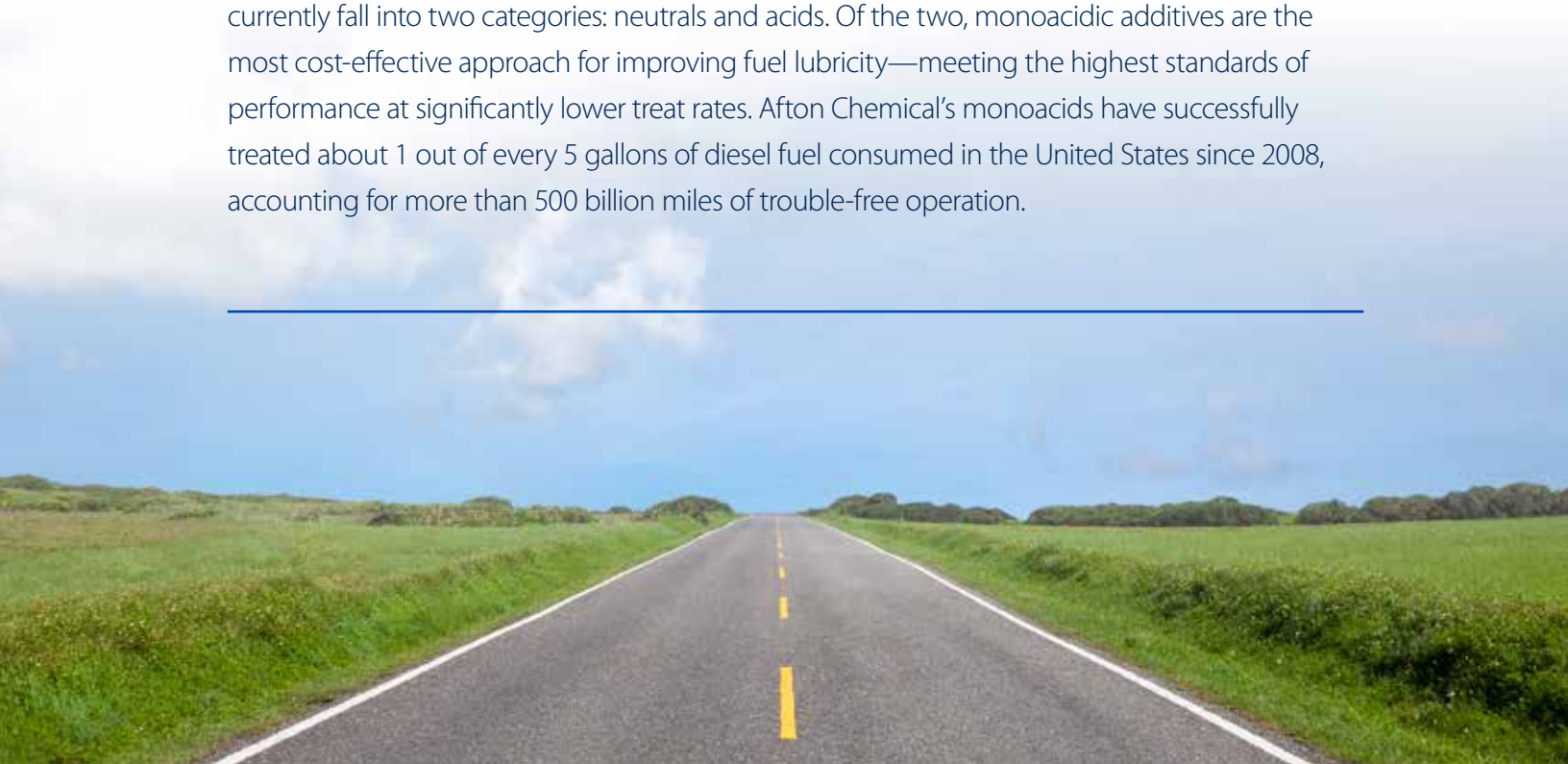
Afton CHEMICAL
Passion for Solutions®

— INTRODUCING HiTEC® 4170, HiTEC® 4171 AND HiTEC® 4172 —

THE NEXT GENERATION OF LUBRICITY IMPROVERS

The impact of emissions regulations and the modernization of engine technology have led to big changes in fuel refining, specifically the desulfurization of diesel fuel.

