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Most of the fuel additives we tested were concentrates that came in bottles designed to allow pre-measuring. In most cases, just a few ounces could treat a full fuel tank.

Additives vs. Gum, Sludge

PS *tests seek out best overall gasoline and diesel additives.*

If we used our boats like the family car, back and forth to work each day, fuel would never sit for more than a few weeks and it would never age. Instead, boats sit for weeks at a time in-season, and for months during the off-season. Water, oxygen, bacteria, metal ions, and even instabilities in the molecules themselves combine to turn fresh fuel into a soup that will clog filters, corrode fuel systems, and leave us stranded. Fuel refineries have long known this, and all products are dosed with inhibitors at the refinery; however, these dosages are calculated for the normal distribution and storage times, not half-full tanks that will sit for months or even years.

We've studied the impact of aftermarket additives on corrosion (*PS* November 2012 and August 2013) and biological bugs (*PS* July 2009). And we've reported on how silica-gel fuel-vent filters reduce corrosion, separation, and oxidation (*PS* January 2013 and January 2014). Here, we examine long-term storage stability in both gasoline (E-10) and ultra low sulfur diesel (ULSD). In the accompanying Value Guide table, we've combined these new findings with a summary of prior testing and presented our top picks for overall additive effectiveness. No more mystery claims; only measured results.

For this test, we followed standard test methods for fuel storage stability. Diesel was tested using American Society of Testing and Materials Method D 4625, Standard Test Method for Middle Distillate Fuel Storage Stability at 43C. For more details on the test procedure, see the accompanying "How We Tested."

WHAT WE TESTED

Our test focus was on products claiming to improve storage stability, and there are many. We also tested some additives that do not make this specific claim, but we included them because performance additives are often used as storage additives.

Giving these products a grade for overall performance wasn't easy. Some products weren't tested in all categories. Some are single-purpose additives—biocides, for example—and would typically be combined with other products to give multi-function protection. Some were simply

not considered or available during prior testing. In one sample, we combined two additives (Star Tron and Hammonds BioBor JF) to confirm that they would work together against corrosion. They did, and we don't foresee any problems combining additives to treat distinct problems, although a single product might be just as effective—and is probably less expensive.

LAB OBSERVATIONS

Even under accelerated aging conditions, our fuel samples aged very, very slowly. Without treatment, all diesel samples survived the equivalent of three years' storage with no changes that would disturb engine operation or render the fuel off-specification. Under our lab's optimal storage conditions, diesel can be stored for three years, but the temperature, humidity levels, and tank conditions that meet our definition of optimal are extremely difficult to replicate at sea (see *PS* January 2014 and August 2014).

Gasoline deteriorated more quickly. Some of our untreated control samples and some treated samples only slightly exceeded specification after the equivalent of two years. Any sample treated with products that we rated as Recommended remained in specification throughout the test period and should allow safe storage up to two years.

Ironically, components in the fuel system itself can accelerate aging. In previous *PS* additive tests, we saw catastrophic aging of fuels that were exposed to copper and zinc. Our testers witnessed this again in this round of testing. The only samples experiencing significant aging were those with brass and copper coupons, and the effects were dramatic. In the gasoline sample, color and visible cloudiness appeared within a week. Diesel was less affected, but since it is often stored for longer periods, and is exposed to more copper as the fuel recirculates, exposure to harmful metals is still a concern.

Both gasoline and diesel were rendered off-specification after 75 days of testing (with copper coupons), the equivalent to seven to 10 months of storage, or a single off-season in some chillier climates. The diesel was barely off-specification, while the gasoline sample contained filter-clogging sediment and very high gum levels. This test intensified the conditions in the tank, because the ratio of copper to fuel was exaggerated. Even so, the scenario was not unrealistic for some systems with brass jets and copper fuel lines, especially when you consider that the fuel in our test was refinery treated and of the highest quality—something seldom found at a dockside pump.

