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Investigation of the Emission Reduction Potential of HVO-OME Fuel Blends in a Single-Cylinder Diesel Engine

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Abstract

The aim of current research on internal combustion engines is to further reduce exhaust gas pollutant emissions while simultaneously lowering carbon dioxide emissions in order to limit the greenhouse effect. Due to the restricted potential for reducing CO_2 (carbon dioxide) emissions when using fossil fuels, an extensive defossilisation of the transport sector is necessary. Investigations of future propulsion systems should therefore not focus solely on further development of the prime mover, but also on the energy carrier which is used. In this context, fuels from renewable energy sources are of particular interest, e.g. paraffinic diesel fuels such as hydrogenated vegetable oil (HVO) or potentially entirely synthetic fuels like POMDME (polyoxymethylene dimethyl ether, short: OME) as well as blends of such fuels. If renewable energy is used for fuel production, the current disadvantage of fossil energy carriers regarding CO_2 production is eliminated, while at the same time further advantages can be exploited through lower pollutant emissions compared to conventional fuels. As an example, soot emissions can be significantly reduced with both of the above-mentioned alternative fuels in comparison to diesel. When using OME without additional blend components, the soot-NOx (nitrogen oxides) trade-off is no longer relevant as combustion is almost soot free.

However, further research and development is required, particularly with regard to the identification of suitable fuels (e.g. concerning emission reduction potential, suitability as a fuel for mobile applications and availability) and with respect to the optimization of the combustion process for the corresponding fuels. Within the framework of a joint funded project, OME and blends of HVO and OME are investigated in a single-cylinder research engine. The different fuel blend combinations are systematically compared with respect to the experimental results, and the most promising combinations for an ultra-low emission concept based on such fuel blends will be determined.

Introduction

Limiting the consequences of climate change is one of the most important challenges for the 21st century. For this reason, it was agreed in the "Paris Agreement" in 2015 to limit global warming – which is attributed primarily to the use of fossil fuels – to well below 2 °C compared to the pre-industrial level. This requires a significant reduction in the worldwide emission of anthropogenic greenhouse gases such as carbon dioxide (CO_2). Since the potential for reducing CO_2 emissions by technical measures is limited when using fossil fuels, an extensive defossilisation of all energy sectors will be necessary in the medium to long term. The transport sector is an important factor to be considered in this context. In 2016, the transport sector accounted for approximately 24% of global CO_2 emissions, with road transport accounting for approximately 18% [1]. For this reason, ambitious targets have been set worldwide for the reduction of CO_2 emissions from transport, and are expected to be further tightened in the future. In addition, legislation regarding pollutant emissions is also getting more and more stringent. Accordingly, the second major focus in the further development of internal combustion engines is to reduce pollutant emissions. Due to the necessity of defossilisation of the transport sector, the focus should be not only on the further improvement of the engine itself, but also on the fuel which is used.

In this field, further research and development is required, especially with regard to the identification of suitable fuels and the adaptation of the combustion processes to the respective fuel. For application in diesel engines, a potential solution is the use of so-called paraffinic diesel fuels of biogenic origin (such as HVO) or from synthetic production ("e-fuels") as well as other synthetic fuels such as oxygenate fuels like POMDME (polyoxymethylene dimethyl ether, abbreviated: OME), or blends of synthetic fuels.

Within the framework of the German renewable fuels research project "E2Fuels", investigations with OME and various HVO/OME blends are carried out on a single-cylinder research engine derived from a passenger car diesel engine, with the aim of defining the best suited blend ratio for use on a full engine test bench and a demonstrator vehicle using this engine, and optimizing the blend with regard to the combustion process. In the following, first results of these activities are presented.

Theoretical basics

Paraffinic diesel fuels (in Europe according to EN1594; in Japan or USA according to the same standards as conventional diesel fuels, ASTM D975 or JIS K 2204) consist almost entirely of alkanes and are therefore free of aromatics, which means that they have a lower tendency to form soot than conventional diesel fuel (short: DF). The potential for soot reduction, but also for the reduction of CO and HC emissions, under a wide range of operating conditions has already been demonstrated in many studies [2 - 7]. However, some studies have also shown that under certain operating conditions, soot emissions can increase when operating with HVO compared to operating with DF [3,7]. NOx emissions for HVO and DF applications are generally reported to be at comparable levels [2 - 7].

