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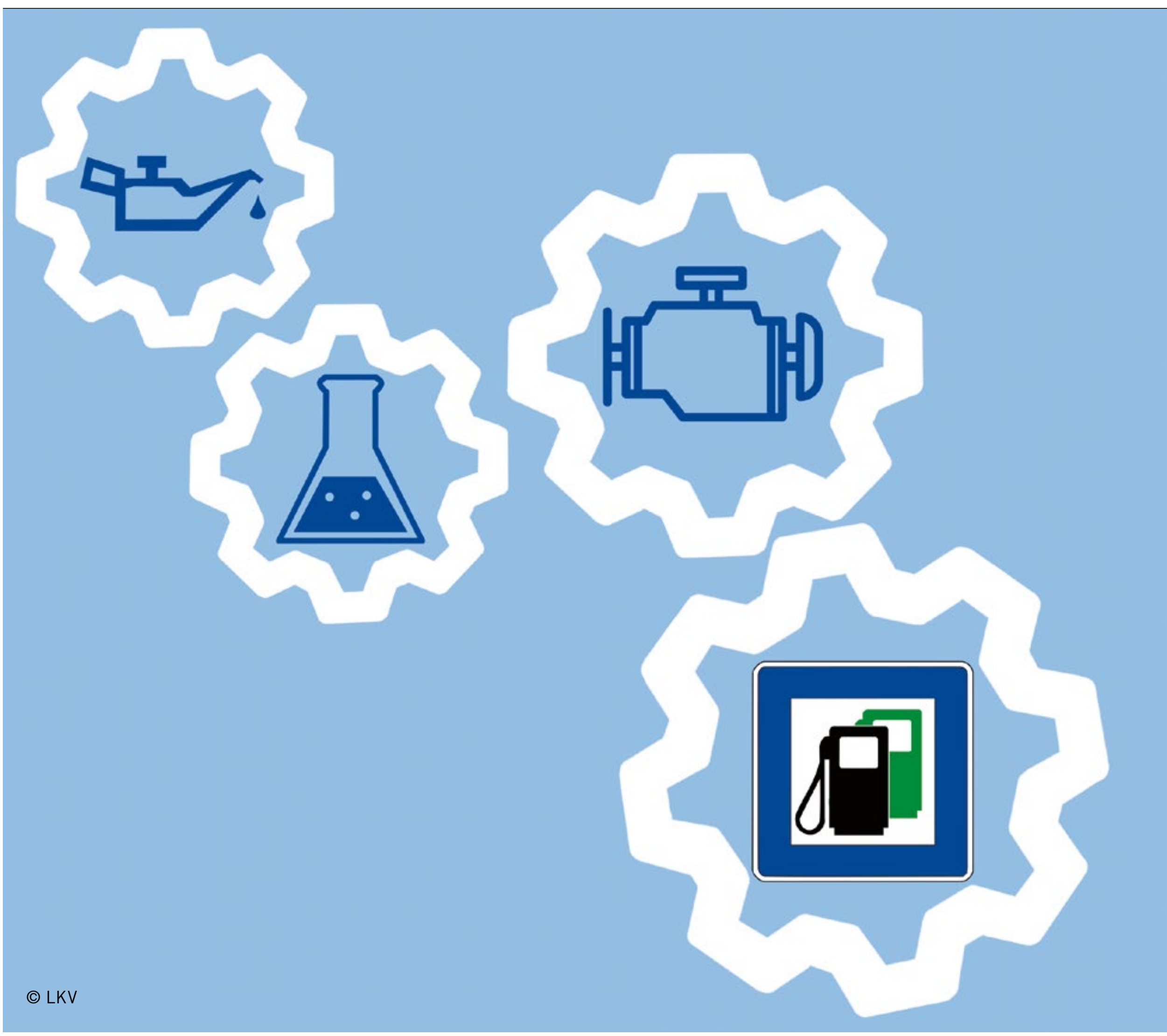
Effects of New Gasoline on the Aging of Lubricants

Due to the growing importance of bio-alcohol blends, it is necessary to understand the impact on the engine lubricating oil system. For this reason the University of Rostock has investigated as part of the FVV research project no. 1228 the influence of higher bio-alcohol contents in gasoline on the aging of lubricating oil and the wear of engine components. The results can also be applied to the use of synthetic alcohols (e-fuels) as blending components.