However, because the desulfurization process results in a reduction of the natural lubricity of diesel fuel, a lubricity specification was incorporated into the fuel specification ASTM D975 in 2005 to mitigate harmful side effects such as engine wear. Lubricity-improving additives currently fall into two categories: neutrals and acids. Of the two, monoacidic additives are the most cost-effective approach for improving fuel lubricity—meeting the highest standards of performance at significantly lower treat rates. Afton Chemical's monoacids have successfully treated about 1 out of every 5 gallons of diesel fuel consumed in the United States since 2008, accounting for more than 500 billion miles of trouble-free operation.



THE RISE OF LUBRICITY IMPROVERS

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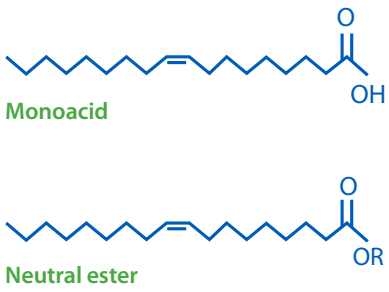
1 Types of Lubricity Improver Additives



As vehicle manufacturers strive to meet demanding government vehicle emissions regulations, diesel engine technology continues to evolve and improve. In turn, the oil industry has modified its refinery processes to support the requirements of modern engine designs. Refineries now include steps in their process to lower the sulfur levels of the fuel. This desulfurization results in fuels with lower viscosities and lower levels of sulfur, nitrogen and other polar and polycyclic aromatic compounds compared to conventional high sulfur diesel fuel.

These ultra-low sulfur diesel (ULSD) fuels have diminished lubricity characteristics, which can lead to metal wear, fuel pump seizures and mechanical problems. To overcome this loss in lubrication and to meet specification, lubricity-improving additives are used. Lubricity additives are generally added at fuel distribution terminals before delivery to end users. Afton Chemical has been providing lubricity additive solutions to meet U.S. industry specifications since 2008.

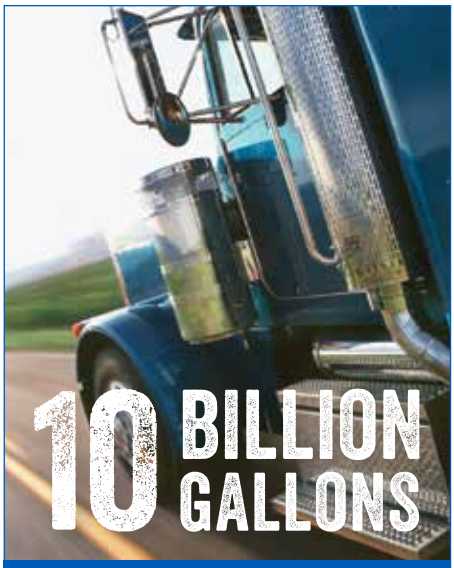
Two Solutions, Similar in Structure

There are two primary types of lubricity improvers available, and they are typically categorized based on their chemistry as either neutral or acidic. Both types are composed of long hydrocarbon chains (tails) with polar end groups (see Figure 1). Neutral and acidic lubricity improvers also function similarly, with polar head groups that adsorb to metal surfaces and soluble hydrocarbon tails that provide a boundary layer. This boundary layer protects metal surfaces from wear and scuffing. Acting in a similar manner, the addition of biodiesel can also improve the lubricity of the fuel.

Acidic lubricity improvers can include those with a single long-chain polar end group (monoacids) and those with two long chains and two polar end groups (dimer acids). Dimer acids are no longer used as lubricity improvers due to interactions that can lead to operability issues, discussed later in this paper.

Neutral lubricity improvers are similar to monoacids with the exception that the acidic end group has been converted to an ester or other neutral headgroup.

MONOACIDS: A LONG HISTORY OF SAFE USE



Our monoacids treat over 10 billion gallons of diesel fuel a year without any performance issues.

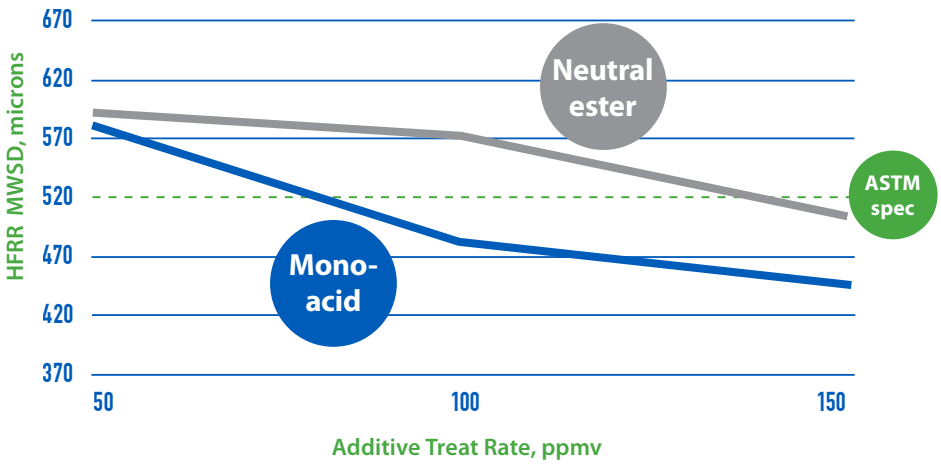
Monoacid lubricity improvers are an extremely cost-effective option that enables users to meet or exceed ASTM D975 lubricity specifications for ULSD. Monoacids provide superior performance at lower treat rates compared to alternative chemistries in the industry-standard High Frequency Reciprocating Rig (HFRR), as seen in Figure 2 below.

