Influence of the Engine Oil on Pre-ignitions
at Highly Supercharged Direct-injection Gasoline Engines

Increased boost levels of downsizing engines intensify engine knock and can at low speeds and WOT conditions lead to pre-ignitions. Droplets originating from the engine oil are currently one possible cause for triggering pre-ignitions. For this reason the influence of different engine oil specifications on pre-ignitions was examined at the Institute for Powertrains and Automotive Technology at the Vienna University of Technology (TU Wien) in collaboration with BP International.

INTRODUCTION

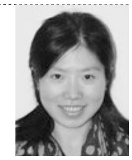
Pre-ignitions are an irregular combustion phenomenon which occur at low speeds and WOT (Wide open throttle) conditions (Low speed pre-ignition, LSPI) in highly boosted downsizing engines. This self-ignition occurs prior to initiation of combustion by the spark. The prerequisite is that already prior to ignition in one or more areas in the combustion chamber, a higher energy state, caused for example by oil and fuel droplets, particles or hot combustion chamber deposits, is pres-

AUTHORS

Dr. Mattias Mayer
is former Project Assistant at the Institute for Powertrains and Automotive Technology at the Vienna University of Technology (Austria).

Prof. Dr. Peter Hofmann
is Associate Professor at the Institute for Powertrains and Automotive Technology at the Vienna University of Technology (Austria).

Dr. John Williams
is Expert Research Technologist at BP Formulated Products Technology in Pangbourne (Great Britain).



Dr. Danlu Tong
is Research Technologist at BP Formulated Products Technology in Pangbourne (Great Britain).

ent [1]. An important mechanism for pre-ignitions is the presence of fluids (for example oil droplets) or particles as well as sufficient time to initiate thermochemical reactions of these substances [2].

FIGURE 1 illustrates on the basis of the cylinder pressure curves, the differences between a pre-ignition, which eventually leads to a mega-knock, compared with a cycle of normal combustion. High peak pressure and pressure oscillations that occur during knocking cause high damage potential.

In addition to oil droplets from the crankcase ventilation and the supercharger, oil fuel droplets may originate from the piston crevice volume. A comprehensive description of the possible triggering mechanisms, caused by oil-fuel-interaction at the cylinder wall, is shown in [4]. Especially increased wall wetting due to direct fuel injection and the presence of high-boiling fuel components [5] lead to a decrease in viscosity and surface tension of the oil. The associated changes in wetting behaviour favour detachment of oil and fuel droplets. Further investigations [6] show that operating parameters, which cause a direct effect on wall wetting, take significant influence on the pre-ignition tendency. After an oil droplet is detached, evaporation takes place and consequently a flame kernel is formed. When the heat release of the flame kernel is greater than the heat losses to the environment, it comes to the self-ignition of the surrounding fuel-air mixture. Otherwise, the flame kernel disappears [7]. Within the context that different causes such as detached combustion chamber deposits or hot residual gas may also initiate pre-ignitions, a methodology was developed at the beginning of this investigations, to verify only oil induced pre-ignitions.

METHODOLOGY IN THESE INVESTIGATIONS

In contrast to other studies [8], in which due to successive load increase critical self-ignition conditions are induced to determine the pre-ignition tendency of individual parameters, this approach is