Paraffinic diesel fuels can be categorized with respect to the way they are produced. So-called HVO (hydrogenated vegetable oil or hydrotreated vegetable oil) is produced by the hydrogenation of vegetable oils [8]. Since animal fats or other raw materials may also be used in the production process, the term HDRD (Hydrogenation Derived Renewable Diesel [9]) is more appropriate as a generic term. Another possibility for obtaining a paraffinic diesel fuel is the so-called Fischer-Tropsch process [8]. In this case the fuel is gained purely from a synthesis process instead of just modifying oil from biogenic sources. In addition to the potential for reducing pollutant emissions, the use of renewable energy offers the chance to significantly reduce well-to-wheel CO_2 emissions (thus taking into account the upstream processes of fuel production), with the ultimate option to become completely CO_2-neutral. For the present study, HVO was used as a representative of paraffinic fuels due to its better availability.

The special characteristic of oxygenate fuels like OME is their molecular structure [$CH_3O(-CH_2O-)_nCH_3$] [10, 11]. Due to oxygen atoms which are bound between the carbon atoms, there are no direct carbon-to-carbon bonds inside the molecule [11]. Therefore, OME combustion is almost soot-free, provided that there are no soot-forming blend components [11 - 13]. As a result, the so-called soot-NOx trade-off can be resolved, allowing also to reach ultra-low NOx levels [11 - 13]. But even in a blend with DF or HVO, significant soot reductions can be observed under many operating conditions [10, 14 - 16]. Investigations of blends of DF and OME indicate at least a slight increase in NOx emissions in blend operation, especially at higher load points [14 - 16]. Comparative studies of different OMEs (OME1, OME2, OME3-4 and more) show only small differences in CO or HC emissions compared with HVO [11, 12]. Studies on blends of DF and OME indicate at least a small potential for reducing CO and HC emissions compared to operation with DF [14 - 16]. The physical properties of OME are strongly dependent on the number of oxymethylene groups [$(-CH_2O-)n$] present in the chain, and in some cases may differ significantly (Table 1) [10 - 12].

Table 1. Characteristic values of OMEn [11] [12]

	Unit	OME3	OME4	OME5
Heating value	MJ/kg	19.4	18.7	18.1
Density (@15°C)	Kg/m³	1030	1070	1110
Kin. viscosity (@40°C)	mm²/s	1.08	1.72	2.63
Cetane number	-	67	76	90
Boiling point	°C	156	202	242
HFRR (@60°C)		534	465	437
O2 concentration	% (m/m)	47.0	48.1	48.9

OME is a synthetic fuel which may also be classified as an "e-fuel" (or PtL = power-to-liquid). It is generally produced via a methanol route. Similar to paraffinic diesel fuels, there is a high potential for reducing CO_2 emissions, including complete CO_2-neutrality. For the production of methanol, hydrogen and CO_2 are required. In order to obtain a CO_2-neutral fuel, methanol has to be produced using renewable energy in the form hydrogen produced by water electrolysis (using renewable electricity) and atmospheric CO_2. Since the production of CO_2 from ambient air is not yet viable economically, taking into account the currently very low CO_2 price, the required carbon dioxide is currently still derived from industrial sources. [12]

Due to the possibility of producing paraffinic diesel fuel by the hydrogenation of fat or oil, the supply of such a fuel in larger quantities will initially be easier than with a fuel which can only be produced in a pure synthesis process (like OME). For this reason, especially with an increasing fleet of plug-in hybrid cars and the associated reduction in the demand for gasoline and diesel fuel, a realistic drop-in scenario could be to replace conventional fossil diesel by a paraffinic diesel fuel. In a next step, OME could then be used as a blend component in order to obtain further advantages in terms of pollutant emissions. With increasing availability of OME, a complete switch to this type of fuel could take place in the medium to long term.

Engine Test Bench Setup

The aim of the investigation described below is to determine the influence of HVO-OME blends on the combustion process of a diesel engine, with a special focus on emissions. The investigations are carried out on a single-cylinder research engine derived from a passenger car diesel engine. The test engine has separate intake ducts and is equipped with a swirl flap. Further technical data on the single-cylinder research engine can be found in Table 2.

The components of the fuel system were adapted to the use of OME with respect to the choice of materials used in the system. For the results discussed in the following, fuel injection was realized by an 8-hole solenoid injector, which – except for the sealing materials used – corresponds to a conventional diesel injector, including the hydraulic flow capacity of the injector. All operating fluids of the test bench (i.e charge air, cooling water, engine oil and fuel) are conditioned with respect to temperature and pressure.