Monoacid lubricity additives are not new to the industry—they enjoy a long history of safe and effective global use. In fact, monoacids have been used in diesel fuel longer than any other chemistry on the market today. Europe almost exclusively utilizes monoacid technology for lubricity improvement.

Afton monoacids treat approximately 20% of on-road diesel fuel in the United States. That equates to more than 10 billion gallons of diesel fuel per year without any performance issues.

As an economical and practical approach to meeting lubricity specifications, monoacids also improve the inhibition of fuel system corrosion and are fully compatible with common materials found in the fuel systems of vehicles and in distribution. Monoacids contain a hydrocarbon backbone very similar to many chemical additives used in an array of petroleum applications, making them compatible with most modern additive chemistries used in the industry today. Monoacids are also proven to not interfere with the primary benefits of other fuel additives such as detergents, conductivity improvers, cold flow improvers or cetane improvers. Formulations can be diluted or pre-blended with other additive chemistries if needed.

2 Performance of Lubricity Additives



MONOACIDS: A LONG HISTORY OF SAFE USE

3 A Representation of Dimer Acid Deposits on a Fuel Filter

All Acids Are Not Created Equal

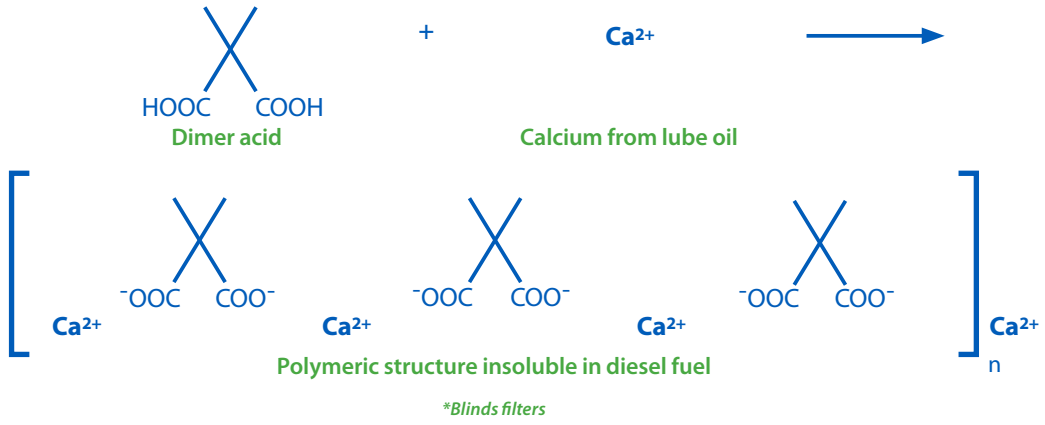
Monoacids are sometimes implicated as contributors to negative interactions in fuel, but these concerns are often misplaced. There is some confusion and inaccurate comparisons drawn between monoacids and other compounds, such as dimer acids, based solely on their acidic nature. In actuality, monoacids have enjoyed a long history of safe use. To ensure the problem-free and safe use of our monoacid technology in fuels and vehicles, Afton conducts extensive no-harm testing.

Dimer Acids

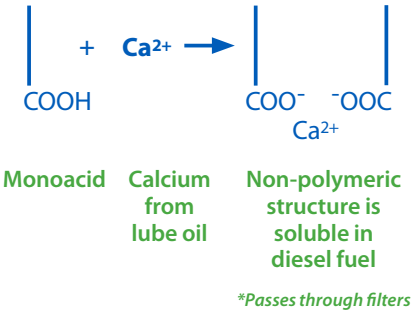
When Europe was at the forefront of desulfurization efforts, dimer acid additives were the first to be used by industry for lubricity improvement because they were already being used in jet fuel. Shortly after the entrance of dimer acids into the passenger car market in Sweden in 1991, field problems were reported and subsequently linked to the use of dimer acids. It was determined that dimer acid lubricity improvers and overbased crankcase oils were interacting to form polymeric insoluble compounds. This resulted in fuel filter deposits, camshaft deposits and fuel pump failures. Figure 3 shows an example of a fuel filter plugged by dimer acid deposits.