Although we have pointed out the importance of keeping ethanol-blended gasoline tanks full (or completely empty, where practical) during storage, diesel is different. We saw no difference in the aging of diesel samples that were 90-percent full versus 25-percent full. Thus, leaving the diesel tank partially full during winter storage and topping off in the spring is acceptable. This is not a valid approach for gasoline, whether or not it is an ethanol blend.

COPPER AND ZINC

Scientists have long known that copper and zinc are catalyzing agents that can foster fuel polymerization, the gum and varnish buildup that can clog carburetors. Land diesel storage tanks don't experience this because steel and aluminum are the only acceptable materials. Although our tests could not quantify the risk posed by copper and zinc valves and fittings in the fuel system, other studies suggest that this is a legitimate worry.

The American Society of Testing and Materials (ASTM) clearly states that stored fuel should not be exposed to copper and copper-containing alloys and that zinc coatings can "react with water or organic acids to form gels, which rapidly clog filters." British Petroleum (BP), Caterpillar, Cummins, Yanmar—the list goes on—offer similar warnings.

DIESEL

HAMMONDS BIOBOR JF

One of Hammonds' most popular products, Biobor JF (jet fuel) is perhaps the most widely used biocide for diesel and jet fuel, and thus is among the most available. It rated highly as a biocide in our tests, but it did little to protect against corrosion. In a previous test, we paired Biobor JF with Star Tron Diesel, and corrosion was very well controlled.

Bottom line: This wasn't the top overall pick, but it's the Best Choice for a biocide.

HAMMONDS BIOBOR MD

Hammonds' multifunction additive Biobor MD is intended to compliment Biobor JF, specifically as a storage additive. Unfortunately, it is a new product, so it was not available during our initial anticorrosion trials; although this prevented it from getting an overall rating, it did well in our storage testing.

Bottom line: We will be looking at Biobor MD's anticorrosion performance in future tests. For now, it is Recommended for storage.

VALVTECT BIOGUARD

Although ValvTect's Bioguard proved to be an effective biocide, it produced higher than normal levels of precipitate in our tests. If there is any significant amount of bottom water (water that has been separated by gravity and settled to the bottom of the tank), this precipitate should stay in solution and will evaporate, or burn through the engine without harm. The sample also yielded a higher than normal amount of sediment.

Bottom line: Not recommended for storage. If you like the ValvTect brand, go with Bioguard Plus 6.

VALVTECT BIOGUARD PLUS 6

ValvTect's Bioguard Plus 6 includes the same biocide used in Bioguard, along with extra additives to control corrosion and reduce sludge formation. It did not produce the sediment that the plain Bioguard did.

Bottom line: This is a good multifunction additive that can be used for storage and/or routine treatment. A Recommended product for overall use.

STAR TRON DIESEL + BIOBOR JF

A top performer in anticorrosion tests and anti-aging tests, Star Tron Diesel also performed well when used in combination with Biobor JF. In biocide testing trials (Star Tron is not marketed as a biocide), it showed properties that complimented Biobor JF (killed different strains), making the pair a powerful one-two punch.

Bottom line: While this blend requires adding two products, based on our testing, it is the Best Choice overall.

STAR BRITE BIODIESEL

Using the same basic chemistry as ValvTect Bioguard, Star brite's Biodiesel also produced an unacceptable level of precipitate, rendering the diesel off-specification. As with the Bioguard, in the event of any significant bottoms water, the precipitate should stay in solution and evaporate or be so minor that it won't harm the engine, but it is still an undesirable condition.

Bottom line: There are better choices.

GASOLINE

HAMMONDS BIOBOR EB

A top performer in PS's gasoline corrosion tests, Hammonds' Biobor EB is a comprehensive gasoline fuel treatment that claims to prevent phase separation, although we have yet to see any product achieve this. During phase separation a concentrated water/ethanol layer can collect in the bottom of your tank, accelerating tank corrosion and possibly harming the engine. It also claims to stabilize gas to prevent gum and varnish buildup and prevent corrosion. In our tests, it preserved the clearest samples with the lowest gum levels.

Bottom line: A clear winner in this category, Biobor EB is our Best Choice for overall gasoline treatment.