Table 2. Technical details of single cylinder engine

Bore diameter	83 mm
Stroke	91.4 mm
Displacement	494.5 cm³
# of valves per cyl.	4
Injection system	common rail (max. 2,500 bar)
Injector	8-hole solenoid injector

An IAV FI2RE prototype ECU (electronic control unit) with integrated pressure indication is used to control the test engine. The ECU controls the injection parameters (including rail pressure), the EGR (exhaust gas recirculation) and swirl flap position as well as boost pressure and exhaust backpressure. Supercharging is realized by an external compressor unit, providing intake pressures of up to 4.5 bar_{abs}. For the analysis of the exhaust gas components, an FTIR was used to determine the gaseous components. The soot concentration was measured with an AVL Micro Soot Sensor. The setup of the test bench is displayed in Figure 1.

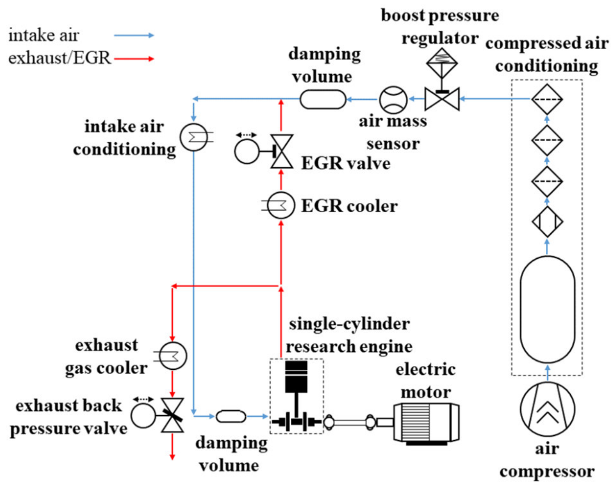

Figure 1. Test bench setup

Several fuel blends of HVO and OME3-5 are investigated within the scope of the project, while conventional diesel fuel (filling station quality with 7 vol% FAME, according to EN590) and HVO as a paraffinic diesel fuel (according to EN15940) are used as a basis for comparison. The following blends have been investigated so far:

1. **Blend A**: HVO/OME3-5 (90/10 %vol)
2. **Blend B**: HVO/OME3-5/2-ethyl-1-hexanol (80/15/5 %vol)

In **Blend B**, 2-ethyl-1-hexanol is used as a mixing promoter, as otherwise phase separation effects may occur at low temperatures with OME fractions of this order of magnitude. The most important characteristic values for the fuels used can be found in Table 3.

Table 3 Fuel characteristics of the test fuels

	Unit	DF	HVO
Heating value	MJ/kg	41.4	43.4
Density (@15°C)	kg/m3	833.0	779.9
Cetane number	-	54.2	78.5
Kin. viscosity (@40°C)	mm2/s	2724	2862
O2 concentration	% (m/m)	<0.5	<0.5
C/H ratio	-	6.43	5.54
	Unit	Blend A	Blend B
Heating value	MJ/kg	40.33	38.65
Density (@15°C)	kg/m3	804.7	820.0
Cetane number	-	74.6	78.1
Kin. viscosity (@40°C)	mm2/s	2412	2155
O2 concentration	% (m/m)	7.2	9.4
C/H ratio	-	5.46	5.51

Engine Test Bench Results

The aim of the currently ongoing experimental investigations is to characterize the different blends with respect to the emissions produced, and to identify the most suitable blend for the following investigations to adapt the combustion process. The investigations include operation at several part load operating points as well as investigations at full load (short: FL).

In the first phase of the project, a conventional diesel parameter set including pre-injection (max. 3 injection events) and post injection (1 injection event) was used as a basis for engine operation. With respect to the basic parameter set, the gravimetric injection quantities of the individual pre- and post-injections were corrected according to the calorific value of the fuels used. For this purpose, the required injector actuation time of the pre- and post-injections is determined for each part load point before the actual test is carried out. In part load operation, the duration of the main injection is defined through the control unit by means of a load controller (based on IMEP - indicated mean effective pressure), while another controller adjusts the required center of combustion via the SOI of the main injection. Changing the SOI of the main injection also shifts the pre- and post-injections. In full load operation, the control duration of the main injection and the SOI are controlled manually (with the peak pressure being kept constant). In the following, the results at two part load points as well as an injection quantity variation under full load operation are presented as an example (Table 4).

