What is LSPI?

BY **LAKE SPEED JR.**

Low Speed Pre-Ignition (LSPI) is an abnormal combustion event that can lead to catastrophic engine damage, and LSPI is common to Turbocharged Direct Injection Engines. Normally, combustion follows the spark event as controlled by the engine management system. In a LSPI event, the combustion event begins prior to the spark event, which causes abnormally high pressures within the cylinder. These high pressures can damage the piston.

Why is LSPI unique to Direct Injection?

Low Speed Pre-Ignition occurs in Direct Injected engines because of the higher compression ratio, 11.5:1 for a GM LT1 and even higher for many others, of direct injection engines and because of the shorter amount of time the fuel has to vaporize. A typical direct injection engine has less than 160 degrees of crankshaft rotation to atomize the fuel compared to over 320 degrees of crankshaft rotation to atomize the fuel in a traditional port injection or carbureted engine. The combination of higher compression and shorter atomization time make direct injection engines more prone to abnormal combustion events such as LSPI.

Engine	Compression Ratio
GM LT1 Direct Injection	11.5:1
GM 3.8 V6 Port Injection	8.5:1

How does fuel atomization and vaporization effect LSPI?

As crazy as it may sound, engines don't burn liquid fuel. I know the gasoline that goes in the tank is a liquid, but the engine must convert the liquid fuel into a vapor in order to burn that fuel. Just like boiling water changes the water from a liquid state into a gas, an engine "vaporizes" the liquid gasoline by spraying the fuel as a fine mist into the hot and turbulent air moving through the engine. This process is typically called atomization, and it is simply the conversion of the fuel from a liquid state into a vapor. If the fuel doesn't turn into a vapor, then the engine can't burn the fuel. Some of that unburnt fuel finds its way into the crevice between the top of the piston and the upper ring land where it mixes with the motor oil that lubricates the cylinder walls. This mixing of the liquid fuel and motor oil is where things begin to go bad chemically.

How does oil chemistry effect LSPI?

It is also important to mention that DI engines create soot, just like a Diesel engine. The soot created in a DI engine can lead to increased abrasive wear in the engine. Because DI engines offer both fuel economy and emissions advantages, the US Department of Energy provide a research grant to Oak Ridge National Laboratory to investigate ways to overcome the current limitations of DI engines and mainstream motor oil chemistry. These challenges pushed Oak Ridge National Laboratory to seek out a lubricant development partner that could supply small volumes of custom motor oil formulas and had a keen understanding of engine hardware. This led Oak Ridge National Laboratory to contact Driven Racing Oil to provide these custom formulated motor oils. Driven partnered with EFI University and even invested in their own direct injection engine, a GM LT1 engine, to quantify the results of formulation, tuning and hardware changes in a high performance direct injection engine.

The efforts of this group found that reducing the amount of Calcium detergent and eliminating the Sodium detergent in the motor oil formula reduced the frequency and severity of LSPI and other abnormal combustion events. Testing also revealed that increasing the level of Molybdenum reduced the tendency of abnormal combustion events. Once the main culprits, calcium and sodium based detergent additives, had been identified, research began to understand why these additives contributed to LSPI. It is hypothesized that calcium and sodium detergents chemically react with the fuel to create a third chemical that is neither fuel nor motor oil. This third chemical has a lower octane value than either the fuel or the motor oil, so the detonation resistance is lower. Because of the lower detonation resistance of this "blended" molecule, abnormal combustion

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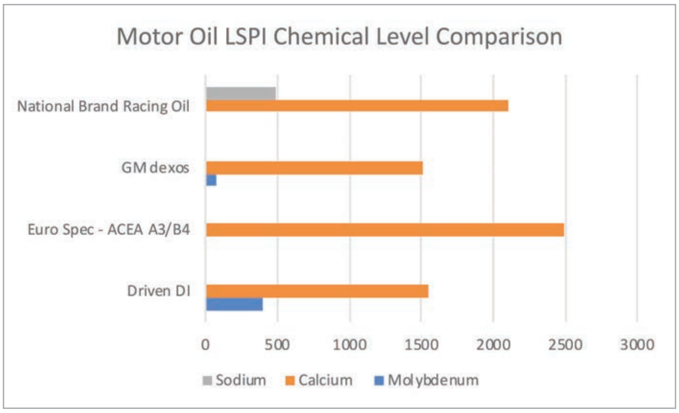
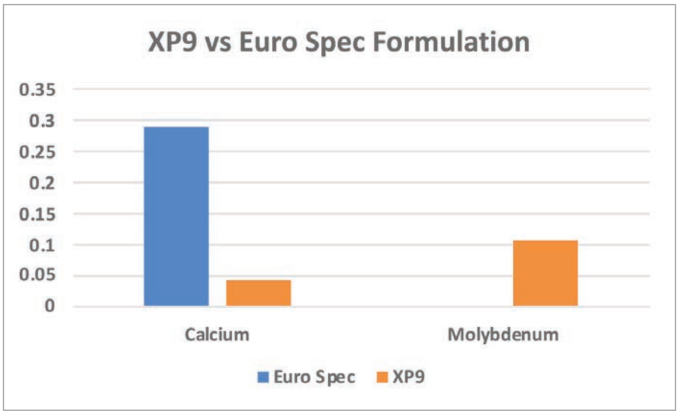




results, which we call Low Speed Pre-Ignition. This was proven out by blending oil formulas that eliminated Sodium detergents and greatly reduced Calcium detergents. These research formulas also eliminated LSPI events.

