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UNIVERSITY MAGDEBURG

Institute of Mobile Systems – Chair of Reciprocating Machines

Final Report Abstract

"Oil Dilution of a Passenger Car Diesel Engine in Operation with blended Diesel Fuel B10"

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- Fachagentur Nachwachsende Rohstoffe e.V. (FNR
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1 Introduction

Currently Biodiesel (RME) is mixed according to EN 14214 and EN 590 with up to 5% of fossil Diesel fuel. With a further increase of RME fraction to 10% (B10 blend), there are uncertainties regarding the undisturbed longlife behavior due to variations of the physico-chemical properties of RME in comparison to commercial Diesel fuel.

It is known that an irreversible oil dilution appears in the engine lubrication system as a result of regeneration mode of current passenger car Diesel engines with particulate filters. The cause of these is the higher distillation characteristic of RME in contrast to the fossil Diesel fuel. If unburnt fuel reaches the lubricant in the oil sump via the piston-cylinder assembly during the regeneration of the particulate filter, the RME fraction cannot evaporate from the engine oil due to its distillation characteristic (boiling point > 340 °C) [1]. As a consequence of the oil dilution, an irreversible decrease of the viscosity results with the risk of increasing wear [2].

The engine bench tests carried out in this project should clarify whether the share of the RME fraction in the engine oil of a passenger car diesel engine equipped with a particulate filter and operated with B10 blend is higher than the share of the Diesel fuel fraction.

The Fachagentur Nachwachsende Rohstoffe e.V. (FNR) and the Union zur Förderung von Oel- und Proteinpflanzen e.V. (UFOP) financed this project. It was supported by Volkswagen AG Wolfsburg with the provision of the diesel engine and by Fuchs Europe Schmierstoffe GmbH Mannheim, which provided and analyzed the engine oil.

2 Tasks

At the Institute for Mobile Systems IMS, Chair of Reciprocating Machines of the Otto-von-Guericke University Magdeburg, was tested a passenger car Diesel engine 2.0-l-TDI-CR-4V operating with B10 blend. The task was to measure at the engine test bench the entraining of fuel into the engine oil and the discharge of fuel out of the oil in four different operating conditions. The engine with a rated power of 103 kW fulfilled the standard Euro 5 and was equipped with common rail injection system, turbocharger, intercooler, exhaust gas recirculation with low-temperature cooling, and with upstream oxi-cat and particulate filter [3]. **Tab. 2-1** describes the four operating points.

Tab. 2-1 Operating points of the engine 2.0 l TDI CR 4V, 103 kW

OP	n in r.p.m.	T in Nm	bmep in bar
1	2140	30	1.9
2	1000	17	1.1
3	2000	250	16.0
Idle	790	0	0

The bench testing should answer the following questions:

- At which of the operating points OP1 to OP3 takes place the fuel (B10) entraining into the engine oil during engine operation without post-injection?
- What is the time-course of B10 blend entraining for retarded post-injection at operating point OP1?
- What is the amount of fuel entraining at 100 engine starts with B10 blend at ambient temperatures of about 22 ºC each with following idle running of 10 minutes?
- How is the evaporating behavior of the RME and the Diesel fuel fractions contained in the engine oil at operating point OP3 for running with “pure” Diesel fuel?

The share of RME and Diesel fuel in the engine oil as well as the influence of the fuel contained in the engine oil on the oil viscosity were to measure in all tests.

As a result of the tests corrective measures for the reduction of fuel entraining into the engine oil were to propose.

Engine oil

The engine bench tests were carried out with engine oil of the description "Titan GT1 Longlife III 5W-30" (VW-Norm VW 507 00) approved by the manufacturer. After each test run, the engine oil was drained at operation temperature and the engine oil filter was changed. The oil could drop out at least for 12 hours before the engine was filled with fresh oil again.

Oil analyzes

The oil samples taken out of the oilpan during the running phase and were analyzed for quantification of RME and Diesel fuel fraction by means of gas chromatography according to DIN 51380 by Fuchs Europe Schmierstoffe. Additionally, viscosity measurements of the oil samples were carried out.