Table 4. Operating points

	Engine speed	IMEP	Number of pre-injections	Number of post-injections
	[rpm]	[bar]	[-]	[-]
PL1	1,250	3.7	3	-
PL2	1,250	17.4	2	1
FL	4,000	variable	-	-

At the beginning of each measuring day, the measuring equipment was calibrated to determine the gaseous components and the soot concentration. To ensure good reproducibility, a reference measuring point was set and controlled before the start of a measurement campaign in order to verify the validity of the measurement data. The engine was operated for 120s at each operating point until stable conditions were established. Then the emissions were acquired for 60s and the emission results are obtained from the average of these 60 seconds.

At the first part load point PL1 (engine speed: 1250 rpm; IMEP: 3.7 bar), a variation of both the EGR rate and the swirl level was investigated. During these investigations, the EGR rate was increased until the well-known soot-NOx trade-off could be observed through increasing soot levels. These investigations were carried out for different levels of swirl, which were generated by activating the swirl flap. In PL2, only the EGR rate was varied; a swirl variation was not carried out, since in diesel operation, there are no advantages for this operating point due to increased swirl, and the specific optimization of the combustion process for the new fuels is planned for the later phases of the project, after the selection of the most suitable blend.

Figure 2 shows the soot, NOx, CO (carbon monoxide) and HC (hydrocarbon) emissions depending on the EGR rate and the swirl flap position for the part load point PL1. As could be expected, the HVO as well as **Blend A** and **Blend B** exhibit significantly lower soot emissions compared to diesel operation. Furthermore, the soot limit is shifted towards higher EGR rates. By adding the blend components, the soot level can be reduced even further compared to HVO. This soot reduction is due to the lack of aromatics in these fuels as well as the absence of carbon-to-carbon bonds and the oxygen content of the OME components in the two blends. At this operating point, **Blend A** produces a slightly higher soot level compared to **Blend B**. Especially at higher EGR rates, starting from the fully open swirl flap (minimum swirl level; swirl: 0; swirl flap is 0% closed), an increase in the swirl level leads to an improvement in mixture formation and thus to a further reduction in soot emissions at this load point. For the two blends, the lowest soot emissions are obtained in the case of the highest swirl level examined (swirl: 65; swirl flap is 65% closed), while for diesel and HVO, soot emissions already start to increase again as soon as the intermediate swirl flap position (swirl: 50; swirl flap is 50% closed) is exceeded. To take into account the influence of SOI on soot and NOx emissions, it should be noticed that at identical EGR rate, the variation in SOI between the fuels is mostly less than 0.5 °CA. Only the SOI of DF deviates somewhat more from that of the other fuels at higher EGR rates, but the deviation is still less than 1.0 °CA. The center of combustion was kept constant. The influence of SOI deviation on emission results is thus considered to be small in comparison to the influence of fuel composition.

Only relatively small differences in NOx emissions are discernible between the various fuels, and only in operation without EGR or at very low EGR rates. At a very low EGR rate HVO and **Blend B** result in slightly higher emissions compared to diesel fuel and **Blend A**. A minor influence of the swirl stage is also only evident in operation without EGR or at very low EGR rates. At higher EGR rates, no significant difference can be observed between the fuels or between different swirl levels. At higher EGR rates, no significant difference can be seen between the fuels. There is also no discernible influence of the swirl level. The most significant influencing factor is the EGR rate. As expected, nitrogen oxide emissions drop sharply for each fuel as the EGR rate increases.

The CO emission characteristics are similar for all fuels. For conventional diesel fuel, the increase in emissions can be observed at a significantly lower EGR rate compared to the other fuels at this operating point. HVO, **Blend A** and **Blend B** are all at a comparable level; a noticeable increase of CO only occurs at significantly higher EGR rates for these fuels. For **Blend A**, the curves are almost identical to those of HVO, while for **Blend B**, the curve tends to increase minimally more at high EGR rate. The reason for these increased values may partly be attributed to the 2-ethyl-1-hexanol content of **Blend B**. The difference compared to diesel fuel can be traced back to the different autoignition tendency as described by the cetane number. Conventional diesel fuel has a significantly lower cetane number than both HVO and the two blends (see Table 3). As the EGR rate increases, the conditions for auto-ignition deteriorate and the ignition delay increases. The resulting slower combustion with reduced air-fuel ratio results in an increase in CO emissions. Due to the higher auto-ignition capability of the HVO and both of the blends, the EGR rates set during the test do not have the same effect as in operation with conventional diesel fuel. Changing the swirl does not appear to have any discernible effect on CO emissions.