1 MOTIVATION

In order to limit global warming, fossil fuel is already being substituted by bio-alcohol components such as ethanol and methanol. With regard to the well-to-wheel balance, the second generation of bio-alcohols [1] has a significant potential to reduce CO_2 and Greenhouse Gas (GHG) emissions, which allows further decarbonization in case of further substitution. The influence of higher bio-alcohol contents in gasoline on lubricating oil aging, the entry of short-chained organic acids into the lubricating oil and the wear of engine components, has not yet been sufficiently clarified. The aim of the research project was the systematic analysis and evaluation of the influence of two bio-alcohol fuel blends on lubricating oil aging in a modern Euro 6 gasoline engine, **FIGURE 1**.

2 TEST ENGINE AND OPERATING MATERIALS USED

For the investigations, four identical 2-l R4-TFSI engines from Audi AG were used. These modern series gasoline engines are equipped with a three-way catalyst to comply with the Euro 6 emissions legislation [2]. Furthermore, the engines use a state-of-the-art gasoline direct injection system as well as a port fuel injection system.

In total three fuels were used for the short- and long-term engine tests at the test bench. The two bio-alcohol blends 30 %-vol ethanol (E30) and 15 %-vol methanol (M15) were specially formulated and certified for the research project. A commercial gasoline without alcohol content (E0) according to DIN EN 228 was used as the reference fuel. Selected characteristics were compared, **TABLE 1** and **FIGURE 2**.

A specially manufactured test lubricating oil of viscosity class 0W-20 was used, where the alkaline reserve was reduced by half compared to the series lubricating oil. The aim of this measure was to accelerate oil aging effects and any resulting component wear; analogously, the engine operating time should be reduced in order to be able to detect any potential component wear caused by this more quickly.

3 EVALUATION OF CRITICAL ENGINE OPERATING CONDITIONS BASED ON SHORT-TERM TESTS

For the evaluation of the fuels, short-term engine tests were carried out at eight engine operating points (speed, torque) in cold and hot operation (cooling water and lubricating oil temperature: 35 to 40 °C and 90 to 100 °C). In order to evaluate critical operating conditions for the engine lubricating oil, classic oil parameters had been analyzed. In addition to this, the focus of the project was on the determination of inorganic and organic acid entry (formic and acetic acid as well as nitric acid) into the lubricating oil according to a specially developed evaluation procedure [3]. For this purpose, sample gas was continuously extracted from the combustion chamber (cylinder gas) and the crankcase (blow-by gas) during engine operation and condensed or crystallized by cooling traps embedded in liquid nitrogen (-196 °C). After thawing of the samples, a two-phase mixture consisting of an organic phase (unburned fuel or fuel components) and an aqueous phase (combustion product) was obtained. Within the aqueous phase, the concentrations of inorganic and organic acids were determined to calculate the acid entry of the lubricating oil, **FIGURE 3** and the fuel and water content of the lubricating oil were analyzed. From all of these parameters a systematic has been developed to determine and evaluate the total degradation potential to the engine lubricating oil.

As a result of the evaluation, the following significant findings were achieved for the engine operation with bio-alcohol blends (E30, M15) compared to operation with purely fossil fuel (E0):

- The entry of nitric acid into the lubricating oil is significantly higher for all fuels compared to the input of formic and acetic acid; maximum levels were found for E0 fuel.
- Due to the boiling characteristics of bio-alcohol fuel blends, the fuel content of fossil components in the lubricating oil is generally higher compared to the E0 fuel.
- At operating temperatures of 35 to 40 °C, the fuel and water content in the lubricating oil is significantly higher for M15 and E30 compared to the reference fuel E0. During full-load operation, emulsion formation was partially observed for the bio-alcohol fuel blends.