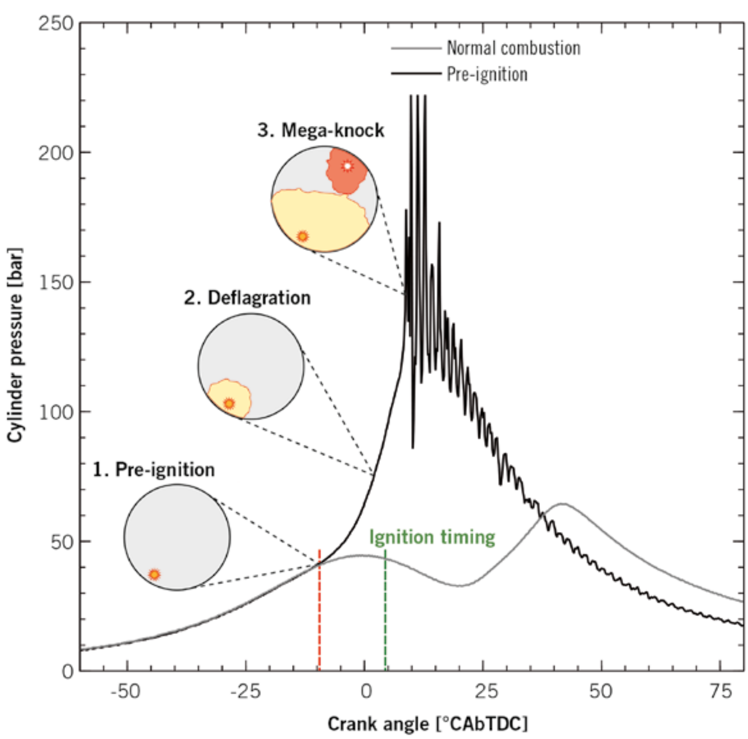


FIGURE 1 Comparing a pre-ignition with subsequent mega-knock with a cycle of normal combustion [3] (© TU Wien)

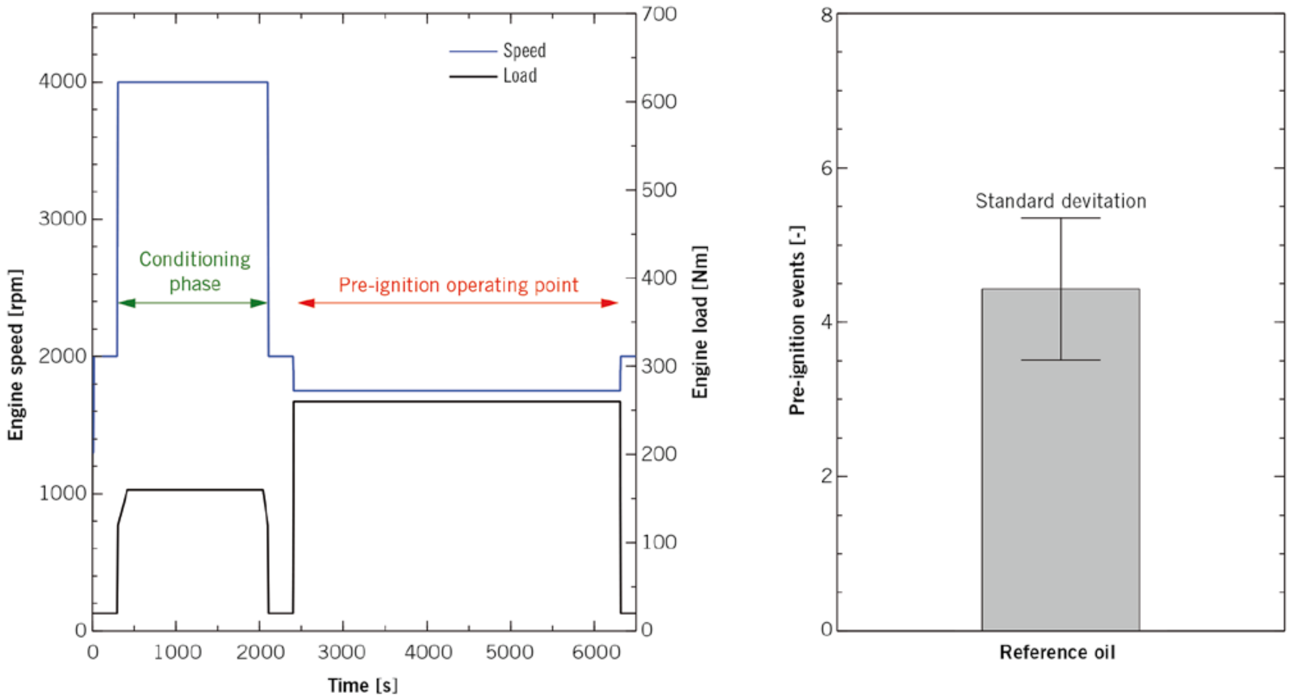


FIGURE 2 Test cycle to verify oil-induced pre-ignitions (left) and illustration of the reproducibility by the reference oil (right) [3] (© TU Wien)

not effective in this case. For the evaluation of oil-induced pre-ignitions a statistical approach is necessary, since the oil-fuel-interaction on the cylinder wall and an associated accumulation have a strong influence on oil-induced pre-ignitions. The test cycle described below, **FIGURE 2** (left), allows under exclusion of further pre-ignition causes a highly accurate, reproducible assessment of oil-induced pre-ignitions.