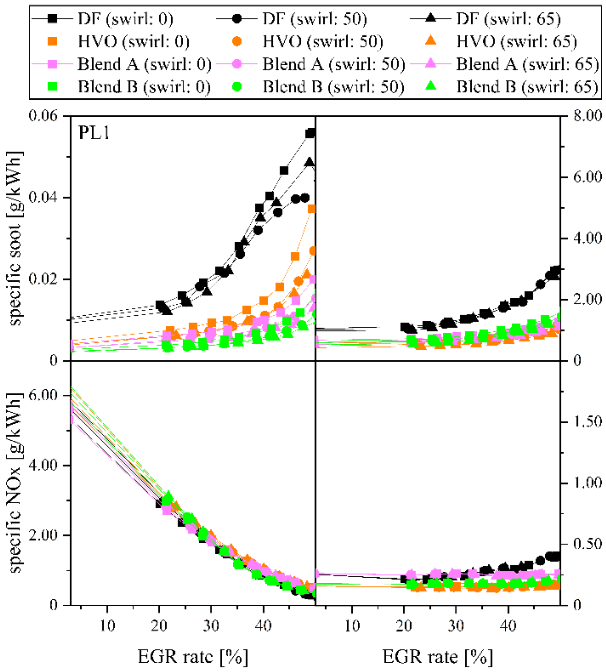

Figure 2. Soot, NOx, CO and HC emissions (part load point 1)

The course of HC emissions as a function of EGR rate is very similar to that of CO emissions. For DF, slightly higher values are obtained than with the other fuels at higher EGR rates. However, the overall emissions are very low for all fuels. The swirl level variation has no discernible effect on HC emissions.

Figure 3 shows the trade-off of soot vs. NOx as a function of the EGR rate at three different swirl levels. Generally, the results are comparable to the soot vs. EGR analysis in Figure 2. At comparable nitrogen oxide emission level, the aromatic-free HVO produces significantly lower soot emissions compared to the operation on conventional diesel fuel. At a specific NOx emission level of 3 g/kWh, soot emissions are reduced by approx. 40% compared to diesel fuel by the use of HVO. With both blends, soot emissions can be significantly reduced once again compared to HVO at the same nitrogen oxide concentration. **Blend A** results in a reduction of up to 15% and **Blend B** in a reduction of up to 40%, so that the soot emission drops to about one third of the diesel value with **Blend B**. Increasing the swirl level does not produce any significant advantages with respect to soot in these operating points, on the contrary. A noticeable difference between the two blends only appears at significantly lower NOx emissions (< 1 g/kWh).

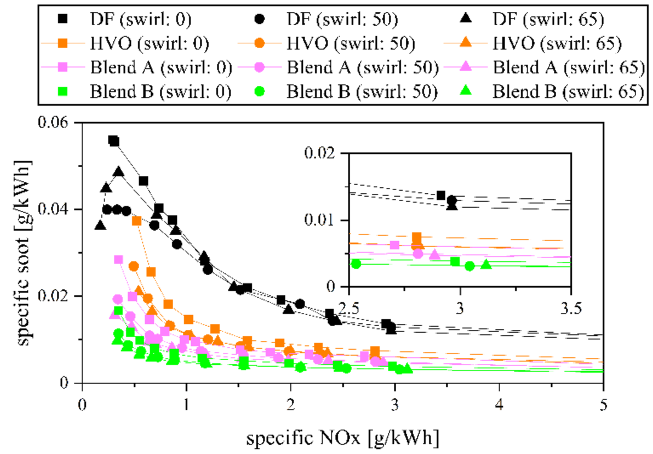

Figure 3. Soot vs. NOx trade-off (part load point 1)

Looking at normalized cumulative heat release, the positive influence of the higher ignition tendency of both HVO and the two blends compared to conventional diesel with increasing EGR rate becomes even clearer, especially in the energy conversion of the pre-injections. Figure 4 shows the normalized cumulated heat release at the lowest swirl level for the cases without EGR and with an EGR rate of approx. 40%.

