



*A Ford illustration shows  
direct injection in action.*

A close-up, black and white photograph of engine gears, showing the teeth and circular shapes of the internal components.

# Small, Hot and Stressed

By KEITH HOWARD

## Turbocharged Direct- injection Is Engine Oil's Next Big Hurdle

**T**he relentless drive to improve engine efficiency and performance has led to the development of small turbocharged, gasoline direct-injection (TGDI) engines. As governmental regulations on emissions and fuel efficiency become increasingly more stringent worldwide, original equipment manufacturers are using TGDI to improve fuel efficiency and reduce carbon dioxide emissions versus comparable port fuel injection technology, while maintaining or improving power output and performance.

It is predicted that 50 percent of new passenger cars sold by 2020 will be equipped with GDI or TGDI engine technology. These engines feature increased power density, squeezing more performance out of a smaller package. However, they have the adverse effect of running hotter and harder than conventional

engines, placing the oil under more stress.

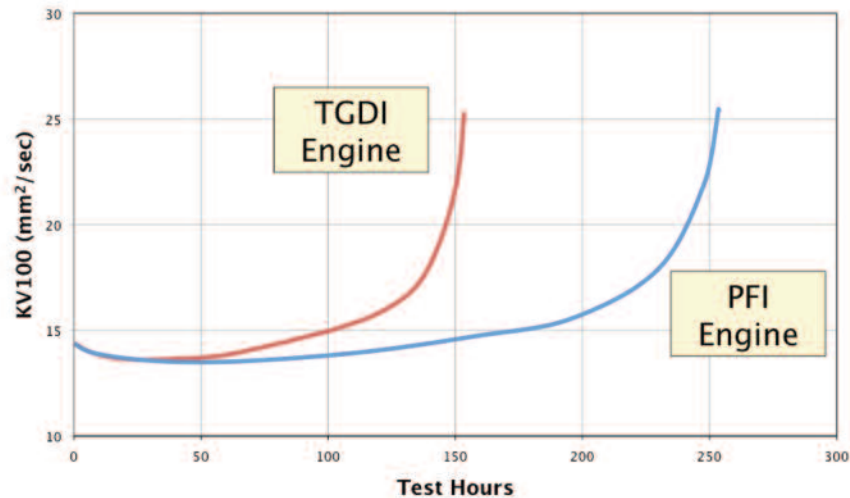
The higher temperatures, often combined with higher fuel dilution, can lead to oxidation, oil thickening, deposits and sludge. Studies show that fuel quality is critical to the reliable operation of TGDI engines. This is a particular concern when these engines are introduced to developing countries. Although fuel in major urban areas is well controlled, the quality in many outlying areas can be very poor, containing more so-called “heavy ends” and sulfur. These constituents lead to increased fuel dilution and acid generation compared to high-quality fuel, causing significant oil degradation.

Under these operating conditions, severe deposits can form on some of the very hot surfaces within the engine, such as those within the turbocharger bearing housing, and lead to bearing failure. In addition to these hard deposits, the increased oxidation can generate significant sludge that blocks filters and oil galleries. Fortunately, engine oil formulators have a lot of weapons in their arsenal to meet these challenges.

### **DI: The Good and the Bad**

In a GDI engine, gasoline is injected directly into the combustion chamber, rather than into the intake port. This arrangement provides significant benefits in power and efficiency over the tradi-

Figure 1.  
**Direct Injection and Oil Viscosity**



*Tests show that viscosity increases at a much faster rate in turbo-charged direct-injection engines than in conventional port fuel injector engines. (Source: Lubrizol Ltd.)*

tional port fuel injection method. Adding a turbo-charger to gasoline direct injection engines greatly increases power, cuts CO<sub>2</sub> emissions and improves fuel economy.

However, with direct injection some of the fuel does not fully vaporize, with the result that GDI engines generally have relatively high levels of very fine particulate matter in the exhaust. This leads to a number of consequences, but most especially health concerns that are spurring governments to place strict limits on emissions of GDI particulates.

