes

A wide variety of organisms can do damage. These are often incorrectly referred to as algae, but for photosynthesis algae require light, which typically is not present in fuel tanks. The rule is simple: no light, no algae. Instead, more than a hundred different strains of bacteria, fungi, and mold *can* exist in the fuel in a planktonic (individual) form or in a biofilm, with bacteria being the most common. Some of these bacteria are aerobic, meaning they need oxygen to survive (oxygen is frequently present in diesel, especially after the turbulence caused during refueling); and some are anaerobic. Aerobic and anaerobic bacteria can coexist in a symbiosis in which the aerobes consume oxygen, creating a local environment in which anaerobes then thrive.

The coexistence of different microbes is known as a consortium. The bacteria initiating surface biofilms generate a starchlike substance, often referred to as slime, which houses the consortium. The slime can be a thin film on the sides of tanks, or it may be in the form of fuel sludge on the tank bottom. Biofilms can also break off and form floating colonies. A consortium produces a microenvironment with a complex food chain in which bacteria multiply more or less impervious to conditions in the rest of the tank.

Within a consortium we may have bacteria that metabolize hydrocarbons and in the process create chemicals that other microbes can use. The hydrocarbon-utilizing bacteria in the colony break down certain hydrocarbon molecules, resulting in unstable remaining hydrocarbon molecules. These react with other unstable molecules to form microscopic solid-hydrocarbon particles. These can agglomerate into larger filter-blocking particles commonly referred to as asphaltenes, which look like coffee grounds. Note that asphaltene is a naturally occurring contaminant in crude oil, and may be present even without biological contamination. These solid fuel particles, combined with water, bacterial slime, and inactive bacteria, drop to the bottom of tanks and form an anaerobic sludge that is fertile ground for further bacterial colonization. If the particles remain small enough to pass through filters, they can wreak havoc on fuel-injection systems, especially on injectors in high-pressure common rail (HPCR) engines.

Some by-products of the biofilm chemistry occurring in ULSD tanks are acetic and other organic acids. These acids are corrosive to metal fuel tanks and fuel systems. Other common bacterial by-products include surfactants, which add to the fuel's ability to hold water in suspension, frequently resulting in a cloudy layer of emulsified fuel at the bottom of a tank just above any "free" water (known as water bottom) in the base of the tank.

Above—*This sample of the fuel taken on board at a high-end marina in Sweden shows a likely combination of bacterial fouling and gunk broken loose from the marina's fuel tank by the biodiesel's solvent properties.* ***Right—****A series of samples illustrates the progression of serious saltwater contamination from the base of a tank upward. The saltwater contamination occurred in heavy weather through a poorly sited tank vent.*

Water Is Life

Bacteria find the water they require for growth as condensate on the walls of fuel tanks, some dissolved in the fuel, and most abundantly as a layer of water on the bottom of many tanks. Some microbes inhabit the fuel side of the interface and some the water side. They can be brought on board in fuel supplies, or be carried in through tank vents on particles of dust or droplets of water vapor as fuel is burned and tank levels decrease, drawing in air. Further air exchanges occur when partially full tanks "breathe" with variations in ambient temperature.

Boat fuel tanks are particularly susceptible to water contamination, because, unlike in the automotive world, vents are typically open directly to the atmosphere, and the environment is especially humid. Sometimes I see poorly sited vents that can directly admit water when a boat is heeled a lot or waves are surging past.

The bottom line: Because the chemistry and processes by which microbes are introduced and reproduce are many and complicated, prevention and eradication are difficult.

Tank Sampling

The first line of defense against microbial contamination of a fuel tank is to keep water out and as quickly as possible remove any that gets in. To do this, the tank needs a defined low spot and a means to empty this low spot—either a drain, if the tank is set high enough in the boat, or a sampling/pump-out line set to within about an eighth of an inch (3.2mm) of the bottom of the low spot, with an attached manual or electric pump discharging into a hose with a shutoff valve.

I have had such a system on my boats for decades. My standard refueling procedure has been to take on fuel, let it sit for 10 minutes, and then pump a sample from the tank's low spot into a jam jar or similar container. If the fresh fuel is seriously contaminated, that's enough time for sufficient levels of contaminants to settle out and be clearly visible. If you find contamination, of course you must remove the fuel from the tank.

