Ash Isn't All Bad

By Ian Bell and Huifang Shao


Photo: Tenneco

New research finds balance is key for ZDDP

The lubricants industry is at a critical tipping point. As environmental pollution and its effect on humans grows, pressure continues to drive new legislation designed to control vehicle carbon dioxide emissions and improve fuel economy.

Chemists and engineers at Afton Chemical are collaborating with industry leaders and academic experts to determine how gasoline particulate filters may impact pollutant emissions and system performance on gasoline direct injection engines. This research provides an opportunity to gain groundbreaking insight on particulate filter technology and understand how it interacts with critical ash-forming lubricant additives.

With no previous or standard industry testing to rely on, Afton developed an accelerated method to assess filter durability across the full useful life of an engine, including exposure to fuel and motor oil derived soot and ash. The complex performance impact of the oil on particulate filter durability was mapped out throughout testing, and it was discovered that it is possible to use the ash from oils to actually help filters meet emissions standards.

The use of GDI engines in new vehicle designs has continued to grow as vehicle manufacturers turn to this technology to meet CO_2 reduction and fuel economy standards. Global growth of GDI technology increased from 1 percent to 44 percent of engine production in the last 17 years, and is forecast to reach 62 percent in the next five years.

Compared to conventional port fuel injection engines, GDIs produce high levels of particulate matter that include carbon (soot) and inorganic material (ash). Because this particulate matter can harm the environment and impact health, legislators have taken measures to tighten particulate emission standards on motor vehicles.

Automotive engineers have explored a range of potential solutions designed to lower particulate matter, from in-cylinder control to exhaust emissions reduction. Current research continues to point to gasoline particulate filter technology as the most viable and cost-effective leader for particulate emissions control.

In the future, global legislation requirements for light-duty emissions and target deadlines will only continue to tighten. With GDI adoption showing no signs of slowing down, it is essential to design today for tomorrow's need to control particulate emissions.

Addressing Particulates

Several years ago, gasoline particulate filters emerged as a cost-effective filtration system to help meet future particulate matter standards. In anticipation of this implementation, Afton evaluated particulate filter performance as well as the impact of lubricant formulations.

Though gasoline particulate filters may resemble diesel particulate filters, they are precise systems that require specifically designed solutions, as shown in the table on Page 32. Even though they seem to resemble other technologies, scientific understanding of gasoline particulate filter function and its working mechanisms is important for developing methods that accurately assess filter performance and interactions with other components and fluids.

Gasoline particulate filters are generally of a monolith design. Channels are alternately blocked either at the front face or rear face of the monolith, requiring exhaust to enter the monolith through a channel open at the front face. To exit the monolith, the exhaust gas must pass through the wall to an adjacent channel open at the rear face. This wall flow architecture is designed to trap the particulate matter, which is a mixture of soot and ash inside the filter.

As the exhaust gases move through the filter wall, the particulate matter is deposited in the filter. As exhaust flows into the filter, particulate deposits and an ash cake build up in the filter. As a result of this particulate buildup, a pressure difference emerges across the filter.

This can impact vehicle operation; once enough soot is accumulated, the filter temperature is elevated via the engine operating conditions, and the soot portion of the particulates is burned off (converted primarily to carbon dioxide). This leaves behind the residual ash and prevents it from being expelled into the atmosphere.

Developing a Test Method

Particulate filter adoption has raised questions as to how engine oil combustion byproducts impact their durability. However, no reliable and accurate testing methodology existed previously, so Afton R&D first focused on achieving this objective.