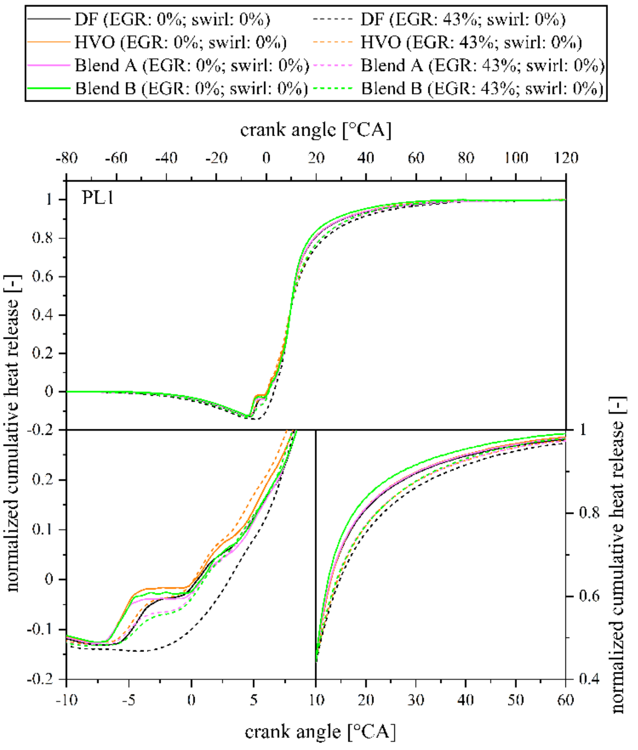

Figure 4. Normalized cumulative heat release (part load point 1): overall trace (above) and zoom on SOC (start of combustion) / EOC (end of combustion) phase (below)

For all fuels, the start of combustion of the fuel mass injected with the first two pre-injections is clearly visible for the operating points without EGR. As the EGR rate increases, the start of the pre-injection fuel mass conversion shifts significantly towards TDC, especially in the case of diesel fuel, and can hardly be distinguished from the start of combustion of the main injection. For the other fuels, the start of combustion is shifted much less in the direction of TDC (top dead center) at this EGR rate, and the start of combustion of the first two pre-injections can be distinguished even more clearly from the main injection. It should be noted that as the EGR rate rises, the start of all injections is subsequently shifted towards TDC due to the center of combustion control carried out automatically by the ECU. Due to the lower cetane number of diesel fuel, a slightly larger shift in comparison to operation without EGR is required than in the case of HVO or one of the blends.

As an example for an operating point of at elevated part load, Figure 5 shows the resulting soot, NOx, CO and HC emissions for PL2 (engine speed: 1250 rpm; IMEP: 17.4 bar) as a function of the EGR rate.

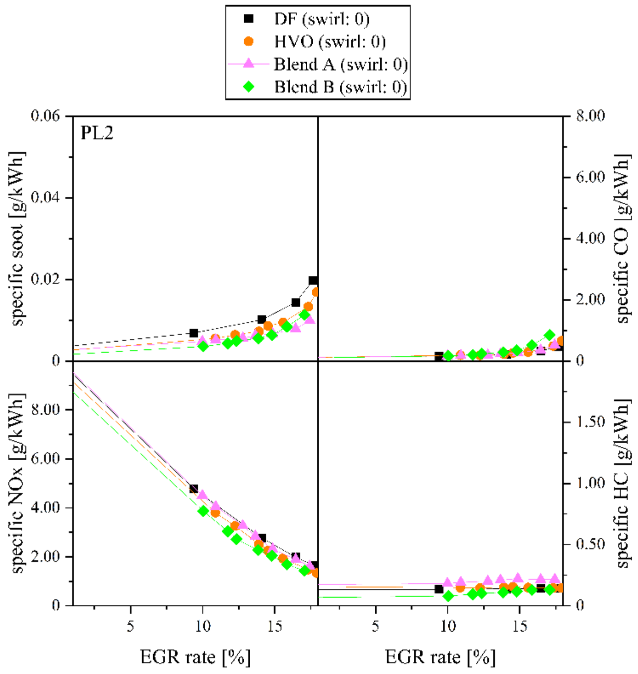

Figure 5. Soot, NOx, CO and HC emissions (part load point 2)

As expected, the soot emissions at this operating point are again lower than for conventional diesel fuel when using HVO or one of the two blends, but the effect is less pronounced than in the case of PL1. Among other reasons, this is probably due to the significantly higher combustion temperature at this operating point, which means that the soot particles produced during combustion are likely to oxidize more effectively during the combustion process. This is additionally supported by the existing post injection in the application parameter set of this operating point. Furthermore, it can be assumed that at this operating point, the influence of the reduced auto-ignition capability of diesel fuel is less than observed at PL1 due to the higher end-of-compression pressure level (as a result of increased boost pressure) and higher combustion temperatures. Only minor differences in soot levels are seen between HVO and the blends, even at higher EGR rates. It is noticeable that at higher EGR rates, soot emissions increase a little more for **Blend B** than for **Blend A**, despite the higher OME content of **Blend B**. Possibly, the 2-ethyl-1-hexanol in **Blend B** has an unfavorable effect on soot formation, and at this operating point this influence outweighs the advantage of the higher OME content compared to **Blend A**.