On a recent occasion, I had to pump contaminated diesel into plastic milk jugs and haul them to a boatyard disposal facility, 3 or 4 gal (11.4 or 15.1 l) at a time; it was an all-day exercise. I changed my refueling practices so now I first pump a small sample from the marina's outlet directly into a clear glass jar, and if this sample is not absolutely crystal clear, the fuel does not go in the boat.

The other practical function of the drain/sampling pump is to periodically remove the inevitable water that condenses out in any fuel tank over time and settles to the bottom. I do this every month or two that we are on the boat, and before first firing up the engine after a layup.

Killing Fields

Two categories of chemical treatments can be added to a tank to combat harmful microbes:

- biocides, which kill the microbes
- biofilm dissolvers, which disrupt the microbial colony, mitigating its associated problems

The U.K. Water Saturation

The marina had just cleaned and flushed its fuel-delivery system, making this an unusual case. We were the first boat to fill up after this, and were pumping fuel at the same time as the tanker truck was refilling the marina's tank. My guess is we got a load of water-saturated fuel from the bottom of the tanker truck. We detected it soon after, and I informed the marina. The sample they pulled from their tank came up crystal clear, and they claimed the contamination must have already been in our tanks. However, I had sampled our tank immediately prior to refilling to make sure there was no contamination, and their sample was not taken from the bottom of their tank, so was not a valid test. Even with a badly contaminated tank, the fuel at the top is likely to come out looking just fine. To be at all useful, samples should be taken only from the bottom of a tank. Fuel retailers and suppliers often drop a specialized device onto the bottom of a tank, where it opens to capture a sample, which is removed for testing.

Over the next six days I drew two small samples each day of less than half a pint (0.2 l) each from the bottom of our tank, one immediately after the other. The first would capture anything that had settled out since the previous day ("free" water), and the second any saturated layer immediately above this. Each day the first sample had a small amount of water, while the second was really cloudy but without any free water. By the following day, water would begin dropping out of the second sample. As mentioned in the main text, after six days we pumped the fuel through a fuel-polishing system into an auxiliary tank and let it sit for a couple of months, after which I pulled almost 2 gal (7.6 l) of water off the bottom of the tank. The remaining fuel was still cloudy, but no further water dropped out. I then dosed it with Fuel Right, and it slowly clarified over the next few weeks, at which point I put it in the main tank and burned it.

—Nigel Calder

*Water-saturated diesel taken on board in the U.K. **Left to right—**The three samples represent the water that has settled out at the base of the tank immediately after refueling, 24 hours later (2-1), and then another 24 hours after that (3-1). The rate of water dropout decreased but nevertheless continued for weeks.*

Biocides are the best known. They are used widely in diesel and aviation fuel. Because they work in all hydrocarbons, they can also be applied to gasoline. However, it's not widely understood that these can actually worsen a problem. To be effective, a biocide needs to be deadly to all the various microbes that may be found in a tank, and must also reach all the microbes. Biocides get "used up" in the process of killing microbes and also lose their effectiveness over time. A partial kill rate with a subsequent decrease in the biocide's toxicity can lead to an intensified infestation, especially if the biocide has a nitrogen component, which can become a food for the bacteria.

Biocides are most effective against individual (planktonic) bacteria floating in the fuel, but they may have trouble penetrating accumulated slime, sludge, and biofilms. Consequently, the ideal way to use biocides is in a more-or-less clean tank, treating fuel as it is pumped in. Experience suggests that even in seriously fouled tanks, high enough doses of biocides will be reasonably effective over time.

Another issue can be problematic. As noted, some microbes inhabit the water side of the water/diesel interface and some the diesel side. To be effective, a biocide must be soluble in whichever side is harboring the microbes, or for a dual-phase biocide, in both sides of the interface.

Some biocides prioritize a "contact kill," whereas others focus on disrupting bacterial growth mechanisms. Although both may have components that are soluble in water and fuel, the contact killers tend to prioritize the water side and *act* faster, while the disrupters tend to prioritize the fuel side and *last* longer.