The test cycle is a refined cycle, based on [9] and [10], which has a very high reproducibility and especially a short cycle time of less than two hours. At the beginning of the test run a 30-minute conditioning phase is carried out at 4000 rpm and medium load, which allows nearly complete removal of deposits and particles in the combustion chamber. After this conditioning phase

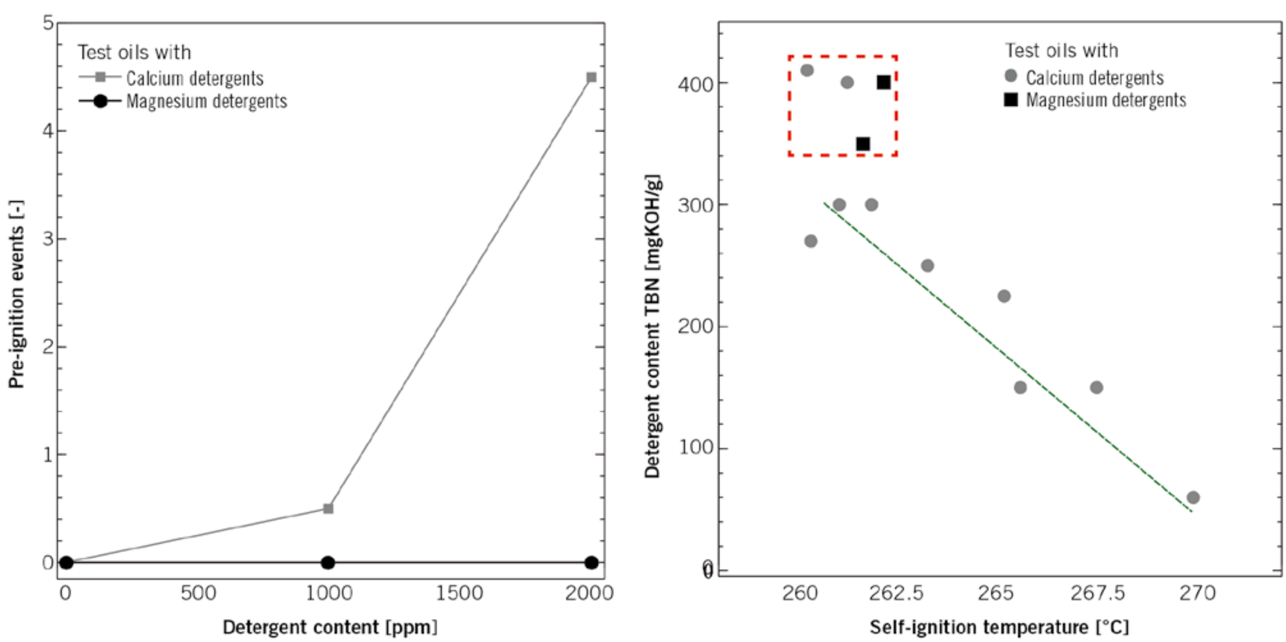


FIGURE 3 Influence of the calcium and magnesium content on the pre-ignition behaviour (left) and influence of metal-based detergents on the self-ignition temperature various test oils according to differential scanning calorimetry at 10 bar (right) (© TU Wien)