3 Results

Fuel blend B10

The B10 blend was mixed from 10 percent by volume Biodiesel (RME) and 90 percent by volume RME-free Diesel fuel. The distillation curves of RME-free Diesel fuel (DF), RME and B10 shown in **Fig. 3-1** were made by the Analytik-Service Gesellschaft and documented in the test report 161935.

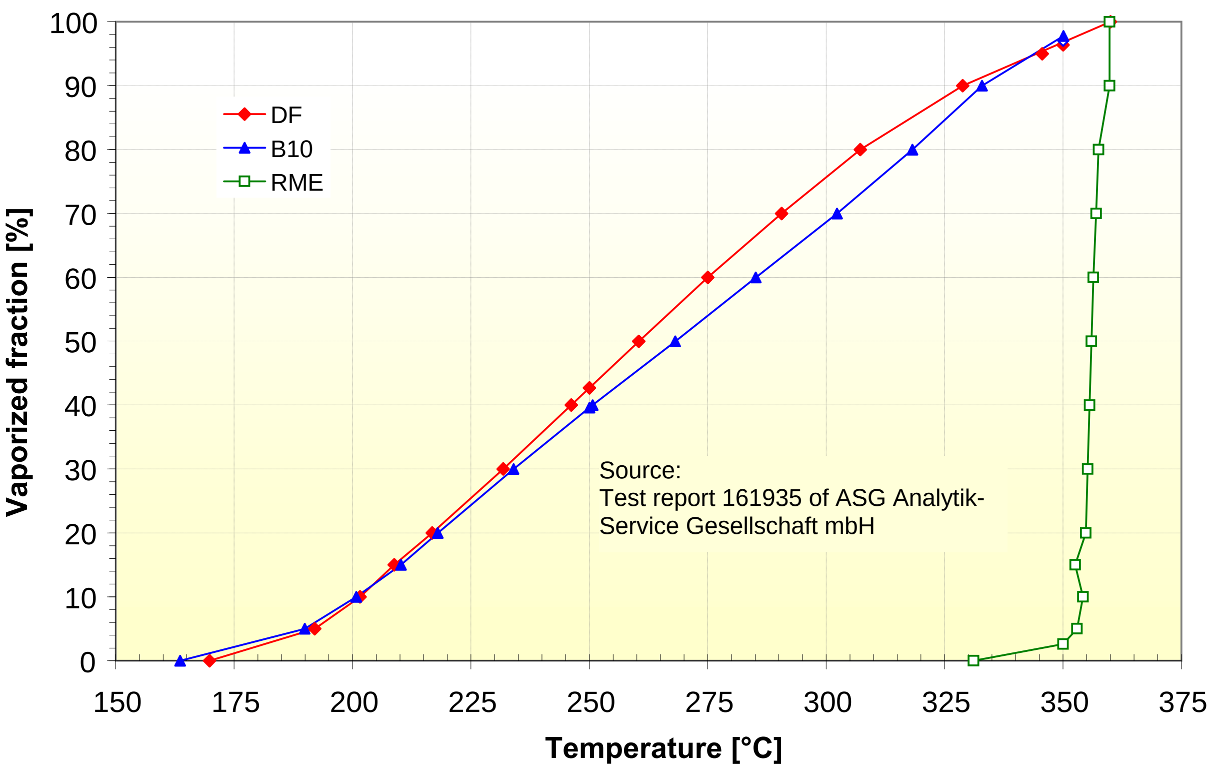

Fig. 3-1: Distillation characteristics of Diesel fuel (without RME fraction), RME and B10

The boiling temperature of RME is very high and nearly constant in the range from 353 ºC to 360 ºC for the vaporized fraction of 5% to 100 %. In contrast DF starts to vaporize at approx. 170 ºC. The vaporized fraction of DF increases with a nearly constant temperature gradient. DF is fully vaporized at 360ºC. The distillation curve of B10 is located approx. 7 ºC above the distillation curve of DF. The final boiling point of B10 was determined at 350 ºC and the distillation residue amounted 2.2 %.