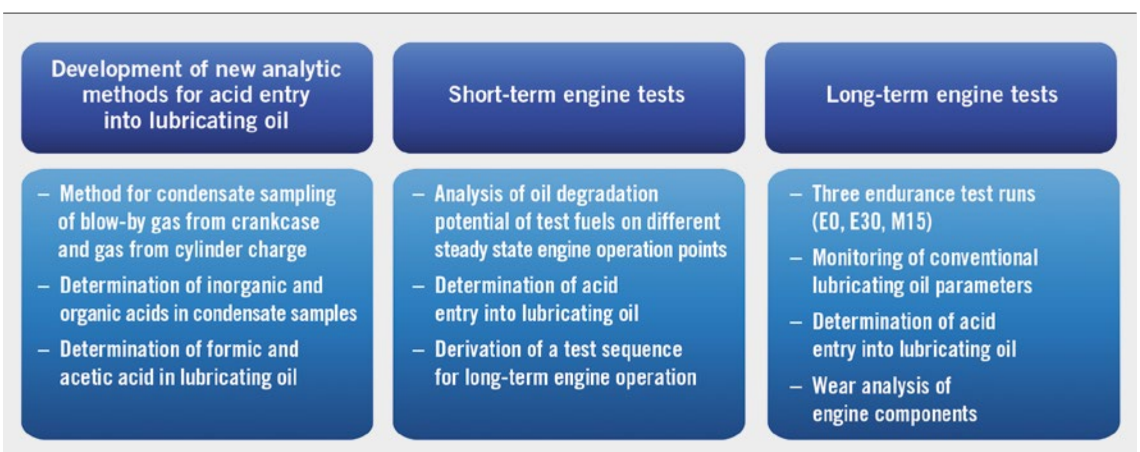


FIGURE 1 Scientific approach of the research project (© LKV)

Parameter	Test method	Unit	Fuel		
			E0	**E30**	**M15**
Density at 15 °C	DIN EN ISO 12185	kg/m^3	745.9	761.7	759.8
Methanol	DIN EN 13132	vol-%	< 0.1	< 0.1	15.0
Ethanol	DIN EN 13132	vol-%	0.3	31.1	0.1
RON, corrected	DIN EN ISO 5164	–	100.3	101.8	99.3
MTBE	DIN EN 13132	wt-%	< 0.1	< 0.1	7.0
ETBE	DIN EN 13132	wt-%	13.1	< 0.1	1.1

TABLE 1 Properties of test fuels (© LKV)

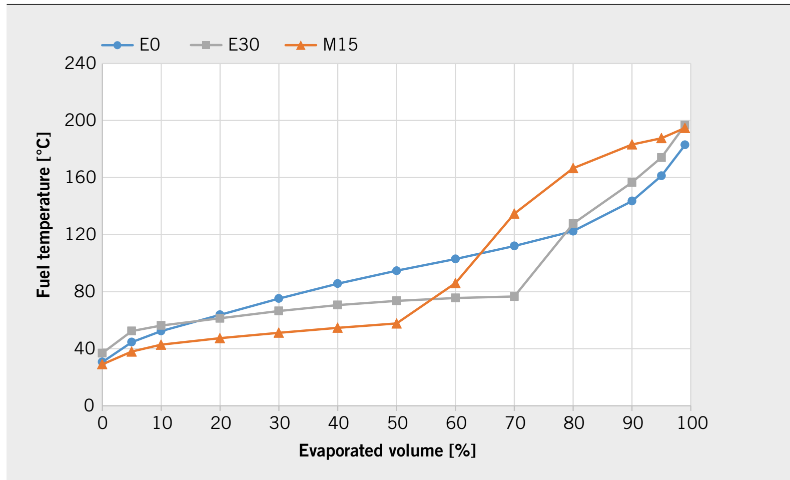


FIGURE 2 Boiling characteristics of test fuels (© LKV)

4 LUBRICATING OIL AGING AND COMPONENT WEAR AS PART OF LONG-TERM ENGINE TESTS

Based on the results of the short-term tests and the determined oil degradation potential, the operating regimes for the three long-term tests were derived. For each of the fuels, one test engine was operated for a total operation time of 230 h. The following conditions were defined as operating regimes:

- Hot operation (serial application, cooling water and oil temperature: 90 to 100 °C):
  - operating point with highest oil degradation potential (80 % of operating time)
  - operating point with higher load (5 % of operating time)
  - operating point with lower speed (5 % of operating time)
- Cold operation (cooling water and oil temperature: 35 to 40 °C):
  - operating point with highest oil degradation potential (10 % of operating time).

Due to the high fuel and water content while operating at cooling water and oil temperatures of 35 to 40 °C, it was defined that engine operation under these conditions was to be carried out at the end of each test day. The aim was to ensure interactions between the fuel or water and the lubricating oil, as well as possible corrosion of engine components, during the engine's standstill overnight. In accordance with the measurement sequence in **FIGURE 3**, a lubricating oil sample and a condensate sample of the blow-by gas and cylinder gas were extracted from the engine every 41 h to examine the lubricating oil parameters and the acid entry into the lubricating oil. During each long-term engine test, no oil change or refilling of fresh oil took place.

Because of the boiling characteristics of the bio-alcohol blends, increased fuel entry and enrichment of the high-boiling fuel components in the lubricating oil occurred, especially during cold operation with E30 and M15. For this reason, the kinematic viscosity (at 100 °C) of the lubricating oil decreased significantly after only a short engine operating time, **FIGURE 4**.