In fact, pending Euro 6 legislation will include limits on GDI particulate levels that may require the use of particulate filters on gasoline engines, such as required on diesel engines. Many OEMs believe they will be able to meet the new legislation by improving combustion, but environmental groups are already calling for the universal adoption of particulate filters on GDI engines, even if limits are met. Ash blocking of these filters will then

become an issue, and low SAPS oils — low in sulfated ash, phosphorus and sulfur — will be needed, just as they now are in diesel engines.

A second issue is that the particulates entering the oil via blowby gases increase wear rates. A number of OEMs have noted issues with cam-chain wear when they switch from port fuel injectors to GDI.

Third, the combination of higher torque and smaller engines inevitably results in increased bearing loads. Many OEMs are looking to reduce viscosity to improve fuel economy and CO<sub>2</sub> emissions, but lower viscosity puts these highly loaded bearings at risk. Improved antiwear additive technology will be required to allow a move to very low viscosity engine oils.

One of the lesser understood issues that plague TGD engines is low-speed pre-ignition (LSPI). The ability of these engines to operate at high torque and low speed is of great value to the driver, but it places the engine in the area of the

speed/load map where pre-ignition can occur. In severe cases, LSPI can damage pistons, degrade performance, lower fuel efficiency and increase emissions.

Investigation is under way to determine the connection between engine oil and the LSPI phenomenon. Several OEMs have expressed interest in investigating and minimizing LSPI, and automakers have included it as a performance parameter in their proposed ILSAC GF-6 gasoline engine oil standard.

### The Oil Challenge

A number of studies have been undertaken to investigate oil-related issues in TGD engines. In one study, tests were run on a small TGD engine to examine sludge generation using a test cycle similar to that of the M111 sludge test previously used in Europe's ACEA Oil Sequences. Although the TGD engine was run on a slightly different test cycle, more suitable for this engine type, the severity of the cycle was considered similar to that of the port fuel



Figure 2.

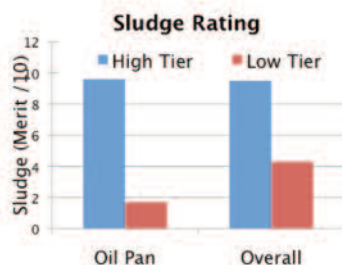
## Sludge Performance in TGDl Engines



Low tier oil: High temperature oxidation drives viscosity increase and sludge deposits



High tier oil: No significant sludge deposits



Low tier = API SG

High tier = ACEA A3/B4 plus added performance for developing markets

injected engine.

The study revealed that the oxidation was much more aggressive with TGDl, and a rapid viscosity increase occurred much earlier (see Figure 1). One conclusion from this test is that running for an equivalent distance on the road can have catastrophic effects on oil condition and, therefore, on the engine. The situation can be significantly improved by using oil formulations that include more oxidatively stable base stocks and more robust additive packages. To verify this conclusion, a test was performed to compare a low tier oil and a modern, high tier oil.

The low tier oil was an API SG quality level, which is technically obsolete but can still be found in developing markets. When the test reached about 180 hours, viscosity rose rapidly, and sludge blocked the oil filter to the point where the bypass valve opened, allowing unfiltered engine oil through to the valve gallery. When the engine was disas-

sembled, large amounts of sludge were found in the oil pan and valvetrain area. The high tier oil was an ACEA A3/B4 lubricant with additive technology developed specifically for use in developing markets, mainly to address the issues of poor fuel quality. This oil has improved antioxidants, detergents and dispersants designed to minimize sludge deposits. At the end of the test, this oil produced sludge deposit ratings close to 10 out of 10 for cleanliness (Figure 2).

The hot gases in the turbocharger turbine area create a very harsh environment for the oil in the bearing housing. This is probably the most severe area in the whole engine for the oil, with oil temperatures exceeding 350 degrees C for short periods.

Under these conditions, lower-tier oils can produce hard carbon deposits on the turbine shaft and bearings. These deposits can build up to the point where the shaft can seize in the bearings, and many of the hard parti-

cles are then transferred into the oil, increasing the sludge-forming tendency.