The fuel entraining in the engine oil at operation points OP1, OP2 and OP3

Fig. 3-2 shows the DF, RME and total fuel fractions contained in the engine oil at the end of the 80-hour test runs. In OP3 and OP1 (bmep = 16.0 bar resp. 1.9 bar) could proven no fuel in oil by means of gas chromatography. In OP2 (n = 1000 r.p.m., bmep = 1.1 bar) a total fuel concentrations of 0.8 % resp. 0.7 % were detected in both test runs.

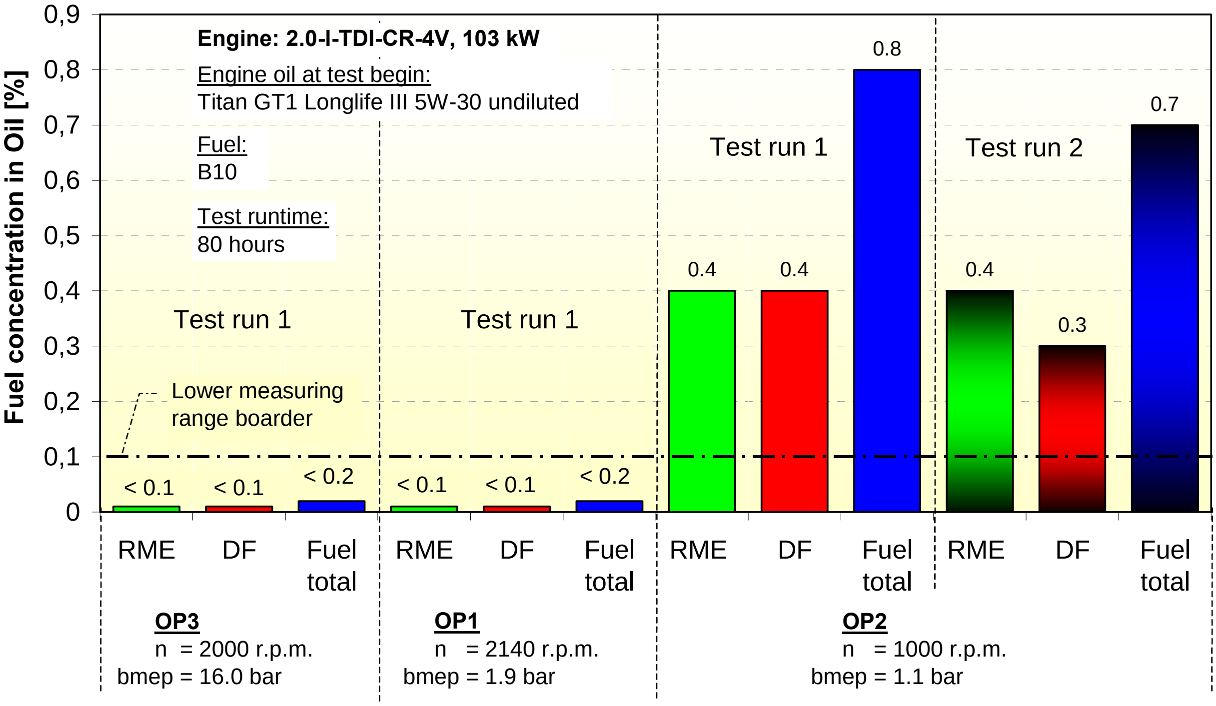

Fig. 3-2: Fuel entraining in the engine oil during the 80-hour test runs with B10 in OP1, OP2 and OP3

The kinematic viscosity of the diluted oil constantly lay within the permissible viscosity limits of 9.3 to 12.45 mm²/s for a SAE 30-oil after both 80-hour test runs at an oil temperature of 100 ºC at OP2.

Fuel entraining in the regeneration mode with engine-internal retarded post-injection at operating point OP1

In the regeneration mode fuel is injected into the cylinder during the exhaust stroke when the exhaust valves are already open. Through the retarded post-injection the fuel vaporizes in the cylinder and is oxidized in the catalytic converter. Thus increases the exhaust gas temperature for regeneration of the particulate filter.

The test run with retarded post-injection at OP1 was operated altogether three times, over 8 hours each. The purpose of these test runs over 8 hours was to collect exactly the changes of RME and DF entraining. In practice, the duration of the regeneration mode is considerably shorter.