Because dimer acids have two polar end groups, each molecule can interact with a divalent calcium metal ion—found in overbased crankcase oil—to form a long-chain, polymeric compound (see Figure 4). Dimer acids were subsequently removed from the market as ULSD lubricity improvers because of their propensity to form these polymeric compounds and their associated problems.

4 Dimer Acid Interaction with Calcium (Simplified Structures)



5 Monoacid Interaction with Calcium (Simplified Structures)

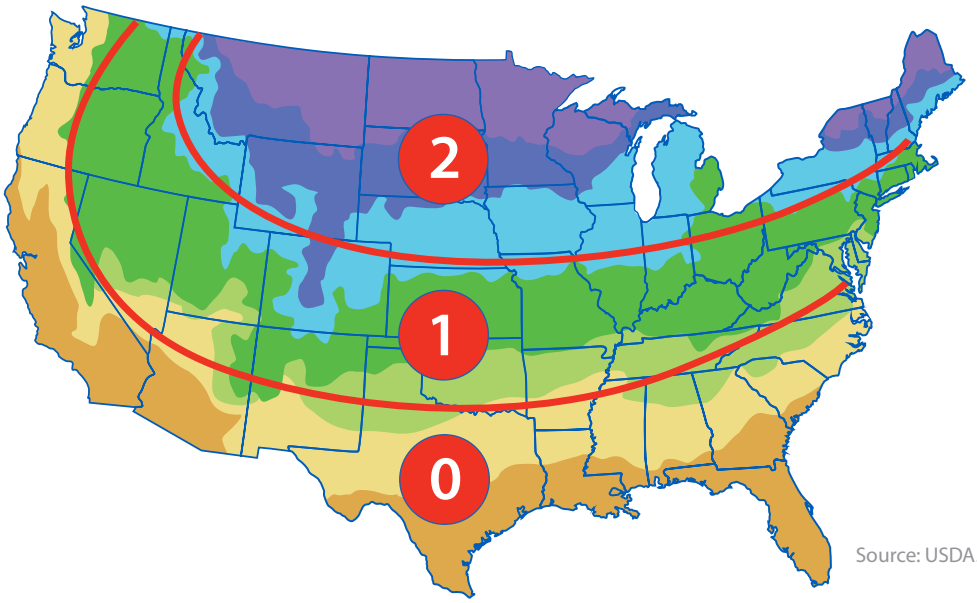


It is important to distinguish that the interaction resulting in polymeric insolubles from dimer acids is not possible with an undimerized fatty acid. Because there is only one polar headgroup on a monoacid molecule, a polymer-type structure cannot be formed (see Figure 5). As added assurance, Afton Chemical conducts lubricating oil interaction tests on all its lubricity additives to ensure no side reactions are occurring.

DDS and HDS Acids

Reports of vehicle operability issues have increased as engine technology improves and tolerances tighten. One leading cause of engine operability issues is fuel injector sticking due to internal diesel injector deposits (IDID). While some have hypothesized that monoacids are the cause of IDID, Afton Chemical has identified the deposits as sodium and calcium salts of dodecenyl succinic (DDS) acid and hexadecenyl succinic (HDS) acid. (See published paper SAE 2010-01-2242 for more details.) DDS acid is a commonly used pipeline fuel corrosion inhibitor. Calcium and sodium contamination can enter the fuel through various inlets including a refinery salt dryer malfunction, seawater or contaminated biodiesel. The salts of these corrosion inhibitors have poor fuel solubility, leaving them available to be collected on fuel filters and form deposits on engine parts where high temperatures and low tolerances are found, such as the fuel injector needle. These needle deposits cause sticking, which can result in incomplete fuel combustion, sluggish engine performance and even engine failure. To help prevent and clean up IDID, Afton recommends the use of alternative corrosion inhibitors for ULSD as well as detergent technology, such as Greenclean®.

A SOLUTION TAILORED TO YOUR TEMPERATURE



Source: USDA.gov

Monoacid Temperature Zones

Zone 2
Formulated to meet the more severe cold temperature handling requirements of the northern region.