As expected, the most important factor influencing NOx emissions at this operating point is the EGR rate, whose increase leads to a significant reduction in NOx emissions. There are hardly any differences between the fuels. At identical EGR rates, the variation in SOI between the fuels is less than 0.6 °CA.

CO and HC emissions are at a very low level throughout the variation, and there are only minimal differences between the fuels. Due to the boundary conditions prevailing in the combustion chamber at PL2 and the significantly lower maximum EGR rate compared to PL1, there are no significant advantages for these two emission components at this operating point which could otherwise be attributed to the higher cetane number of the HVO or the blends. For **Blend B**, higher EGR rates actually tend to result in slightly higher CO emissions, possibly again due to the influence of the 2-ethyl-1-hexanol content.

The soot-NOx trade-off for PL2 is shown in Figure 6. With aromatic-free HVO, emissions can be reduced by about 40% compared to conventional diesel even at this load point. The values of **Blend A** are mostly at the same level as with HVO. Only at very low NOx emissions (thus at higher EGR rates), slightly lower soot emissions can be detected. For **Blend B**, the specific soot emissions are about 30% below the HVO values. As the EGR rate increases and NOx emissions are further reduced, the soot levels of the two mixtures converge, possibly as a result of a potentially unfavorable influence of the 2-ethyl-1-hexanol in **Blend B**, as discussed above.

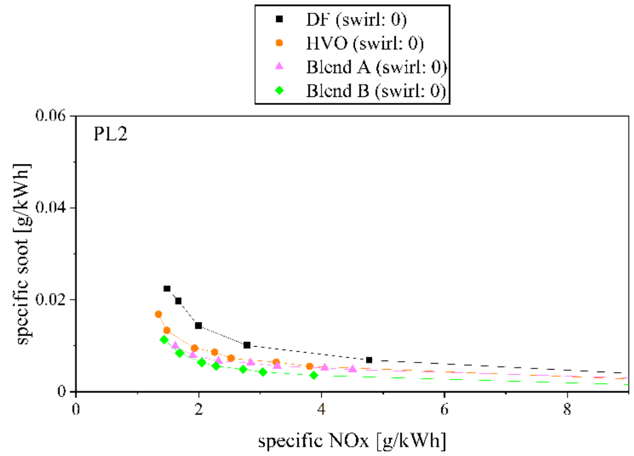

Figure 6. Soot vs. NOx trade-off (part load point 2)

In addition to the tests at part load, measurements were also carried out at full load (FL: engine speed: 4000 rpm; IMEP: variable). Since the main injection quantity is varied in the full load investigations, engine load is also varying. The results of this test are required for the design of the operating range of a multi-cylinder engine to be operated within the scope of the project. At this operating point, therefore, other measured variables such as exhaust gas temperature are of particular interest in addition to soot and NOx emissions. For these investigations, the air mass was kept constant, resulting in a variation of the air-fuel ratio with the different fuels and injection quantities. The peak pressure was kept constant as far as possible by adjusting the SOI. The changes in SOI between minimum and maximum injection rates were less than or equal to 0.3 °CA.

For DF and HVO, manual adjustment of the peak pressure results in approximately equal SOI settings. For **Blend A** and **Blend B**, the result is a slightly earlier start of injection; for **Blend A**, this shift in SOI compared to the DF/HVO values is less than or equal to 0.5 °CA and for **Blend B**, less than or equal to 1.1 °CA. Figure 7 shows the soot and NOx concentration as well as the air-fuel ratio (lambda) and the exhaust gas temperature for the test at full load as a result of an injection quantity variation. For the soot concentration, there is a potential for further reduction compared to conventional diesel fuel, similar to the results obtained at PL1 and PL2. When HVO is used, the observed soot emissions are already well below the values for diesel operation due to the lack of aromatics, and also the increase of these values with increasing load shows a slightly lower gradient. Due to the absence of carbon-to-carbon bonds of OME, soot emissions are again significantly reduced with the two blends. However, no significant difference can be seen between the two blends. Furthermore, compared to diesel fuel, soot emissions increase with higher load with an even lower gradient than observed with HVO.