VALVTECT ETHANOL

ValvTect's Ethanol additive proved to be a good anti-corrosion product with acceptable anti-aging properties.

Bottom line: Recommended.

STAR BRITE STAR TRON ETHANOL

We previously tested Star Tron Ethanol for its ability to delay or prevent phase-separation in ethanol fuels, and its ability to burn cleanly without leaving behind any ash residue. In that test, the product came out with a Recommended rating. Although its anti-corrosion protection did

not impress testers, its anti-aging performance was good, which nudged it higher in terms of overall performance.

Bottom line: Star Tron Ethanol offers acceptable anti-corrosion and anti-aging properties at a good price. Recommended.

CRC PHASE GUARD 4

CRC Industries' Phase Guard 4 has been a disappointment. In both corrosion testing and stability testing, our results seemed to indicate that this additive has the potential to do more harm than good under certain conditions.

Bottom line: We do not Recommend this product.

TWO-STROKE OIL

Some claim that adding common two-stroke oil to gasoline can offer all the storage and corrosion protection you need. We categorize this myth as busted. In corrosion testing, the oil actually increased corrosion due to increased water absorption. We saw cloudiness in the aging test as well.

Bottom line: Don't expect two-stroke oil to protect gasoline during storage or use; use one of the Recommended additives.

SEA FOAM

For years, recreational fishermen have been using Sea Foam Motor Treatment to resurrect balky outboards. We found it very effective against corrosion, good in aging tests, and inexpensive. It's available in 16-ounce cans through auto parts supply chains.

Bottom line: Sea Foam gets the Budget Buy pick.

STA-BIL ETHANOL

Sta-Bil's Ethanol additive performed well in our corrosion test at lower seawater levels and earned a Recommendation. In terms of protection against aging and overall performance, it did not excel.

Bottom line: Although Sta-Bil has a long history in the marketplace, our tests indicate that better products are available.

CONCLUSIONS

While anti-oxidation additives logically help against fuel aging, it seems clear to us that copper and zinc ions are the main driver and that corrosion control additives are key. Keeping water out of the fuel system and avoiding the use of copper and zinc alloys in the system should be high priorities. Gasoline is more vulnerable to both atmospheric- and metal ion-induced aging, but if you follow our storage guidelines, use a good additive, and install a vent filter, you can expect fuel to still be good after two years.

See our blog post, "Fuel Storage Tips for Sailors," (Sept. 21, 2015) for our storage guidelines and links to related articles.

Without taking any safe guards, fuel quality will deteriorate within months. Diesel will also require an effective additive and careful attention to our storage guidelines. If these are followed, you could see up to three years of storage life—although this may be an unreasonable expectation in the real world. In both cases, the stability of the base product and the effectiveness of the refinery additive treatment will affect results.

We launched our investigation into fuel additives five years ago, full of skepticism and expecting mostly snake oil. In the end, we've found products that can do remarkable things. However, each testing round reinforced a very simple maxim: Pure fuels are quite stable and only turn foul when contaminated—not uncommon in marine fuel systems. Water won't burn. Once it is in your system, it supports corrosion, biological growth (diesel only), and phase separation (E-10 gasoline only).

One of the most common entry points for water is the filler cap. Inspect the filler cap for leaks. A silica-gel vent filters provide further protection against moisture absorption in diesel and gasoline tanks, and prevent the loss of volatiles in gasoline tanks.

Diesel bio-sludge can clog filters, so we recommend regular use of biocides and multi-function additives to reduce corrosion and sludge formation. Copper and zinc greatly accelerate

oxidation; try to use only stainless-steel, cadmium-plated steel, and aluminum fittings and valves. If the tank is dirty or contains free water, a pump-out and cleaning is the solution. No miracle additive can fix these problems.

Although our fuel storage tests—showing multi-year protection—are encouraging, they don't mirror the real world. A better plan is to try to burn through your fuel in less than one year.

The accompanying Value Guide table tells the complete story. Unfortunately, a few products did not earn overall recommendations simply because they were not included in the past corrosion trials. When we revisit the topic of fuel additives in the future, we will work to fill in these blanks.