The fuel concentrations almost linearly increase in the engine oil during the test duration (**Fig. 3-3**). At OP1 (n = 2140 r.p.m., bmep = 1.9 bar) the retarded post-injection of B10 causes a very high enrichment of fuel in the engine oil. During the 8-hour test runs, the mean fuel concentration increases were 3.5% for RME and 5.5 % for DF and 9% consequently for the total fuel. Hence, more DF than RME was in the oil.

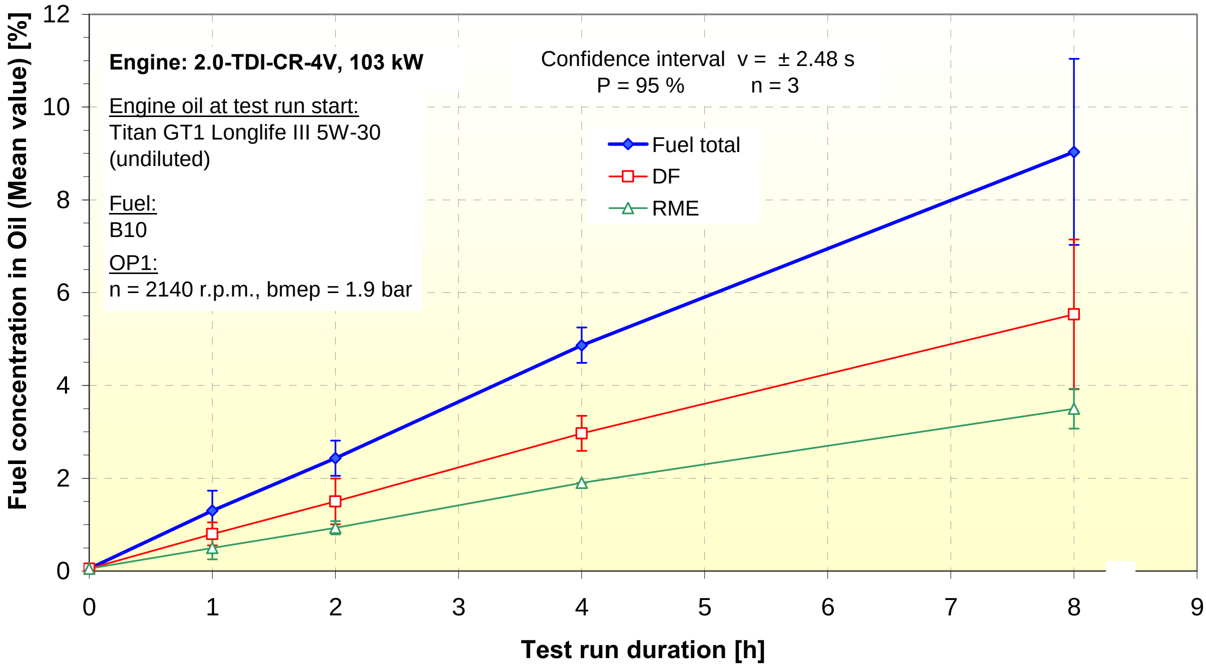

Fig. 3-3: Mean values of the fuel concentrations depending on running time for three test runs with B10 at OP1 with retarded post-injection.

The fuel entraining at retarded post-injection resulted in a strong viscosity decrease of the engine oil. After four hours of testing with retarded post-injection, the viscosity felt below the permissible limit of 9.3 mm²/s according to the SAE specification for 5W-30 at temperature of 100 ºC.

Fuel discharge out of the diluted engine oil at high load operation point OP3

For the next task new engine oil was diluted with 15 % B10. Thus 1.5 % RME and 13.5 % DF were in the engine oil at start. At OP3 with high load (n = 2000 r.p.m., bmep = 16.0 bar) was tested how the fuel concentration in the diluted engine oil was influenced by running time. The test was carried out in two test runs (PL1 and PL2) of 32 and 64 hours respectively. To avoid an additional RME entraining, the engine runs with B0 (DF without any RME).