This was a key finding, but it also presents a problem for the vast majority of off-the-shelf motor oils. Because calcium based detergents are the most cost effective detergents, calcium based detergents are widely used detergents in off-the-shelf motor oils, typically in high concentrations.

Around this same time, Driven had the opportunity to work with the Mini Challenge series in the UK to help them solve a problem with LSPI in their Turbo DI engines. The UK based

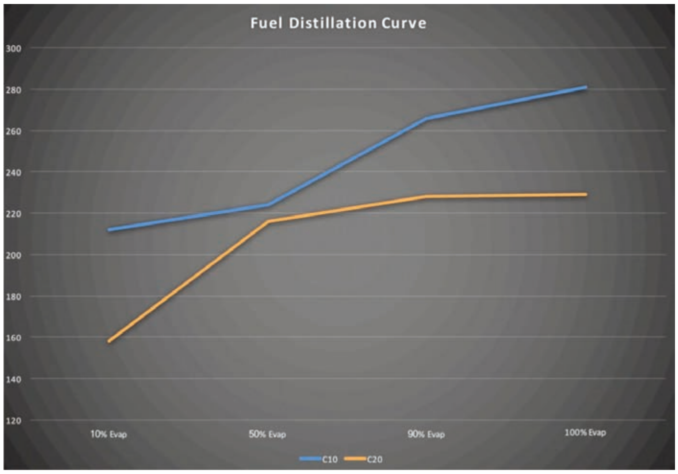
Mini Challenge series had been using a European road spec oil that happened to contain over 2,500 parts per million (ppm) of Calcium detergent. While using this oil, the Mini Challenge series suffered from several engine failures due to LSPI. Once the series organizers and engine builder became aware that these failures were due to LSPI, the series fuel supplier, Sunoco recommended contacting Driven Racing Oil. That call resulted in a change to Driven's XP9 Racing Oil, which contained only 250 ppm of Calcium detergent. Compared to the previous oil with more than 2,500 ppm of calcium detergent and no Molybdenum, lowering the calcium level to 250 ppm and adding 1,000 ppm of Molybdenum eliminated the LSPI related engine failures.

Simply put, motor oils formulated with high concentrations of Calcium detergents are the primary contributor to LSPI events in direct injection engines. To avoid potentially catastrophic damage, motor oils must be formulated specifically for direct injection engines to ensure engine durability.

Why Low Speed?

You may be wondering why the focus is on low engine speed. That is a fair question. At low engine speeds the turbulence of the intake charge is less than at higher engine speed. The lower turbulence leads to less atomization "assistance" by the intake charge. Imagine an engine running at idle at a stop light. The engine speed is low and there is no load on the engine. In this scenario, the fuel charge has less turbulence to assist atomization/vaporization as well as lower piston temperatures due to lower engine loads. Both reduced turbulence and lower piston temperatures work against atomization/vaporization of the fuel. Now add in back pressure from a turbocharger, and you have a recipe for reduced cylinder scavenging of a poorly atomized fuel charge. It is no wonder that direct injection engines experience higher levels of fuel dilution in used motor oil samples than port injection engines!

A long, low speed idle followed by a hard acceleration at full throttle is the perfect condition for an LSPI event – increased fuel dilution of the motor oil followed by high cylinder pressures.



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Further proof of the atomization theory came from a recent test at EFI University. Utilizing the GM LT1 Direct Injection engine at their testing facility, EFI University was able to data log the factory "knock" sensors to watch for early signs of possible LSPI events.

Ben Strader and his team at EFI University tested two similar octane fuels – VP C10 and VP C20. While these fuels are very similar in octane, 100 octane for C10 and 98 octane for C20, the distillation curves of both fuels are drastically different.

Essentially, distillation is a measure of the ease of a liquid fuel to turn into a vapor. The higher the distillation temperatures, the more resistant the fuel is to vaporization. Conversely, the lower the distillation temperatures, the easier the fuel will vaporize.