For gasoline, we like Biobor EB, Mercury Quickstor, and Sea Foam. For diesel additives, we like Star Tron and Biobor JF used together; Star Tron provides complimentary anti-bug activity (different chemistry from BioBor JF), good anti-aging properties, and superior corrosion protection. ValvTect Plus 6 was also impressive. Our on-the-water experience with these products tells the same story; combined with best management practices, our fuel system problems have been vanquished.

Photos by Drew Frye

SYSTEMS

PS VALUE GUIDE — DIESEL ADDITIVES FOR STORAGE

PRODUCT	CORROSION (*PS* AUGUST 2013)	STORAGE STABILITY	OVERALL RANKING	APPROX. COST TO TREAT
HAMMONDS BIOBOR JF	Not tested as stand-alone	✓		2 cents / gallon
HAMMONDS BIOBOR MD	Not tested	✓		10 cents / gallon
RAYCOR BIOCIDE	Not tested as stand-alone			1 cents / gallon
BIOBOR JF PLUS STAR TRON DIESEL	✓	✓		6 cents / gallon
VALVTECT BIOGUARD	Not tested as stand alone			2 cents / gallon
VALVTECT BIOGUARD PLUS 6	✓	✓	✓	8 cents / gallon
STANDYNE PERFORMANCE		✓		13 cents / gallon
STAR BRITE BIODIESEL	Not tested for corrosion			2 cents / gallon
STAR TRON DIESEL		✓	$	4 cents / gallon
GOLD EAGLE	✓	✓		44 cents / gallon
FUEL RIGHT				3 cents / gallon

SEA FOAM	4 cents / gallon

Best Choice ✓ Recommended $ Budget Buy

PS VALUE GUIDE GASOLINE ADDITIVES FOR STORAGE

PRODUCT	CORROSION (*PS* AUGUST 2013)	STORAGE STABILITY	OVERALL RANKING	APPROX. COST TO TREAT
HAMMONDS BIOBOR ETHANOL BUSTER				7 cents/ gallon
MERCURY MARINE QUICK STOR	✓	✓	✓	18 cents/ gallon
CRC PHASE GUARD 4			Avoid for this use	4 cents/ gallon
POWER RESEARCH PRI-G				4 cents/ gallon
SEA FOAM ENGINE TREATMENT	$	$	$	4 cents/ gallon
STA-BIL ETHANOL	✓			11 cents/ gallon
STAR TON ETHANOL		✓	✓	6 cents/ gallon
PENZOIL 2-STROKE OIL		Emulsif. noted	Avoid for this use	63 cents/ gallon
VALVTECT ETHANOL GAS				15 cents/ gallon

Best Choice ✓ Recommended $ Budget Buy

Testing Fuel Stability in Diesel and Gasoline

We followed standard test methods for storage stability. Diesel was tested using ASTM method D 4625, Standard Test Method for Middle Distillate Fuel Storage Stability at 43C. Samples were exposed to air for up to two years at 113 degrees (45 degrees Celsius); each day simulated about four days of real-world storage, according to industry experience. We settled on 8½ months of exposure, the equivalent of about three years. At the end of each period, samples were filtered, and the insoluble solids weighed.

Gasoline testing was similar, but it was run at 95 degrees (35 degrees Celsius) to limit evaporation; each day simulated about three days of real-world storage. We settled on eight months, the equivalent of about two years. The gasoline samples were evaporated to dryness, and the non-volatile residue measured. For both diesel and gasoline, we used untreated samples as controls. All samples were dosed at vendor-

recommended rates. (See the online version of this article at www.practical-sailor.com for the table of results from our gasoline test.)

FUEL TANK LEVELS

We also explored leaving diesel samples both 90 percent full and approximately 25 percent full. There has always been some debate as to whether it is better to fill the tank before storage to reduce breathing, or to leave room to add fresh fuel in the spring. We did not do this test for gasoline, since our past tests clearly indicate that storing half-full gas tank is a bad idea for many reasons—including an increased risk of explosion. The gasoline samples evaporated fairly rapidly and were refilled when they reached about half-full.