Ideal Biocides

We end up with these desirable biocide characteristics:

- Soluble in fuel and water
- A broad spectrum that has a high kill rate. In the case of a "shock" treatment, this is often recommended to be above 99% within 8 hours.
- The ability to penetrate biofilms and reach the embedded microbes
- Long-lasting efficacy, especially on boats infrequently used or seasonally stored, where the fuel may sit in tanks for months at a time. It is often recommended that the biocide remain effective for at least 8 weeks.
- Compatibility with fuel and additives. The biocide should not affect fuel stability, performance, or color.

Compatibility with other system components, notably any rubber components and FRP tanks

- Safe handling. Biocides are obviously designed to be toxic to microbes; we need to ensure that they are certified to have no health impacts on humans and, in particular, to look for registration with the appropriate government agency (e.g., the EPA in the U.S.).

Shock rates are typically recommended at around 3 oz. to 4 oz. of biocide per 100 gal (379 l) of fuel, with maintenance rates being half of that. Two popular brands are Biobor JF (www.Biobor.com), primarily a growth disruptor that has been in use since the 1960s, and ValvTect Bio-Guard (www.valvtect.com), which is optimized for a contact kill.

Because the biocide must reach all areas of the tank and fuel system that may be inhabited by microbes, it must penetrate biofilms, sludge, and slime. The ideal approach is to start with a waterfree, empty tank and to meter the biocide into the incoming fuel supply to ensure thorough mixing and dispersion. This metering is, of course, something most operators and fuel docks are not able to do. The recommended alternative is to half fill a tank, add the biocide, and then rely on the turbulence of filling the rest of the tank to mix the biocide and fuel. This will still not penetrate seriously fouled areas of the tank. If the fuel then sits in the tank for weeks and months at a time, as it commonly does, it is recommended to either give the fuel a shock dose when first put in the tank, or to add biocide periodically, every six months to a year, but in this case it will be even harder to achieve full dispersion.

Slime Dissolution

An alternative to biocides is to dissolve the biofilms that are the building blocks for microbial growth. The only chemical I know of that claims to do this is Fuel Right (www.FuelRight.com). Although that product has been used on several continents for a decade or more to treat millions of gallons of fuel, it lacks the level of evidence of its efficacy that biocides enjoy; their wide use for decades in billions of gallons of fuel has resulted in a wealth of evidence as to when and how they work or don't work.

While Fuel Right offers little independent third-party testing to recognized industry standards, it provides dozens of glowing testimonials, including from extensive testing by several shipping lines, but I am always skeptical of those. On the other side, a test by *Practical Sailor* magazine found accelerated fuel-tank corrosion. With some justification, Fuel Right strongly disputes the test protocol as inappropriate.

Fuel Right literature and numerous e-mail exchanges I have had with the principals explain its processes in terms of "micelle" formation and "filming amines," some of which dissolve the bacterial slime that holds bacteria together, and some of which

Far left—*A seriously contaminated fuel sample drawn from the base of a fuel tank became clear* ***(left)*** *after receiving a "shock" dose of Fuel Right.*

stop slimes from forming—the mix breaks up existing infestations and prevents recurrence. Because the amine coating on tank walls is electrically nonconductive and hydrophobic (impermeable to water), it forms a barrier to corrosion on metal surfaces. Note that recent EPA research in the U.S. into the increasingly widespread fuel tank corrosion since the introduction of ULSD specifically recommends filming amines as one of the measures likely to inhibit corrosion.

I have struggled to get my head around the chemistry, but it is well beyond me. So, over the past couple of years I have conducted experiments with Fuel Right, in particular applying it to the seriously water-contaminated fuel I received from the U.K. marina. I have to say the effect has, at times, been nothing short of astonishing. I have taken samples of fuel that were totally cloudy and opaque, given them a shock dose of Fuel Right, and watched the fuel become clear and translucent in a matter of minutes, with minor deposits dropping out to the base of many of the samples—although interestingly, on some there was no visible precipitation.