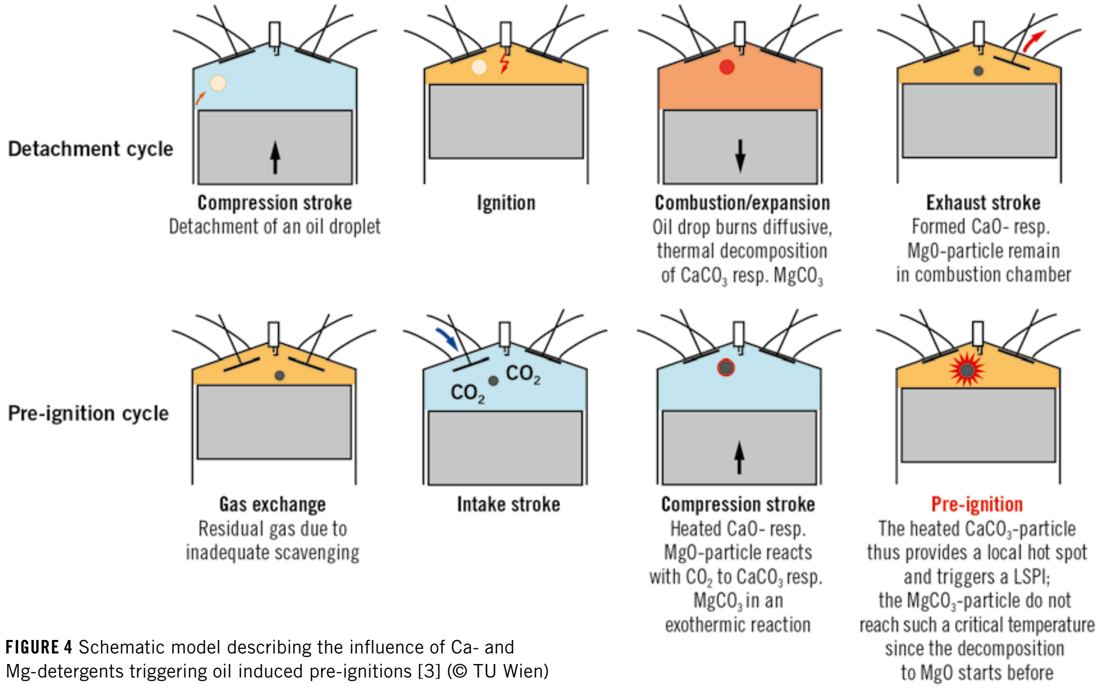


FIGURE 4 Schematic model describing the influence of Ca- and Mg-detergents triggering oil induced pre-ignitions [3] (© TU Wien)

the one-hour measurement in the pre-ignition operating point at 1750 rpm and WOT conditions follows. At this operating point another particle and deposit formation is largely prevented by lean conditions. The number of pre-ignition events in this pre-ignition phase is used for evaluation, wherein at least two test runs are taken into account. In the right half of **FIGURE 2** the reproducibility using the mean value and the standard deviation for more than 20 reference runs is shown. As test engine a modern 1.6-l turbo-engine with lateral injector position was used, which represents a current representative of the downsizing concept.

MEASUREMENT RESULTS

According to the current state of the art the engine oil, and in particular metal-based additives, affect the pre-ignition behaviour [10]. For verification and detailed analysis of this behaviour different detergents and antioxidants at identical base oil are examined. Detergents are metal-based substances (Ca, Mg), which counteract the formation of deposits on thermally stressed components and neutralize acidic combustion products in the oil. These consist of a core of calcium or magnesium carbonate ($CaCO_3$ or $MgCO_3$) stabilized by an oil-soluble group of hydrocarbon chains (Surfactant). **FIGURE 3** shows the influence of Ca- or Mg-based detergents at different additive treat rates on the pre-ignition behaviour and changes in the self-ignition temperature.

The results illustrate from a calcium content of 1000 ppm a highly non-linear increase of the pre-ignition frequency. In contrast to calcium-containing detergents engine oils with magnesium show no tendency to pre-ignite, even at intensified operating conditions. The investigations of the differential scanning calorimetry show basically a very good correlation between the reduction of the self-ignition temperature with increasing detergent content. However, magnesium detergents lead, despite similar low self-ignition temperature as calcium detergents with identical detergent content to no pre-ignitions. These findings illustrate that an increased calcium content triggers or amplifies chemical reactions, which favour spontaneous auto-ignition.

An explanation for this behaviour gives the so-called CaO-theory [11]. Accordingly, a detached oil droplet burns diffusive and the $CaCO_3$ core is decomposed in a CaO particle. The formed particles remain after the gas exchange in the combustion chamber and react during the next compression stroke again with CO_2 (residual gas, EGR). In this exothermic reaction, the $CaCO_3$ particle heats up to about 1000 K and thus provides a local hot spot, **FIGURE 4**.