Again, the higher-quality oil showed significantly better performance in these conditions. The turbocharger shaft and bearings were much cleaner, the oil feed holes were clear, and the possibility of the turbo shaft seizing was greatly reduced (Figure 3, page 5).

### Countering Poor Fuel Quality

A major concern of TGDl OEMs is the wide variation in fuel quality outside major urban areas in developing countries. To assess the effects of low-quality fuel in an actual, on-road environment, Lubrizol ran a field trial in Hangzhou, China, on a medium-size vehicle, powered by the same small TGDl engine used in the dynamometer test. The route was a mix of urban, highway and hilly roads. The trial used a poor-quality fuel, designed to represent those in less-developed areas of China. In particular, the fuel contained some heavy components that are known to

accumulate more in the oil pan and accelerate the degradation of the engine oil.

For this trial, the important goal was to determine whether poor-quality oils would break down in a similar way to that predicted on the engine dynamometer. Therefore, the same low tier oil was used.

In the road test, viscosity began to increase at about 6,000 kilometers and rose rapidly at 8,000 km. Inspection showed that the oil had broken down, and the same oil filter blockage occurred. Sludge deposits were deep and broadly similar to those seen on the dynamometer test.

### Future Oils

The knowledge gained from these investigations has greatly helped in developing oil formulations. The foundation to any good quality engine oil is the right choice of base stock. Two key parameters for TGDl use are oxidation stability at higher temperatures and volatility.

There is a great deal of

Figure 3.

## Bearing Deposits in TGDI Engines



*Low tier oil: High-temperature oxidation drives viscosity increase and sludge deposits.*

*High tier oil: No significant sludge deposits*

focus on API Group III base oils because they provide very good performance in a cost-effective package and are widely available from a number of suppliers across the globe. Performance is close to that of Group IV polyalphaolefin base oils.

In addition, additive technologies are available to provide the much-needed protection from each challenge facing the lubricant. For example, a good combination of antioxidants and detergents can significantly reduce the formation of oxidized species that create sludge, and a balanced mixture of detergents can reduce deposit formation on the pistons. Finally, optimized dispersants can solubilize sludge, preventing its separation from the lubricant.

While the amount of fuel dilution depends on engine design and combustion characteristics, once fuel is in the oil, good antiwear technology can compensate for the fuel's thinning effect. Also, antioxidants and detergents can keep the engine clean if fuel quality is poor.

If future emissions legislation and environmental pres-

sure dictate the use of particulate filters, ash, phosphorus and sulfur content will have to be limited to levels similar to those used in ACEA C Oil Sequences.

Finally, all the chemistries need to be combined in a balanced formulation, including suitable viscosity modifiers. This is where the knowledge and skill of the formulator makes a real difference to the finished fluid.

### Industry & OEM Actions

Industry specifications for engine oils are generally slow to adopt the latest engine types in the list of required performance tests. However, industry organizations and individual OEMs are recognizing that tests based on older engines can no longer guarantee the protection needed for modern TGDI engines. An example can be found in the European ACEA Oil Sequences, where a sludge test using a TGDI engine is currently under development. Also, a TGDI oxidation/deposit test has been proposed, with deposits in the turbo bearing area being a key parameter. TGDI

engine tests have also been proposed for North American specifications.

Individual OEMs need to protect their versions of these engines, and several TGDI engines have recently appeared in OEM oil specifications. In developing markets such as China, domestic OEMs have normally relied on industry standard specifications, but they too are looking at their own specifications, including tests on their TGDI technology.

TGDI engines have many benefits and will be used in greater numbers, especially as fuel economy and CO<sub>2</sub> emissions are increasingly the dominant drivers of engine development. Because of the stress these engines place on the oil, high-quality oils are essential to provide the necessary protection. Experts from the oil and additive industry, in close cooperation with OEMs, are responding to the challenge by developing the next generation of engine oils to enable these hot and hard-running engines to provide years of clean, efficient and reliable operation. ■



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