The results of both test runs coincided well with each other (**Fig. 3-4**). The RME concentration in the engine oil was reduced from 1.5 % to 0.7 % at the 64-hour test run. The fuel discharge resulted basically from reduction of DF concentration from 13.5 % to 0.6 %.

The viscosity of the diluted engine oil with 15 % B10 had a value of 8.5 mm²/s at 100 ºC at test start. So it was slightly under the SAE specification for the minimal permissible limit value of 9.3 mm²/s. As a result of the strong DF discharge during the first test run hours, the viscosity increased to 9.6 mm²/s already before end of the fourth operation hour. The viscosity leveled out at the permissible SAE limit values until the end of the test run **(Fig. 3-5).**

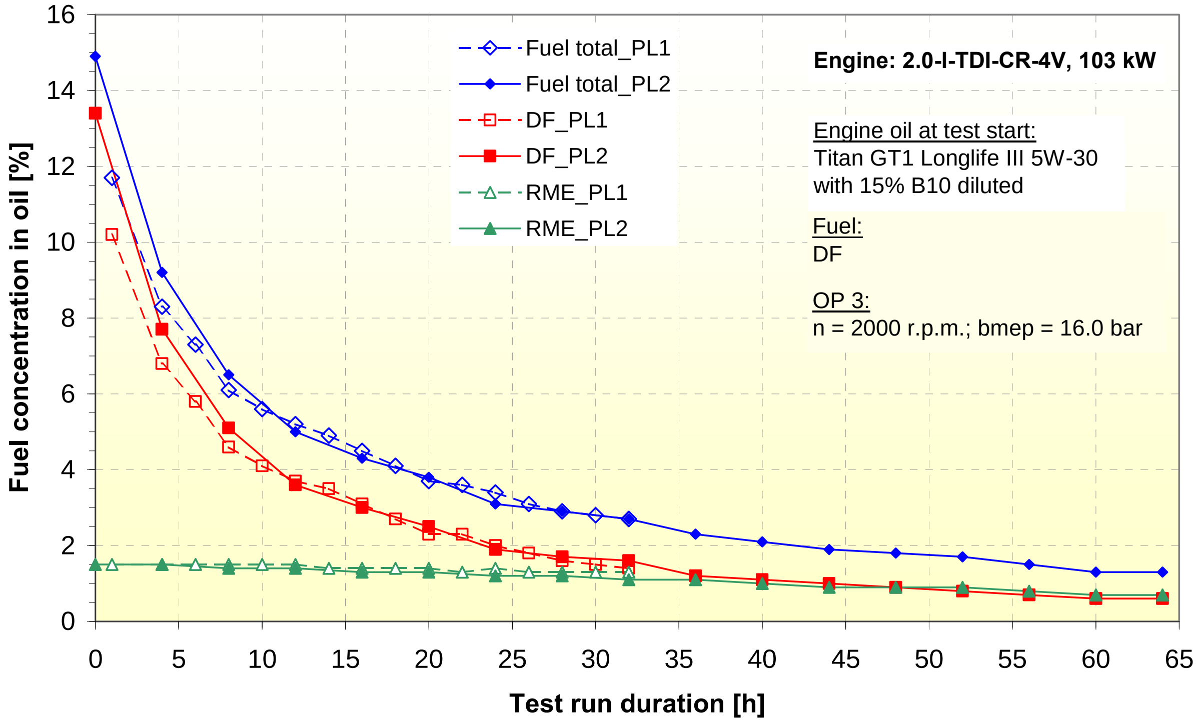

Fig. 3-4: Fuel discharge out of engine oil diluted with 15 % B10 for two test runs PL1 and PL2 with pure DF at OP3, depending on running time.

