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Influence of Lubricating Oil Additives on the Particulate Raw Emission Behavior of Gasoline Engines

Stricter emission limits and increasingly optimized combustion processes are shifting the focus of investigations into further sources of particle emissions and particle formation pathways. At the Institute of Internal Combustion Engines (IFKM) of the Karlsruhe Institute of Technology (KIT), particle-influencing oil and fuel additives were investigated and evaluated in terms of particle number and particle size distribution within the framework of the FVV project no. 1374.

1 MOTIVATION

All of today's fuels and lubricants contain a wide variety of additive components to improve their physical and chemical properties. Although these are usually only added in very low concentrations, their properties and composition can have a noticeable influence, especially on emissions of very small particles. Detailed knowledge of the mechanisms of action and influence is necessary to enable additive manufacturers to develop alternative solutions. Research questions can be directed in particular to the following topics:
- influence of fuel composition
- influence of oil composition
- influence of oil additives on particulate emissions
- differentiation of soot emissions from oil or fuel combustion
- oil introduction into the combustion chamber and its mechanism and effect on particulate emissions.

To be able to evaluate and reduce particulate emissions from gasoline engines with Direct Injection (DI), it is necessary to understand under which influencing variables soot or particles are formed and how these influence the particle characteristics, size distribution and concentration in the exhaust gas. The focus here is on influences on the lubricant side, which, in addition to the type of process interaction, are caused in particular by specially added additive components.

2 COMPOSITION AND FORMATION OF PARTICLES

Particles (aerosol emissions summarized under the term particulates) consist mainly of an organic fraction, nitrates, sulfates, ash, as well as carbonaceous compounds. The composition depends on several factors such as fuel, operating point, combustion process and external influences. Based on the particle formation mechanisms and the diameter, a classification of soot emissions can take place over a continuous size spectrum into a nucleation, accumulation, and coarse dust mode. In the nucleation mode, which is also referred to as the seed mode, in addition to small carbon particles, unstable volatile hydrocarbon compounds are also involved [1]. Subsequently, the particle size increases due to condensation and coagulation processes. This is called the accumulation mode, which contains soot agglomerates from combustion [2].

3 TEST BENCH SETUP

A single-cylinder research unit was used as the test vehicle, **TABLE 1**. The test rig has separate oil, water, and air conditioning units, which means that the external boundary conditions can be kept almost constant, **FIGURE 1**. The fuel supply was realized via two tanks with variable switchover valve, which in turn is connected to a high-pressure pump trolley (rail trolley) to enable DI at the engine. The variable switchover between the fuel tanks allows different fuels as well as fuel-oil combinations to be compared directly during engine operation. An oil injector with reservoir was integrated to realize crank angle accurate oil injection in the intake manifold.

Type	Single-cylinder engine	Unit
Valves	4	-
Bore	84	mm
Stroke	90	mm
Displacement	498	cm³
Compression ratio	10.5:1	-

TABLE 1 Technical data of the engine, an equivalent to BMW's N55 (© IFKM)

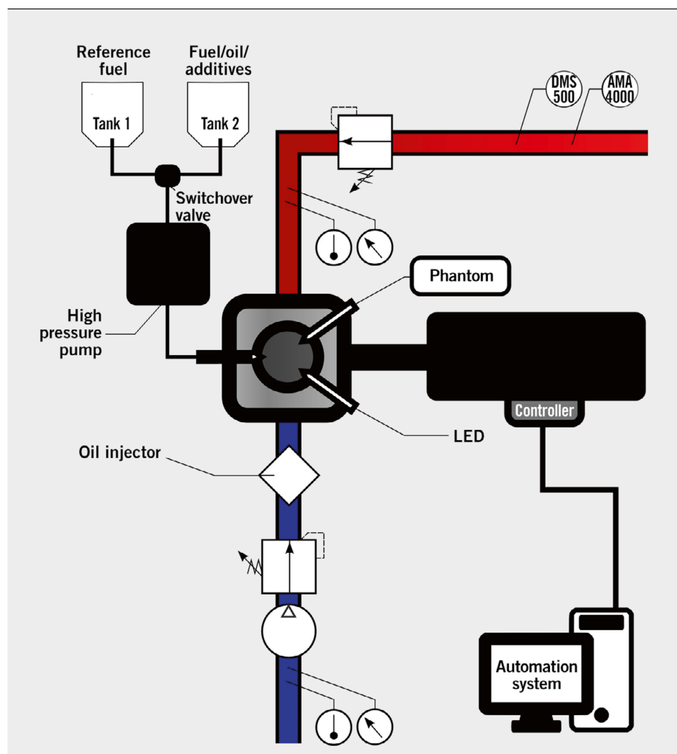

FIGURE 1 Schematic test rig layout (© IFKM))