Due to the endothermic decomposition of $MgCO_3$ already at the temperature level of about 870 K [12] the temperature rise is mitigated. Thus $MgCO_3$ do not reach such a high temperature level as $CaCO_3$, this is about 1100 K [12]. Following this hypothesis magnesium-containing particles do not represent significant hot spots, which can ignite the surrounding fuel-air mixture.

To assess a possible impact of various antioxidants to the release mechanism of oil-induced pre-ignitions the proportion of the friction modifier molybdenum dialkyldithiocarbamate (MoDTC) is increased, as well as the content of organic phosphorus compounds zinc dialkyldithiophosphate (ZDDP) is reduced, starting from a basic configuration. **FIGURE 5** shows in the left half of the model describing the mode of action of antioxidants in the piston crevice volume and the results of the tests with the various antioxidants on the pre-ignition frequency in the right half.

The results illustrate that existing antioxidants effectively counteract the reactions in the low temperature regime, starting with binding free radicals right up to decomposition of hydroperoxides, and thus reduce the pre-ignition tendency.

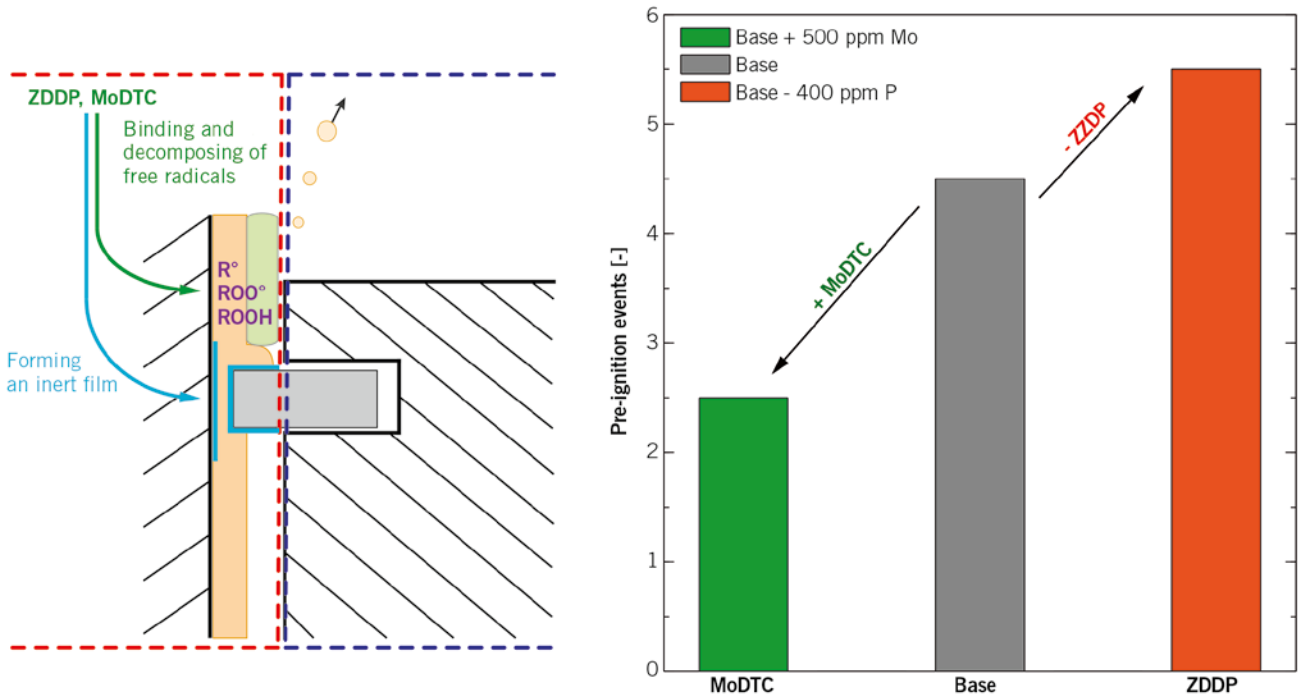


FIGURE 5 Mode of action of antioxidants in the piston crevice volume (left) [3] and influence of various antioxidants on the pre-ignition frequency (right) (© TU Wien)