I have dosed my own tank, already visually clean from the thorough cleaning after the Swedish-fuel contamination, and seen my primary filter element, which normally looks more-or-less spotless at a filter change, come out contaminated with black sediment. Although biofilms themselves are nearly transparent, this was most likely evidence of residual deposits, the asphaltenes mentioned earlier, that were dissolved by Fuel Right. In more severe tank contaminations, Fuel Right claims that its chemicals will soften and clean out the deposits over time. It is also reported to significantly improve lubricity. The minimizing of asphaltenes, combined with other additives in Fuel Right, promotes cleaner-burning engines with fewer injector deposits, which is particularly significant for today's high-pressure common rail (HPCR) engines.

The fouling of this Racor primary filter element is from an ostensibly clean fuel tank treated with a shock dose of Fuel Right. The chemical has broken loose various deposits from within the tank.

Recognizing the weakness of my limited anecdotal evidence, I nevertheless have become a cautious believer and will in future give my fuel system maintenance doses of Fuel Right whenever I top up the tank.

Dose rates are similar to the biocides, i.e., a shock rate of around 3 oz. to 100 gal of fuel, with maintenance rates being around 2 oz. per 100 gal. So far as I have been able to determine, filming amines can be used with biocides, so a paranoid approach might be to use both.

Tank Cleaning

What if your tank has become seriously fouled? This is common on older boats, either from accumulated microbial deposits or simply from sediment buildup over time. How do you clean this out?

First, it might be worthwhile exploring the extent of the contamination. A new tool makes this relatively simple—an endoscope, or borescope, camera. Many of these tiny cameras, typically surrounded by a ring of LED lights on the end of a flexible stem, are waterproof and dieselproof. They can be inserted into any small tank orifice, pushed down to the base, and moved around to see what is going on. Many plug into smart phones. Remarkably, they can cost as little as $10.

Let's say the tank needs to be cleaned. All kinds of fuel polishing systems are on the market. Although these systems clean fuel by pulling it from a tank, running it through external filters and water separators, and returning it to the tank, they are basically ineffective at breaking up accumulated sediment and slime, and at cleaning biofilms off other surfaces. At the least, a high flow rate is needed to create substantial turbulence, with a suction line at the bottom of the tank to grab the gunk and whatever has broken loose elsewhere and settled. Even this system will still not clean a badly fouled tank, nor can it be used to clean inaccessible baffled chambers. It then becomes necessary to open up the tank to gain adequate access, and this is often a major undertaking. (For more on fuel-polishing systems, see "Polishing the Fuel," PBB No. 112.)

One other approach might be tried before opening up a tank: pump most of the fuel out of the tank, find an opening to insert an air hose, and blast the

In the author's initial attempt to pump down a contaminated fuel tank, a lightweight oil-change pump proved totally inadequate to the task.

The Swedish Fouling

The Swedish fouling event I described in the main text forced me to clean our primary fuel tank. By initially removing the fuel-level sending unit, I had a 2″ (51mm) hole in the tank. Holding a wooden batten long enough to reach to the bottom of the tank, I felt around to identify the low spot, then duct-taped a PVC hose to the batten, connected the hose to a manual vacuum-style oil-change pump, and moved the hose around at the bottom of the low spot while someone else operated the pump. The duct tape was a mistake, because the diesel dissolved its adhesive, and the tube came loose, leaving the tape submerged in the tank. So now I had something else to fish for. I reattached the tube to the batten with a couple of plastic cable ties and tried again, but it soon became obvious that I needed better access to deal with the extent of the fouling, and in any case how was I going to find the tape? Luckily, my tank has a substantial metal plate with all the suction and return fittings built into it. We removed this to create a large enough opening to manually reach into the tank and clean it out. —*N.C.*

In an unsuccessful attempt to pull contaminated fuel from the bottom of his tank, the author employed a suction tube duct-taped to a stick fed through a 2″ (51mm) hole. That access proved too small to properly clean the tank.

remaining fuel all over the tank with compressed air. Pump out this fuel, add clean fuel, and repeat as many times as necessary. Check the tank's cleanliness with a camera borescope.