Oil/additive combinations
Standard engine oil (SEO): Engine oil with all standard additives (0W20)
Base oil (BO): unadditivated engine oil
BO + dispersant (Disp)
BO + detergent (Det)
BO + extreme pressure/anti-wear additives (EP/AW)
BO + viscosity improver (VI)
BO + EP/AW additive and adjusted viscosity equal SEO

TABLE 2 Oil additives and their tested combinations (© IFKM)

The engine was fully indicated to evaluate its thermodynamic behavior. Gaseous emissions were determined using the AMA 4000 measuring device from AVL. A DMS500 from Cambustion was used to measure the number of particles and the particle size distribution. For the visualization of the combustion chamber, two access points were made in the cylinder head: one for illumination and another for an endoscope from Karl Storz. The camera used was a Vision Research Phantom V1612, which provides a crank angle resolved color image of the working cycle of an engine. A Ford three-cylinder solid engine (FOX 1.0 l EcoBoost engine with GTDI) with a compression ratio of 10:1 was used for subsequent validation of the single-cylinder engine results. The exhaust gas was sampled before the exhaust gas aftertreatment.

4 TESTING METHOD

For all tests, an unadditivated E10 certification fuel from TotalEnergies was used as a reference. The single-cylinder engine was operated with a 10W40 engine oil approved for it, which is independent of the oil/additive combinations, introduced within the experiments, **TABLE 2**. The components were provided by Fuchs Lubricants.

The combinations were introduced into the combustion chamber by both DI and intake manifold injection (Port Fuel Injection, PFI). PFI simulates how the oil enters the combustion chamber, for example, via the turbocharger or through the crankcase ventilation. The introduction of an oil/fuel mixture by DI from the premixed tank 2 simulates the washing off of the oil film on the cylinder liner. The amount of oil introduced into the combustion chamber is 1.7 % of the fuel mass for both injections, which is a relatively high dosage. In the case of the PFI, tests were carried out with different oils on a flow bench and in the pressure chamber, which proved that this is the smallest possible injection.

The base oil consists only of pure hydrocarbons. The Dispersant ensures that foreign substances are kept in suspension. Deposits can form on thermally stressed components, consisting for example of organic metals (such as calcium) or metal carbonate [3]. Detergents prevent this process. Extreme pressure/anti wear additives provide wear protection. Viscosity improvers ensure optimization of temperature behavior. The standard engine oil also contains other components such as antioxidants, corrosion inhibitors, and defoamers.

Measurements of the particle count of an oil or an oil additive combination, **FIGURE 2**, were started only after the engine exhibited a stationary behavior. After about 90 s, the oil injection was switched on (in each case by the oil injector or the switchover to tank 2). After a stationary behavior was regained, the oil injection was switched off again. After the particle count had returned to the original particle level, the measurement was terminated. Due to the procedure described above, each measurement of an operating point contains reference values in addition to the influence of the oil, starting from the base fuel, thus ensuring better comparability of the results. Environmental influences on particle formation such as ambient temperature and humidity can thus be evaluated. When calculating the particle size distributions, the reference and oil influence measurements were each averaged over 60 seconds.

5 RESULTS

As described above, a corresponding measurement with reference fuel was carried out for each oil/oil additive combination from **TABLE 2**. Since the particulate emissions here are at a low, almost identical level, **FIGURE 3**, only a reference curve for all measurements is averaged (red). The results for PFI are shown in dashed lines and those for DI in solid lines.

The influence of the additives can be clearly seen, with it being greatest for the detergent (yellow). The height of the respective peaks with DI or with PFI is one order of magnitude above the reference measurements. The position of the peaks at 10 nm can be attributed to organic metals, which are a typical component of this additive [4]. The standard engine oil (blue-green) shows compa-