CONCLUSION

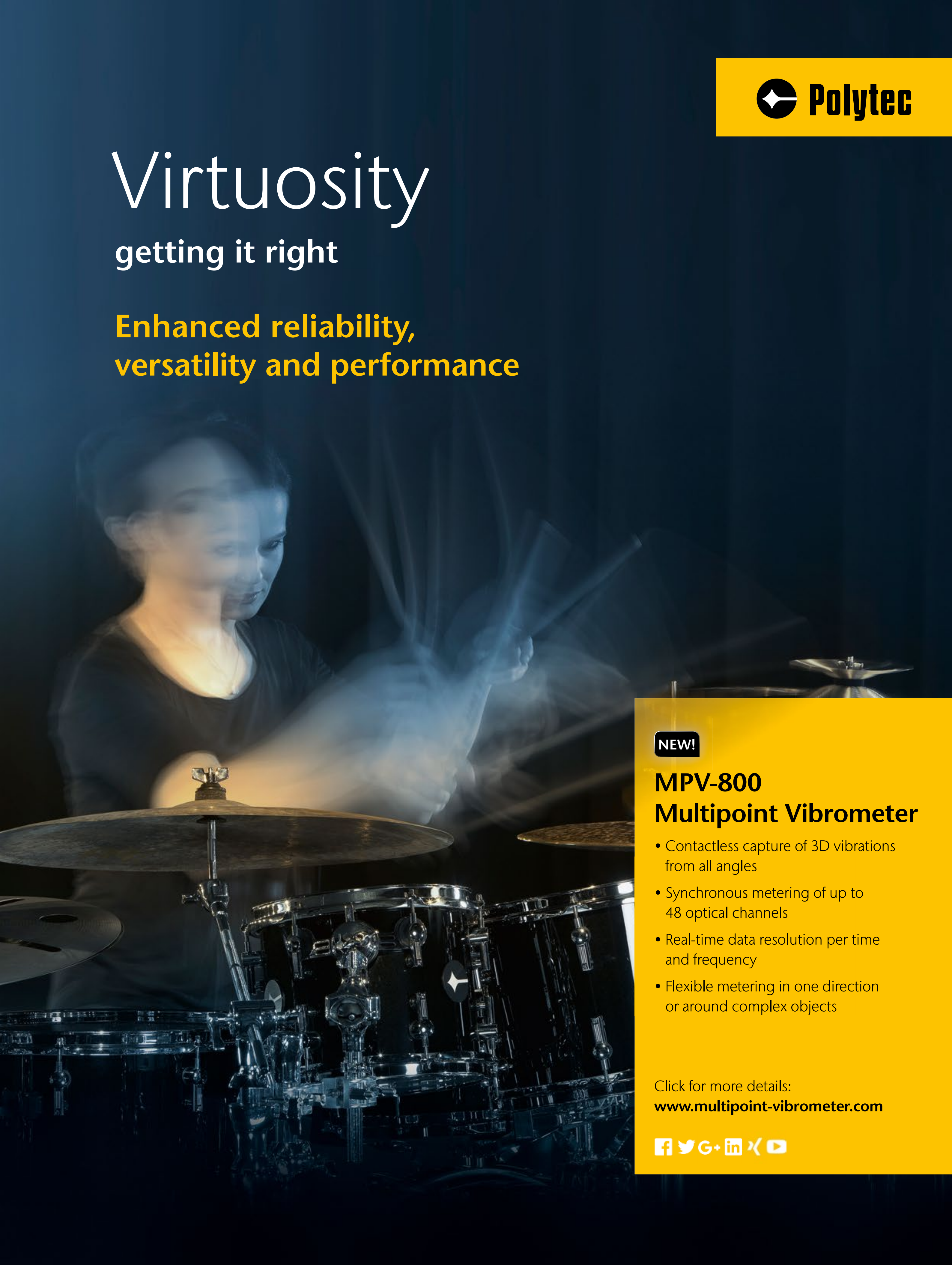
The developed test methodology allows very precise reproducible evaluation of oil induced pre-ignitions. The investigations confirm that the oil composition has a significant impact on the pre-ignition behaviour of highly charged gasoline engines. In addition to the base oil properties especially metal-based additives are decisively involved in triggering pre-ignitions. Increasing the calcium content results in a highly non-linear increase in pre-ignition frequency, while magnesium detergents show no tendency to pre-ignite. In addition, antioxidants effectively reduce the tendency to self-ignition by reactions in the low temperature regime. With appropriate formulations engine oils will be able to make a significant contribution to reducing the pre-ignition problem.