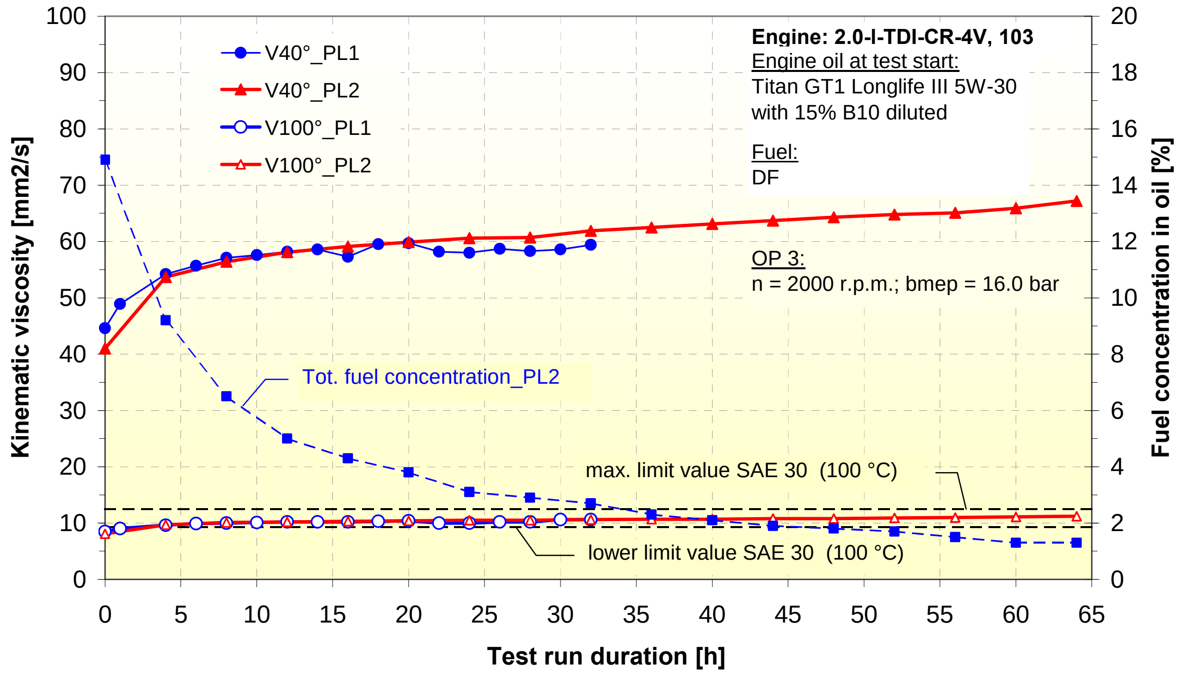

Fig. 3-5: Oil viscosity of the 32-hour and 64-hour test run and total fuel concentration of the 64-hour test run with DF at operation point OP3, depending on running time.

Fuel entraining at 99 engines starts each with following 10 minutes idle operation

The cold starts were carried out at room temperatures of 22 ºC. After each start the engine was operated with B10 at idle state (n = 790 r.p.m., bmep = 0 bar) over 10 minutes and subsequently cooled down to room temperature of about 22 ºC. This procedure was repeated 99 times. The first oil sample was taken after the first cold start.

The fuel entraining was very low at cold starts with following idle operation **(Fig. 3-6)**. After the 100th cold start no RME could be detected in the engine oil. The amount of entrained DF was 0.2 % (≙ 90 % of the total fuel entraining) at test end. The increase of RME concentration was not verifiably by measurement. Assuming that the total B10 was entrained in the oil calculations resulted in 0.022 % (i.e. 1/9 of the DF entraining) for the RME concentration and in 0.222 % for the total fuel concentration.