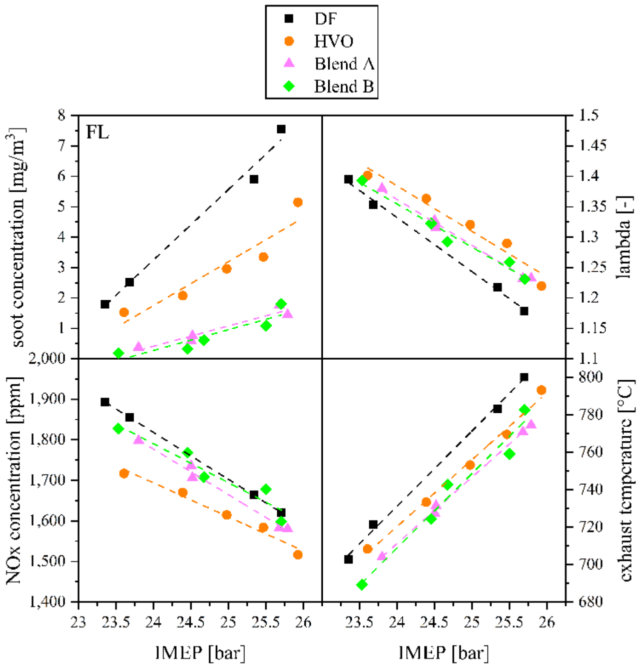

Figure 7. Soot- and NOx-emissions, lambda and exhaust temperature during injection quantity variation (full load)

The NOx level is reduced with increasing load. The lowest NOx values are obtained for HVO, while the two blends are situated between diesel fuel and HVO, with the values for **Blend B** tending towards diesel level with increasing load. As also displayed in Figure 7, the air-fuel ratio decreases with increasing injection quantity due to the air mass being kept constant. The differences in NOx concentration between the different fuels can at least partly be attributed to the different air-fuel ratios. For the air-fuel ratio, the correlation is correspondingly inversed; for the same load, the highest value is obtained for HVO and the lowest air-fuel ratio for diesel fuel.

For the exhaust gas temperatures, differences between the fuels could be observed. The highest exhaust gas temperatures occur when operating the engine on conventional diesel fuel, while with HVO, the exhaust gas temperature is approx. 10°C lower, and both **Blend A** and **Blend B** tend to produce about 20°C lower exhaust temperatures.

Summary and Outlook

The investigations carried out to date have shown that the two blends investigated (**Blend A**: HVO/OME: 90/10 and **Blend B**: HVO/OME/2-ethyl-1-hexanol: 80/15/5) provide significant potential for reducing soot emissions compared to conventional diesel fuel and – at least in some cases – compared to HVO. The soot formation of the paraffinic diesel fuel HVO, which is already considerably lower than for conventional diesel fuel, may be reduced further for most operating points by adding OME. Alternatively, there is a potential to reduce nitrogen oxide emission while maintaining the same level of soot emission due to the increased EGR compatibility.

In a direct comparison, none of the two blends stands out clearly from the other across all operating points with respect to emissions. At operating points with low load, **Blend B** has a slightly higher potential than **Blend A** for the emission reduction of both soot and NOx, which are particularly relevant for diesel engines. In this operating range, the slightly higher OME content and the slightly higher oxygen content due to the higher OME share and the 2-ethyl-1-hexanol additive have a slightly stronger effect than at higher load points, since the soot emissions for all fuels are significantly lower there. However, it needs to be considered that all investigations were based on a conventional diesel application parameter set, with just the injection quantities of the individual injections adapted to the calorific value specific to the fuel. Apart from this, no further adjustments or optimizations with regard to the fuel used were carried out to date. Since in the future continuation of the project, also a fuel-specific optimization of the combustion process is planned, it is still possible that further emission reductions can be achieved. Furthermore, modifications to the injector beyond the adaptation of the materials are also planned for a more in-depth investigation, which could again significantly influence the emission results.

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Definitions/Abbreviations

CO	Carbon monoxide
CO_2	Carbon dioxide
DF	Diesel fuel
ECU	Electronic control unit
EGR	Exhaust gas recirculation.
EOC	End of combustion
FAME	Fatty Acid Methyl Ester
FL	Full load
HC	Hydrocarbon
HVO	hydrogenated/hydrotreated vegetable oil
IMEP	Indicated mean effective pressure
NOx	Nitrogen oxides
OME	polyoxymethylene dimethyl ether (POMDME)
PL	Part load point
SOC	Start of combustion
SOI	Start of injection
TDC	Top dead center