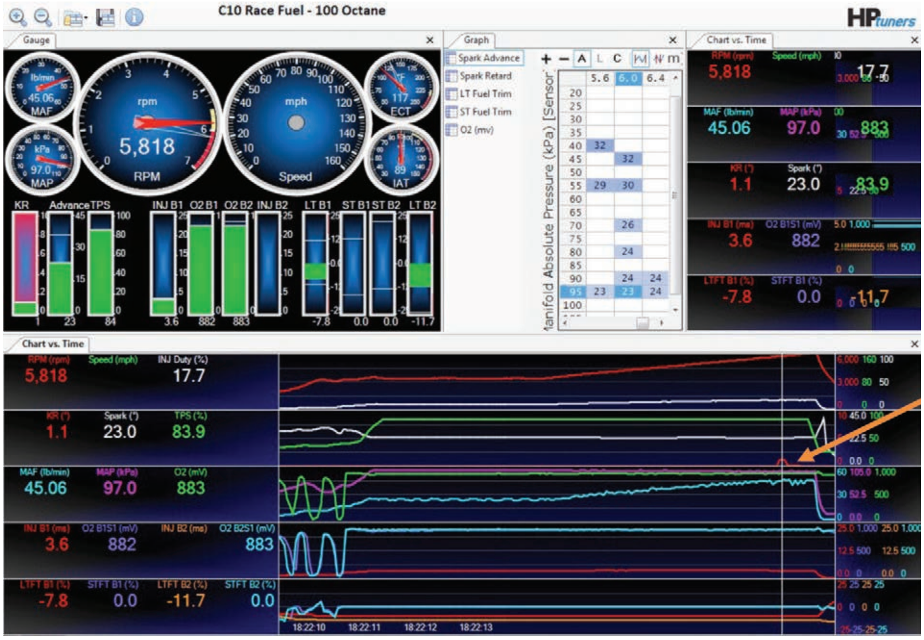
Interestingly, the higher distillation temperatures of the C10 fuel caused the engine to "knock" more than the lower octane and lower distillation temperature C20 fuel. This increased knock due to lessened atomization/vaporization of the C10 fuel proved the theory of non-vaporized/liquid fuel contributing to abnormal combustion events like LSPI.

How to respond to this?

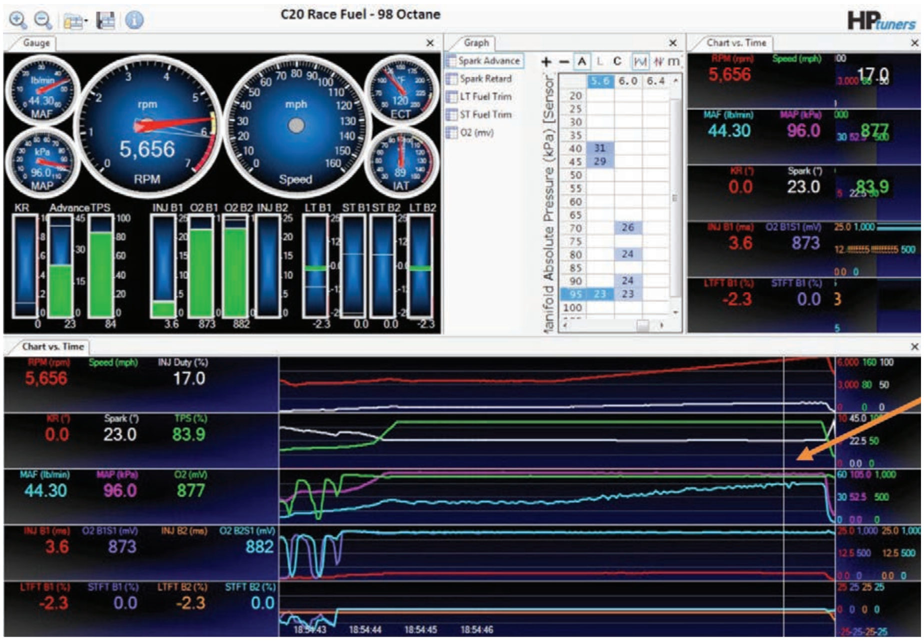
Fortunately, extensive research and engine testing has identified which oil additives contribute to LSPI and which additives can reduce LSPI. By carefully balancing the oil formula, a motor oil can be designed to protect against LSPI without compromising on engine wear protection. In fact, a new API oil specification is under development to bring new generation oil formulas to the market that address these issues related to LSPI.

In the meantime, avoid the use of oils containing high levels of Calcium and Sodium detergents in direct injection engines. GM's dexos spec oils have been reformulated to provide LSPI protection, and Driven now offers a full line of DI specific oils – DI20, DI30, DI40 and DI60.

Motor oils that were built from the ground up to be compatible with turbocharged, direct injection engines provide better protection and performance in direct injection engines. By the end of 2018, the new API SN Plus and GM dexos 1 oil specifications featuring LSPI protection should be widely available.



Orange arrow above points to "knock" event.



Orange arrow above shows NO "knock" events.

Going forward, it is important to pay close attention to the fuel and oil choices for DI engines in order to maximize the performance and durability of these powerful and efficient engines.■

Lake Speed Jr. is the son of Lake Speed Sr., who raced in NASCAR from 1980 to 1998.