During operation with the M15 fuel, the lubricating oil was diluted so strongly that the lower limit value of 6.9 mm^2/s for the viscosity class SAE 20 was already decided within the first 41 h (first sam-

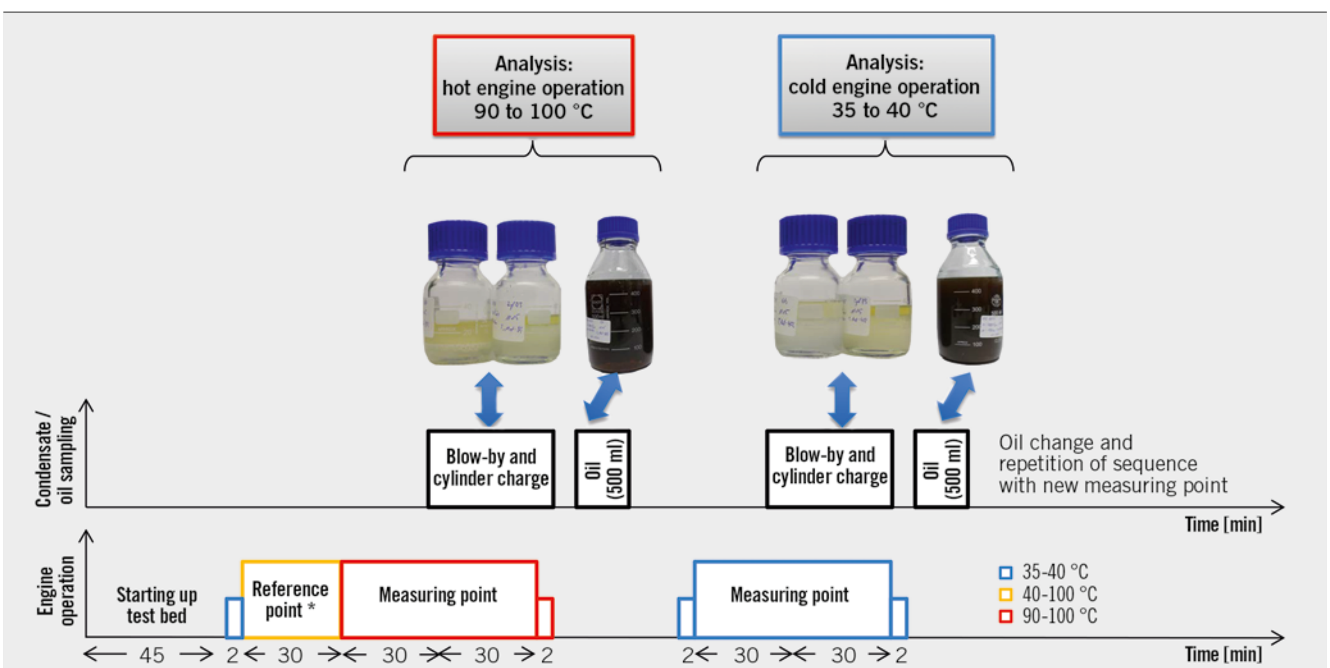


FIGURE 3 Flow chart of sample extraction of blow-by gas and cylinder gas (© LKV)

ple extraction). The further sample analyses revealed almost constant values of the lubricating oil viscosity. The lubricating oil therefore showed a reduced load carrying capacity over almost the total long-term engine test. However, this did not lead to an increased component wear compared to the other test fuels. The measured values of the lubricating oil samples with E0 and E30 operation were in compliance with viscosity class SAE 20 due to the lower fuel content over whole engine operation time.

To analyze the ability of the lubricating oil neutralizing acidic reaction products, the Base Number (BN) was determined according to the American Society for Testing and Materials (ASTM) D4739. The drop in BN to the half of the initial value is often assumed to be the limit value for an oil change. For each of the three long-term engines, a lubricating oil with half the alkaline reserve was used in order to achieve oil aging or component wear within a reduced operating time. For all the three fuels tested, half of the initial alkaline reserve was consumed after 125 h. At the end of the long-term engine test, only a small rest of alkaline reserve in the lubricating oil was detected for the engines operated with bio-alcohol blends. When using the purely fossil fuel, the alkaline reserve was almost completely depleted (0.1 mg KOH/g), **FIGURE 5**.

After completion of the three long-term engine tests, the engines were disassembled and inspected by the manufacturer. The following components were sent back to the respective suppliers for external analysis:
– pistons, piston rings to assess deposits and wear
– crankcase for surface analysis of cylinder bore.