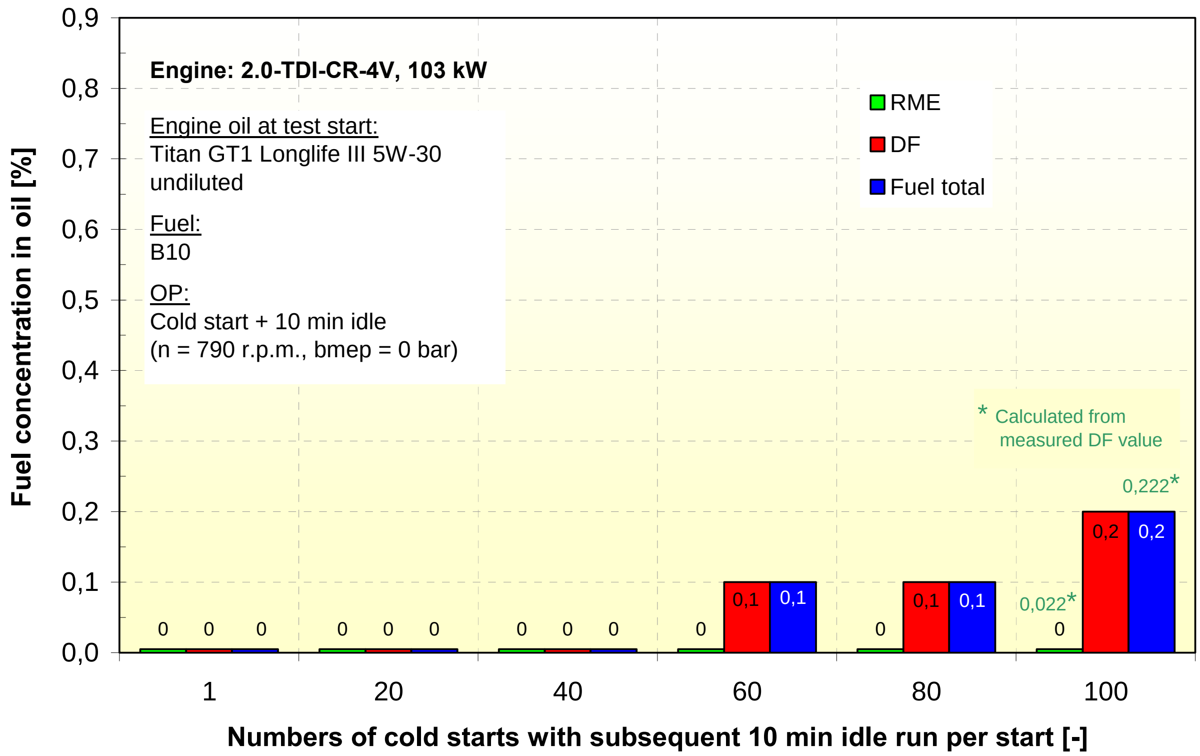

Fig. 3-6: Increase of RME, DF and total fuel concentration in engine oil depending on the number of cold starts with B10 each with subsequent 10 min idle

The viscosity decrease was only 3.6 % during the 99 cold starts and the 16.5 hours idle operation. Due to the marginal fuel entraining the viscosity values do not fall below the minimal permissible limit values of the SAE 30 specification.

4 Conclusions

For comparison the changes of fuel concentration in engine oil and of oil viscosity at the different test runs were drawn with the same time scale (percent per hour).

Fig. 3-7 shows the hourly increase of fuel concentration in engine oil and the hourly reduction of viscosity for engine operation with B10 in percent per hour for the test runs with retarded post-injection, for the start tests with idle run and for the low load operation.