Zone 1
Formulated to provide the improved low-temperature handling needed in this region, while still delivering more activity pound for pound than the competition.

Zone 0
Formulated for maximum activity and efficiency to take advantage of warmer temperatures in southern and west coast regions.

As part of our ongoing commitment to provide our customers with additive solutions at affordable treat costs, Afton Chemical is introducing a new line of monoacid lubricity improvers. Following years of extensive research and testing, we've developed three high-quality monoacid additive solutions that contain optimized components designed to deliver easy handling and performance in specific temperature zones.

Traditional monoacid lubricity improvers have properties that require the use of solvents to enable handling, even in warm climates. Cooler climates in particular often necessitate extreme dilutions, heated storage or the use of neutral chemistry additives. These solvents result in higher treat rates, more frequent deliveries and increased freight.

Our three climate-specific monoacid solutions are available as a lubricity improver or a combination lubricity plus conductivity improver.

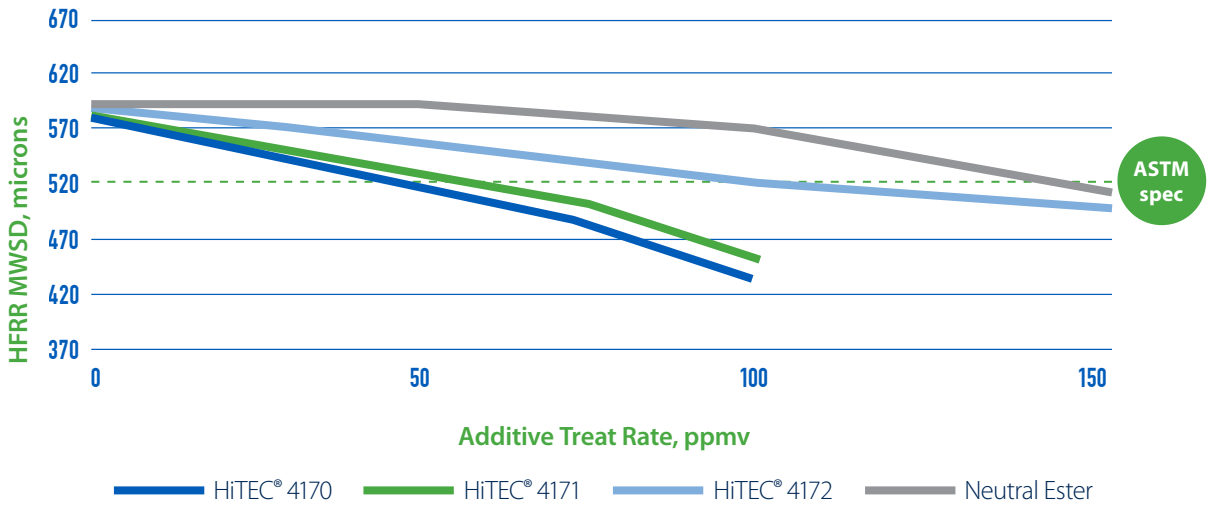
Available exclusively from Afton, HiTEC® 4170 is a low-sulfur and completely solvent-free monoacid lubricity improver additive. For customers in Zone 0, or those with heated storage, a switch to HiTEC® 4170 can result in up to 50% lower treat rates than traditional monoacid packages and up to 70% lower treat rates than traditional neutral packages. Lower treat rates also mean fewer deliveries and lower freight costs—a winning scenario all around.

Customers in Zones 1 and 2 can also benefit from lower treat rates with HiTEC® 4171 and HiTEC® 4172 lubricity improvers, respectively. Carefully formulated for each temperature region, these packages contain a fraction of the typical solvent found in traditional monoacids, while still providing the properties for optimal handling in cooler temperatures. Figure 6 highlights the treat rate benefit you can experience when using HiTEC® 4170-series products.

In addition to our monoacid lubricity solutions, Afton delivers combination lubricity plus conductivity improvers that provide both lubricity and protection from static discharge all within a single injection. Available as HiTEC® 4170AS, HiTEC® 4171AS and HiTEC® 4172AS, our temperature-specific lubricity/conductivity improvers have been formulated to deliver outstanding performance and protection without using excess solvents.

This tailored approach to monoacid lubricity and conductivity improvers is available only through Afton Chemical and exemplifies our Passion for Solutions.

6 HiTEC® 4170 Series Average Lubricity Performance



ENGINEERED TO SAVE MILLIONS

Contact your Afton Chemical sales representative
to learn how our monoacid lubricity improvers can help
you drive home savings without impacting performance.

aftonchemical.com/monoacid

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