Gaining Access

The pump-out line, air hose, and borescope will need a modest access hole. Typically, the easiest way is to remove a fuel-level sensor, as most are fitted through a standard 2″ (51mm) hole. Before removing the sender, mark its rim and the tank with an indelible pen so the sender can be returned to exactly the same position and orientation. Carefully pull out the sending unit to avoid damaging the delicate hinged arm and float on the end of it, which registers changes in fuel levels. These mechanisms are not only sensitive but if put back in the wrong orientation, they can also jam on the tank sides or baffles and not work.

Before removing a tank level sensor, first mark the relationship of its rim to the tank so the sensor can be put back the same way around, and then withdraw it carefully, as many are delicate and easily damaged.

It may well be that a larger access hole is needed. I was lucky, as on my boat the various fuel suction and return lines are mounted on a plate that can be pulled out. Otherwise, an access hole will need to be cut in the tank and sealed after the tank is clean. For many tanks, Dutch company Vetus (www.Vetus.com) has simplified this task with its universal inspection port, first brought to the market in 2016. It allows a 6″ (152mm) hole to be cut in the tank and then sealed relatively easily with an opening port for future inspections. However, after going to all this work, the goal must be to keep the tank clean so it never needs to be opened again!

The author gains excellent access to his tank by pulling off the plate holding all the fuel suction and return lines, including his fuel tank sampling line.

Steve D'Antonio reports that the Seattle, Washington, company Sea-Built has offered stainless steel and aluminum inspection-port kits for many years, which, when properly installed, are leakproof. Note that you must gain access into every baffled chamber to properly clean a tank. See http://stevedmarineconsulting.com/cleaning-diesel-tanks/ for further information and photos of inspection ports, stripper tubes, and a drain well.

The Art of Obsession

Numerous studies over the years suggest that contaminated fuel almost certainly accounts for most marine diesel engine problems. To head them off, I have always been obsessive about ensuring that only clean fuel gets to my engines, and I'm becoming ever more so. In light of my recent experiences, I have revised my long-standing procedures. I now sample the fuel *before* it goes in the tank. If it is crystal clear, I fill the tank, adding a maintenance dose of Fuel Right at the midpoint in refueling, complete the refueling, let the fuel sit, and, for insurance, sample from the base of the tank. The turbulence during filling may have broken loose some deposits I can now pump out. I sample every couple of months to remove any water from condensates, and I sample before firing up after a boat has been laid up for a season or more.

We have sailed in regions where fuel prices vary dramatically. In the past, if we found cheap fuel, we would fill the main and auxiliary tanks, with the fuel in the auxiliary tank then sometimes sitting for a year or two and occasionally more. I no longer do this. Given the increasing potential for fuel-quality degradation over time due to the addition of biodiesel to fuel supplies, I try to cycle the fuel at least

Left—*Before any fuel goes in his tanks, the author takes a small sample to see if it is crystal clear.* ***Right—****With his manual fuel-tank-sampling pump, the author takes samples at the beginning of every boating season, periodically during the season, and at every refueling.*

annually. I am contemplating using a stabilizer such as StaBil.

I change my fuel filters at the prescribed intervals, or before a layup (whichever comes first), and expect them to be visually clean. Finally, I have found some relatively cheap and easy-to-use test kits for dissolved water and bacterial contamination, from Dieselcraft (www.Dieselcraft.com). Another company offering bacterial test kits is Conidia (www.conidia.com). The Dieselcraft water kit consists of a powder that turns pink if more than 200 parts per million of water are detected (this is the upper threshold for dissolved water in various international standards). I use the water test on diesel from the secondary fuel filter when I change it. I want to see if dissolved water is making its way through the water-separating filter element in the primary filter. I use the bacteria test on a sample of fuel drawn from the bottom of the tank, the most likely point for concentrations of bacteria.

My goal is to never again have to haul the diesel off my boat in milk jugs, or to have a yard technician open up the tank to clean it out. PBB

Water and bacteria test kits. ***Top—****Fuel from the secondary filter is tested to see if entrained water is passing through the primary filter's water-separating filter.* ***Left*** *and* ***below—****A fuel sample from the base of the fuel tank is tested for bacterial contamination.*

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