REFERENCES

[1] Merker, G. P.; Teichmann, R.: Grundlagen Verbrennungsmotoren - Funktionsweise, Simulation, Messtechnik. Wiesbaden: Springer Vieweg, 2014
[2] Dobes, T.; Hirsch, A.; Kapus, P.; Ninaus, M.; Ogris, M.; Philipp, H.; Winklhofer, E.: Vorentflammung: Maßnahmen in der Entwicklung und Kalibrierung hoch aufgeladener Motoren. 4. Internationale Fachtagung Ottomotorisches Klopfen, Berlin 2013
[3] Mayer, M.: Einfluss der Motorölspezifikationen sowie unterschiedlicher Kraftstoffeigenschaften auf das Vorentflammungsverhalten von hochaufgeladenen direkt-einspritzenden Ottomotoren. Wien, Technische Universität, dissertation, 2015
[4] Spicher, U.; Gohl, M.; Magar, M.; Hadler, J.: The Role of Engine Oil in Low-speed Pre-ignition. In: MTZworldwide 77 (2016), No. 1, pp. 60-63
[5] Mayer, M.; Hofmann, P.; Geringer, B.; Williams, J.; Moss, J.: Influence of Different Fuel Properties and Gasoline - Ethanol Blends on Low Speed Pre-Ignition in Turbocharged Direct Injection Spark Ignition Engines. SAE International 2016-01-0719
[6] Mayer, M.; Hofmann, P.; Geringer, B.; Williams, J.; Moss, J.; Kapus, P.: Influence of Different Oil Properties on Low Speed Pre-Ignition in Turbocharged Direct Injection Spark Ignition Engines. SAE International 2016-01-0718
[7] Yasueda, S.; Takasaki, K.; Tajima, H.: Abnormal Combustion caused by Lubricating Oil in High BMEP Gas Engines. In: MTZindustrial, May 2013, Special Edition MTZ, pp. 34-39
[8] Kieberger, M.: Untersuchung des Phänomens der Vorentflammung bei der ottomotorischen Verbrennung zur Bestimmung von Einflussfaktoren und von Auslösemechanismen. Wien, Technische Universität, dissertation, 2012
[9] Kunde, O.; Hansen, J.; Zenner, T.; Kapus, P.; Obst, C.; Queenan, B.; Björnsson, H.: Der neue 2.0 SCTi EcoBoost Benzinmotor von Ford. 19. Aachener Kolloquium Fahrzeug- und Motorentechnik, Aachen, 2010
[10] Takeuchi, K.; Fujimoto, K.; Hirano, S.; Yamashita, M.: Investigation of Engine Oil Effect on Abnormal Combustion in Turbocharged Direct Injection – Spark Ignition Engines. SAE International 2012-01-1615
[11] Moriyoshi, Y.; Yamada, T.; Tsunoda, D.; Xie, M.; Kuboyama, T.; Morikawa, K.: Numerical Simulation to Understand the Cause and Sequence of LSPI Phenomena and Suggestion of CaO Mechanism in Highly Boosted SI Combustion in Low Speed Range. SAE International 2015-01-0755
[12] Maitra, S.; Chakrabarty, N.; Pramanik, J.: Decomposition kinetics of alkaline earth carbonates by integral approximation method. In: Cerâmica 54 (2008), No. 331, pp. 268-272

THANKS

Special thanks go to Dr. Andrew Smith and DI Martin Huber of BP International Ltd for their support as well as to Dr. Paul Kapus of the AVL List GmbH for his support and significant involvement in the adjustment of the developed test methodology.


Polytec
Virtuosity
getting it right
Enhanced reliability,
versatility and performance
NEW!
MPV-800
Multipoint Vibrometer
• Contactless capture of 3D vibrations from all angles
• Synchronous metering of up to 48 optical channels
• Real-time data resolution per time and frequency
• Flexible metering in one direction or around complex objects
Click for more details:
www.multipoint-vibrometer.com