If particulate filter durability and performance were tested utilizing only conditions experienced in use, it would result in a prohibitively long test protocol. To achieve the same results in less time, accelerated aging techniques

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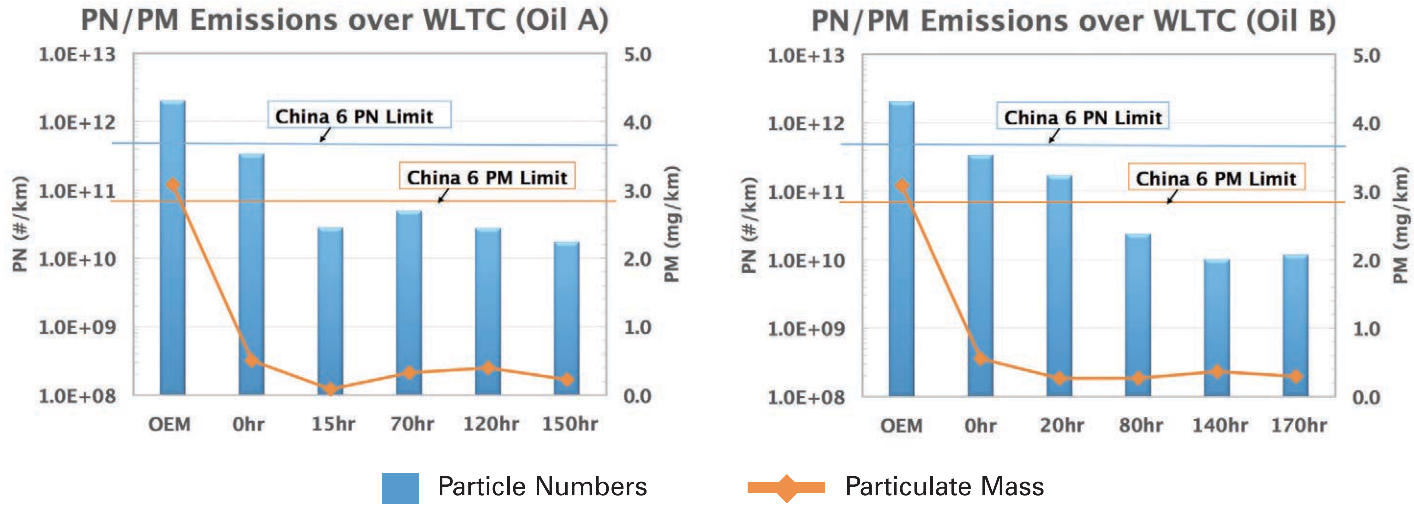
Emissions Performance with Reduced SAP Lubricants



common in the automotive industry were implemented to obtain the appropriate conditions much more quickly than normally experienced in consumer use, while minimizing time and cost.

For a realistic gasoline particulate filter deterioration test method, it is necessary to incorporate key elements, including thermal aging caused by exposure to high-temperature exhaust, loading of ash derived from lubricant and other sources (including wear), and soot generation and regeneration attributed to incomplete combustion and system operations.

The accelerated filter durability method used a passenger car engine as an exhaust generator. In order to define the best test conditions, the researchers developed a comprehensive mapping of engine operation and emission control system performance for parameters such as exhaust temperature, fuel consumption rate, particulate number and soot level.

The map provides guidance to choose conditions and operating modes to balance two contrary aging conditions: the high temperatures that simulate thermal aging and the low to moderate temperature required for soot and ash accumulation and caking. Researchers settled on a three-stage protocol of increased ash loading via oil injection into the fuel, enhanced ash loading plus thermal conditioning, and soot generation and accumulation in the trap without enhanced ash loading. The protocol was utilized to realistically assess hardware technology interactions with lubricating oil and ultimately system performance durability.

High- and Low-Ash Oil Testing

During normal engine operations, a small amount of lubricant is combusted. Some critical components in the

Comparison of Gasoline and Diesel Particulate Filters

	Characteristics	Gasoline Particulate Filters	Diesel Particulate Filters
Similarities	Purpose	Particulate filtration (catalytic conversion)	
	System integration	Packaging concern for light-duty	
	Backpressure requirement	Needs to be reduced	
	Working principle	Three-mode filtration	
	Cost	Comparable	
Differences	Configuration	Ultrafiltration, closed-coupled, four-way catalyst	Ultrafiltration
	Exhaust temperature	High	Low
	Oxygen percent in exhaust	Low	High
	Ash production rate	Low	High
	Ash density	Relatively lower	Relatively higher
	Control strategy	Not available	Onboard diagnostics integrated
	Substrate	Cordierite	Mostly silicon carbide
	Regeneration strategy	Needed, most likely as passive	Needed, can be active or passive
	Cleaning strategy	No physical cleaning	Physical cleaning needed for heavy-duty, not for light-duty
	Technical maturity	+	++