In sum, the wear results of the pistons, pins and rings for the three engines and the three used fuels were comparable for all test engines and on a very low level. With respect to deposits on the pistons, however, slight differences were found for the three test fuels. Particularly on one of the middle cylinders, a slightly increased oil carbon build-up was found on the groove of the second piston ring during operation with bio-alcohol blends. The wear of the first and second piston ring of all middle pistons increased slightly from the engine with alcohol-free fuel (E0) via the E30 blend to the M15 blend. When assessing the wear on the surfaces of the cylinder liner, due to the load spectrum no significant wear worth mentioning could be determined. Below the top dead center of the piston rings, particularly in the case of the engine operated with M15, distinct traces have already been detected on the pressure side of all four cylinders due to possible corrosion while engine standstill. Critical conditions were not achieved.

5 SUMMARY AND OUTLOOK

Within the scope of the project, new analytical methods were developed and successfully applied for the determination of the acid entry into the lubricating oil. On the basis of extensive short- and long-term engine tests, none of the three test fuels (E0, E30 and M15) showed a significant entry of short-chain organic acids (formic and acetic acid). In comparison, the entry of nitric acid into the lubricating oil is an order of magnitude higher for all tested fuels. The engine tests also revealed a significant decrease in the viscosity of the lubricating oil as a result of higher fuel inputs when using bio-alcohol blends with high proportions of high-boiling fossil components. The boiling behavior of these fuels therefore presents a challenge in view of the increasing use of plug-in-hybrid-vehicles with higher amount of engine operation at cold engine temperatures, more frequent engine cold starts and longer engine downtimes as well as the use of water injection in gasoline engines. Despite the decrease in kinematic viscosity, the long-term engine tests did not reveal any critical signs of wear on engine components when using bio-alcohol blends. The results of the project show that a modern passenger car gasoline engine (Euro 6) can be operated with M15 and E30 blends in a vehicle with conventional combustion engine drive and correspondingly high operation time at high temperatures of cooling water and lubricating oil without major problems with respect to the aging of the lubricating oil. The developed test methodology has proved its worth and can be transferred to similar tasks by the publication of the research report.

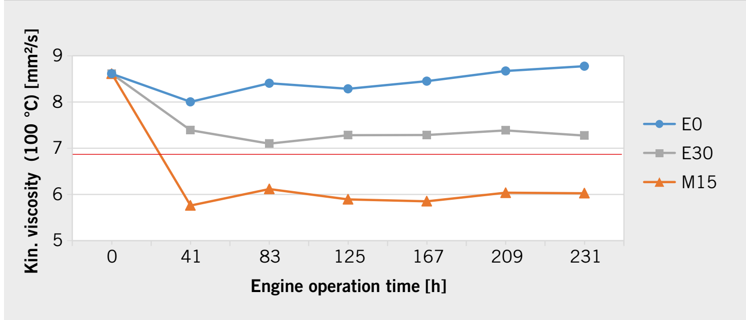


FIGURE 4 Chart of the kinematic viscosity of the lubricating oil at 100 °C over the engine long-term tests (© LKV)

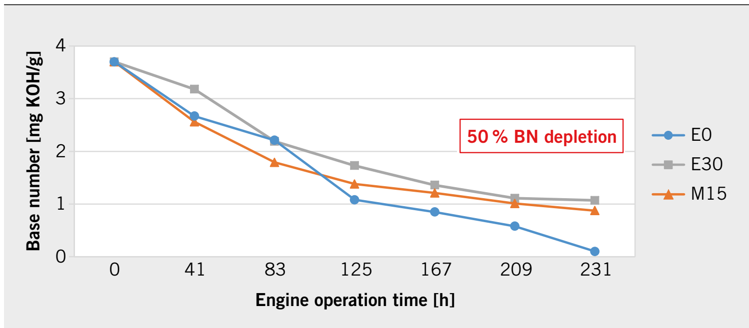


FIGURE 5 Chart of lubricating oil base number over the engine long-term tests (© LKV)

REFERENCES

[1] Naumann, K.; et al.: Monitoring Biokraftstoffsektor. 3rd edition. Leipzig: Deutsches Biomasseforschungszentrum gemeinnützige GmbH, 2016

[2] Budack, R.; Wurms, R.; Mendl, G.; Heiduk, T.: The New Audi 2.0 l I4 TFSI Engine. In: MTZworldwide 05/2016, pp. 16–25

[3] Prehn, S.; Vogel, C.; Buchholz, B.: Effects of Bio-Alcohol Fuel Blends on the Aging of Engine Lubricating Oil. In: SAE Technical Paper 2018-01-1746, 2018

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