METAL AND ACCELERATED AGING

Our past tests indicated that some metals found in fuel systems can accelerate fuel aging. Because the samples in this test did not appear significantly aged at the six-month mark, we added metal corrosion coupons to one of the controls (all samples were run in duplicate), to see whether copper increased oxidation rates. These samples were aged an additional 2½ months, to the same 8½ month total age as all other samples and controls.

ONBOARD TEST

We've been testing certain products on board a Chesapeake-based test boat that did particularly well in early testing: Biobor EB, Sea Foam, Star Tron Ethanol, and Star Tron Diesel. Our experience should be considered nothing more than anecdotal, since we improved our fuel-handling practices at the same time (generally keeping full tanks, using vent filters, and adding in-line filters on small outboards), but we can say that we graduated from routine fuel problems to not a single starting or running issue in the past four years with any of the six outboards and two diesels involved in testing. The carburetor bowls remained exceptionally clean.

Up to 350 milliliters of aged diesel was filtered, and the recovered insoluables (solids) were weighed.

Multi-stage Testing Looks at Wide Range of Bold Claims

As much as possible, our testers tried to stick with standard tests while also replicating actual fuel-tank conditions as they change over time. Although the makers of these products make similar claims, we saw a surprisingly wide variety of results.

1. A larger than usual amount of sediment was recovered after drying and filtering the ValvTect Bioguard. The Bioguard Plus 6 did not exhibit this effect.
2. The Bioguard sediment was visible in the sample prior to filtering.
3. Diesel discoloration caused by exposure to copper (left, next to untreated control) was evident in our samples.
4. After prolonged storage, the effect of the copper on gasoline was more pronounced.

5. **After aging, testers collected 100 milliliters of each sample. The samples were then evaporated to dryness, and the remaining gum weighed to the nearest 0.1 mg. The two Phase Guard 4 samples are clearly identifiable by the dark color, even with no copper added.**

Reduce Gasoline Evaporation with These Tips

Sometimes it is not what has been added to your fuel that matters, but what is missing. The most obvious difference between gasoline and diesel during our vented, fuel-aging tests was that gasoline samples evaporated and required replenishment at the mid-way point; diesel samples did not. Studies by BoatUS and the U.S. Environmental Protection Agency (EPA) have shown that anywhere between 5 and 20 percent of the contents of a portable or installed polyethylene gas tank can vanish in one year through evaporation and permeation. The remaining fuel is lower in octane, contains fewer of the volatiles that are so essential for easy starting, and has reduced solvency for gum and varnish. It often looks perfectly good—most of our samples did—but it is perfectly rotten and potentially harmful as fuel.

There are several things you can do to ensure that fuel doesn't go bad during periods of long-term storage.

Reduce permeation: New EPA requirements for low-permeation jerry cans, plastic tanks, and hoses are a blessing. The loss of vital volatile material is reduced, and odors are reduced. However, our experience with the new jerry cans and portable tanks has been disappointing. Most of the designs we've tried have serious flaws; we can only hope the market place will sort that out. Metal tanks have zero permeation.

Store in a cool place: Keep jerry cans out of the sun whenever possible.

Vent filters: The EPA mandated carbon filters on new boats, and aftermarket silica-gel filters reduce water absorption and reduce tank-breathing losses. Over their typical 10-year life, these filters can pay for themselves in saved fuel alone before factoring in reduced engine problems caused by corrosion and varnish. (Depending on the boat, you can expect to save 1 to 3 gallons per year.) (See PS January 2013 and PS January 2014.)

Keep the tank full: A full tank does not breath, and fresh fuel renews the volatile content.

Keep the vent closed when not in use (dinghy engines only): Water absorption and evaporation affect small tanks more quickly.

Run the engine often: The silence of wind power is nice, but gas does not keep.

For complete table of results of our gasoline additive testing see the online version of this article at www.practical-sailor.com.

After aging, several normal-looking samples had low octane levels and had reduced ability to fight gum and varnish buildup

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