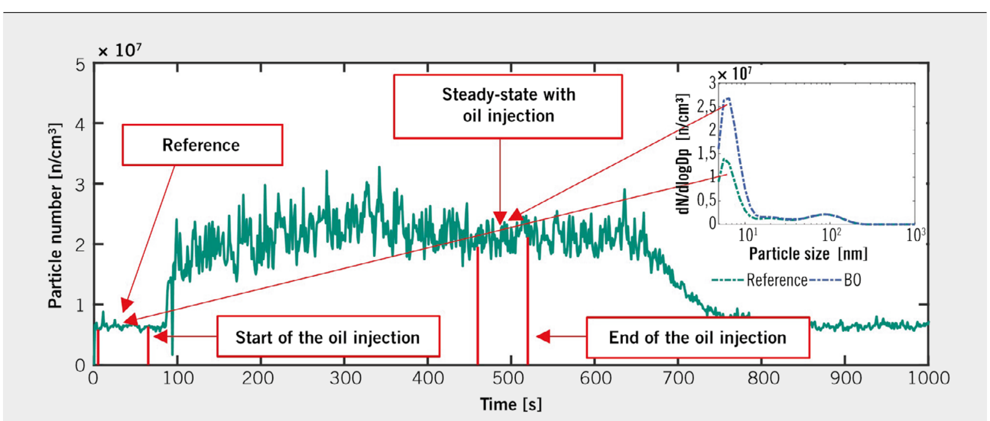

FIGURE 2 Exemplary measurement of a test: particle count before, during and after oil injection (© IFKM)

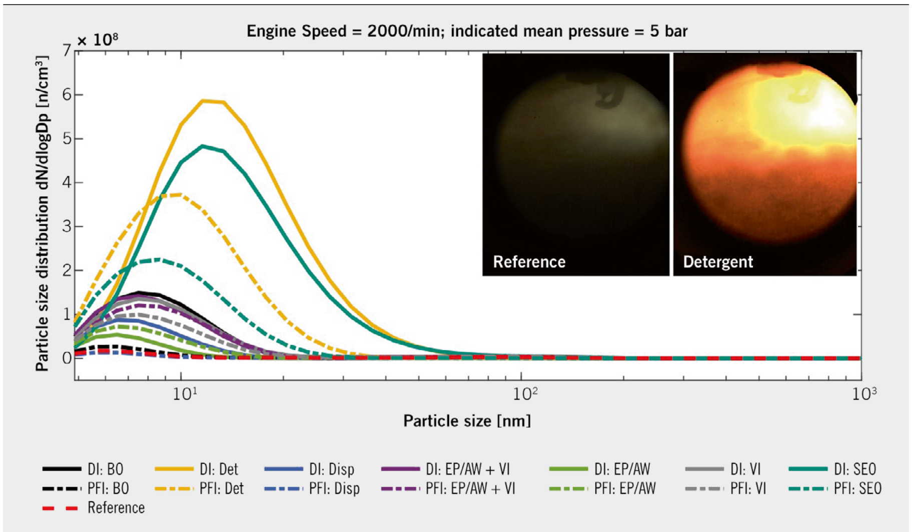

FIGURE 3 Influence of oil injection: comparison of oil injection into the intake manifold (PFI) with direct injection of the oil/fuel mixture (DI), including optical images (top right) (© IFKM)

rable peaks. Since it is a fully additivated and thus also detergent-containing oil, a comparable behavior is to be expected. The lower level can be attributed to the fact that the dosage of the additive in the standard engine oil is lower than that of the detergent in the base oil.

A lower influence is seen with the combination of the anti-wear additive with viscosity improver (violet). The particle size distribution here lies exactly above the curve of the base oil with adjusted viscosity (gray). It can be seen here that viscosity improvers cause an increase in particle emissions. To improve the temperature behavior, oil-soluble polymers are used as viscosity improvers. These can participate fully or partially in combustion and thus promote soot formation [5]. In contrast, the particle emissions measured for the unadditivated base oil, dispersant and anti-wear additive do not deviate at all or only slightly from the respective reference measurement.

For DI and PFI, the trends and position of the peaks are almost identical. Only the level of absolute particulate emissions for the PFI is below the studies on the DI. This is attributed to the fact that in PFI, instead of a spray flowing directly into the combustion chamber with the air mass, an oil film is formed on the bottom of the intake manifold. Here, it is assumed that only a part of the oil participates in combustion due to poor mixture formation and remaining in the intake manifold.

In the case of the reference fuel with detergent additive, a clear homogeneous soot glow is detected compared, which in turn reflects the previously measured particle size distribution. The reddish glow can be attributed to the calcium contained in the detergent, which typically glows in this waveband [6]. Additional investigations on the full engine showed the same behavior in both steady-state and dynamic operation.

6 CONCLUSION

It was shown that some additives have a significant influence on particle formation. Unadditivated base oil shows only a slight influence on particle formation. The addition of dispersant and anti-wear additives compared to the base oil does not cause any measurable changes. Viscosity improvers lead to a measurable, detergents to a significant increase in particle emission. The effects occur independently of the type of oil incorporation. Optical measurements of the soot intrinsic glow confirm the minor influence of the base oil but show a pronounced intrinsic glow with detergent-containing oil. The results were validated in transient operation on a full engine.

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