Source: Afton

lubricant formulation are built around inorganic materials (zinc dialkyldithiophosphate, detergents), and their residue after combustion forms ash. The level of these ash-forming additives are controlled in the formulation, but their use is critical to the full functionality of the lubricant. In many cases, these additives are not readily replaced by non-metallic species, so the challenge is to manage their impact on gasoline particulate filter function while maintaining overall performance.

Some of these requirements are readily addressed in isolation. However, when working to address all simultaneously, it becomes apparent that often one aspect of performance conflicts with the delivery of others. The lubricants and the filter need to be designed and evaluated as part of the whole engine, fluid and emission system.

It is in this context that Afton focused on two major areas. The first was ash loading, or the amount of ash captured by the particulate filter, which is primarily determined by lubricant ash content, lubricant oil consumption rate, trap design and vehicle mileage. The second was ash impact on gasoline particulate filter performance, referring to the change in filter operation attributable to the ash. This is affected by lubricant chemistry, filter properties and ash loading.

Using the adopted gasoline particulate filter testing methodology, Afton assessed how high and low ash-producing lubricants affected emission performance across new and aged particulate filters to understand the extremes of the technology. With an ash level ranging from 0.6 to 1.25 percent, the test program covered most oils found in the lubricants market today. The tests were designed to deliver total ash loading on the filter equivalent to utilizing a high-ash oil under normal operating conditions totaling more than 320,000 kilometers.

During testing, critical performance metrics were evaluated, including backpressure, fuel consumption, particulate mass and particulate number. Particulate number and mass remained comparable for high- and low-ash oils in both new and aged gasoline particulate filters. Further, when looking at particulate emissions from new and aged filters, both oils showed improved filtration efficiency.

These findings tell us that ash cake buildup can help boost particulate filter efficiency while keeping emission levels well below the regulation limit. Specifically, the fresh filter is less efficient in filtration than the aged filter where an ash cake built in place assists in the filtration process.

Therefore, controlling the early ash-loading phase is a critical consideration, meaning lubricant ash levels should not be driven down without considering the impact on the overall system. A certain level of ash in the oil is needed to ensure that the filtration efficiency reaches an adequate level, and the lubricant ash is necessary to build up a filtration cake that provides the system efficiency and the effective emission reduction. Based on this work, other parallel studies and established experience in broader performance requirements, Afton believes the current norm within the industry of 0.8 percent sulfated ash affords a near optimum balance of lubricant and system performance requirements.

Having tested impacts of lubricants producing high and low levels of ash, the group turned to those generating mid-level buildup.

Reduced Ash Oil Testing

Building on the above work, two reduced ash lubricating oils (as opposed to low-ash oils) were tested: a product from Afton meeting the ACEA C3 oil sequence (Oil A) and a balanced detergent formulation meeting the design requirements for reduced low-speed pre-ignition events (Oil B). The graphs on page 32 reveal that each gasoline particulate filter easily met emission requirements at the end of the durability test.

To better understand the early filtration process, particulate number and particulate mass both upstream and downstream of the particulate filters were studied. The research showed that as ash loading continued, filtration efficiency improved, lowering particulate emissions.

With growing attention to environmental concerns and continued use of GDI systems, this research informs gasoline particulate filter technology and accompanying lubricants that contribute to emissions reductions well below existing standards. Using a certain amount of ash in the lubricant to radically increase the filtration efficiency of the gasoline particulate filter is necessary to maintain lower particulate emissions levels. ∎

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