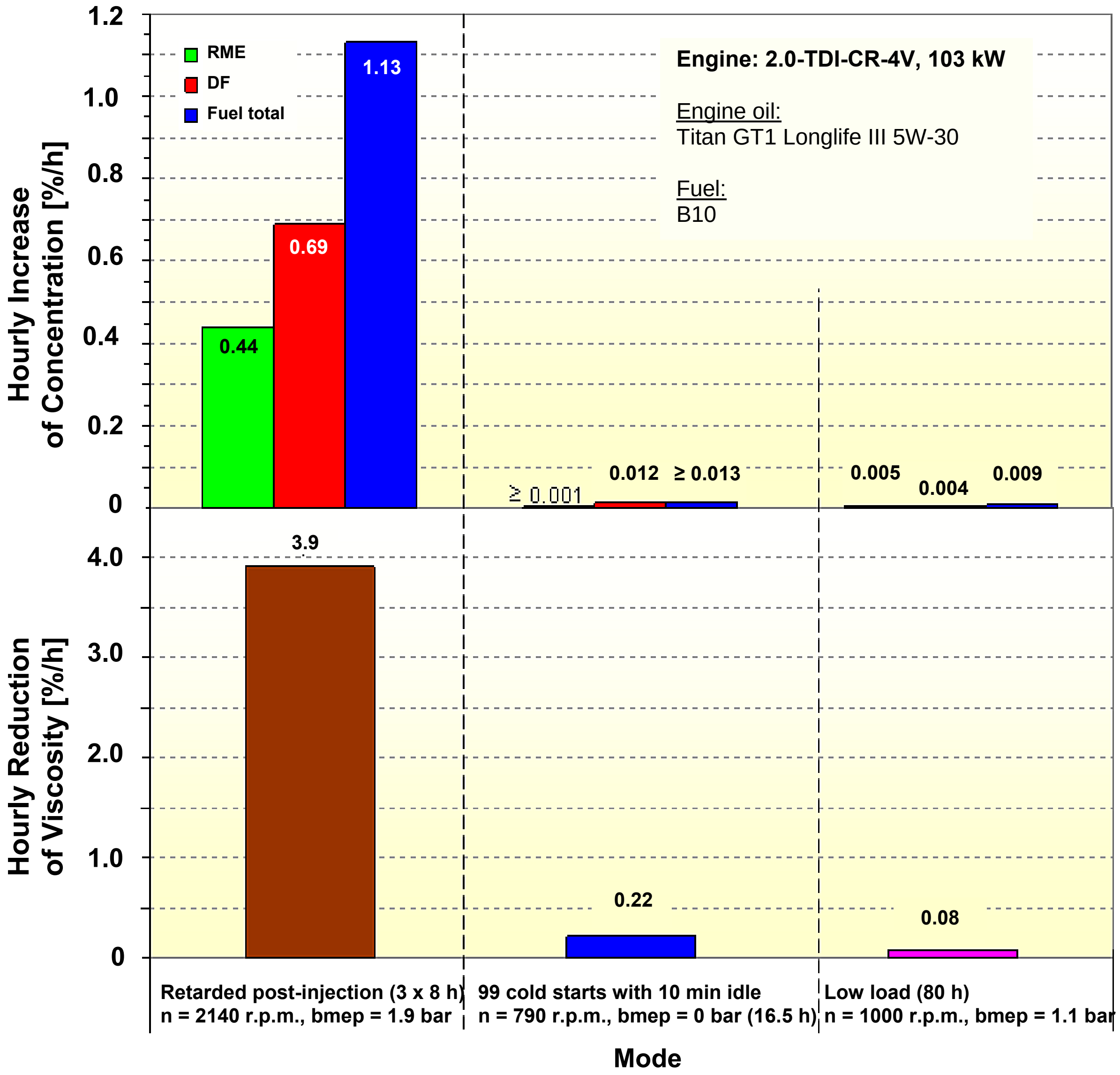

Fig. 3-7: Comparison of fuel entraining and of oil viscosity reduction for three operation modes

The results of the stationary engine bench tests are:

- The highest fuel entraining took place in the regeneration modus with retarded post-injection. In this case the DF fraction in oil was higher than the RME fraction. The oil dilution was considerably only at retarded post-injection.
- At the low load operation mode as well as at the 99 engine starts with idle the fuel entraining and the viscosity reduction of the engine oil were very low, which have minor importance in practice.
- At high engine load, fuel was discharged out of the engine oil, which was diluted with B10. The DF fraction was discharged out of the engine oil with a considerably higher amount than RME. Thus the RME concentration increased in the unevaporated fuel remaining in the oil.

The particulate filter system with active filter regeneration without additives by means of engine-internal fuel post-injection was used in the tested engine. Currently this regeneration system is also used by all German passenger car-producers. Additive-supported systems basically need lower post-injection fuel amount in the regeneration mode. At these systems biodiesel fractions up to 30 percent can be permitted under special conditions (e.g. reduction of the oil-changing interval) [4]. In principle, systems which injected additional fuel for regeneration exclusively upstream the oxidation catalytic converter do not have problems with lubricating oil dilution.

The optimization (timing and quantity) of retarded post-injection could be a solution to reduce the irreversible lubricating oil dilution due to an increase of biofuel fraction in diesel fuel in passenger car engines with engine-internal post-injection in the future. In this case, the particulate filter regeneration should not be affected.

5 Literature

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