

A New Measurement Technique for Online Oil Dilution Measurement

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ABSTRACT

New trends in the development of combustion engines lead to changed engine operating conditions which also result in changed loads of the engine parts and functional components. The application of regenerative fuels and new exhaust after-treatment systems can for example lead to an increased input of fuel into the engine oil. Oil dilution is an issue that impacts the engine operation and life cycle and therefore gains importance during the development process of combustion engines. In order to improve oil dilution to preclude destructive amounts of fuel in the oil it is necessary to investigate and optimize the fuel in oil sorption and desorption processes.

At the University of Applied Sciences Regensburg a new measurement technique has been developed that realizes the online analysis of the fuel quantity in the engine oil. The measurement technique enables a total as well as a selective detection of fuel hydrocarbons so that besides the detection of the total fuel amount in the oil it is also possible to study the sorption and desorption behavior of single fuel components into and out of the oil.

Investigations were carried out with the measurement technique on gasoline and diesel engines at engine operating conditions with high oil dilution risk. The main focuses were for gasoline engines on the study of cold start and warm up behavior of the engine under cold ambient conditions with fuels containing varying amounts of ethanol and for diesel engines on the study of late injection strategies for particulate filter regeneration.

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INTRODUCTION

The development of modern combustion engines is influenced by various factors. One significant factor is the global statutory limitation of emissions that are gradually getting stricter. Reaching these emission limits takes great efforts and often it is not possible to achieve the emission limits solely by optimizing the combustion process. In this case the exhaust gas has to be chemically converted additionally after leaving the combustion chamber by means of exhaust after-treatment systems before leaving the vehicle. In order to reduce exhaust gas emissions there are already numerous systems in use. Today besides the three-way catalytic converter one of the commonly known after-treatment systems is the diesel particulate filter.

In 1997 the industrialized countries also pledged to drastically reduce greenhouse gas emissions in the Kyoto

Protocol. To reach this goal the European Parliament and the Council of the European Union enacted the "Renewable Energy Directives" in 2001, 2003 and 2009 that prescribe the Member States of the European Union a minimum percentage of 20 % of renewable energy of the total final energy consumption by 2020. For the transport sector a minimum rate of renewable energy of 10 % for gasoline and diesel fuels has to be implemented until then. [1] With the increased use of renewable fuels for both gasoline and diesel engines further new challenges arise during the development process of new engines.

An important functional element of the combustion engine which is also affected by these new trends is the engine oil. The engine oil is not only responsible for the lubrication of the engine but also fulfills other important tasks such as cleaning, cooling and corrosion protection and thus the oil is a main influence factor on engine life time [2]

During engine operation the engine oil is exposed to thermal and mechanical strains and contamination with pollutants that reduce the function of the oil and thereby degrade the engine performance. The current development trends due to the new requirements to reduce exhaust emissions and the application of new fuels lead to modified strains of the engine oil. For example an increased dilution of the engine oil by fuel is observed whereby the lubricating properties of the oil are reduced which may lead to a major detraction of the engine operation. [3, 4, 5]

In contrast to that a current objective is also to extend oil change intervals as much as possible due to customer requirements and environmental reasons. Therefore it is necessary to adapt the engine oil to the occurring stresses and reduce oil damaging effects at its best. In the development of modern combustion engines it is therefore necessary to investigate the fuel in oil sorption and desorption processes in order to preclude damaging amounts of fuel in the engine oil.

METHODS FOR OIL DILUTION MEASUREMENT

For the determination of the proportion of liquid contaminants in engine oils several standardized test methods exist. The evaluation of the fuel proportion in oil can thereby be done by distillation, gas chromatography or the analysis of the flash point. [6] In addition to the standardized methods other techniques such as gravimetry or thermo-gravimetry are often used. These measuring procedures are all carried out offline which means that the oil sample needed for the investigation is taken from the engine and is then subsequently analyzed in the laboratory. These methods have on the one hand the disadvantage that due to the required amount of oil sample quantity only a limited number of samples can be taken from the engine without affecting the oil balance of the engine and on the other hand the analysis of the samples takes a rather long time.

In addition to the offline measurement methods there are also online methods that allow a rapid analysis of the fuel proportion in the engine oil directly when the engine is operated. These methods include the radiotracer method and the laser-induced fluorescence (LIF) spectroscopy. Both methods use tracer substances for detecting the fuel. Due to the used radioactive tracer the radiotracer method is associated with considerable safety risks; for the LIF spectroscopy the used fluorescent tracer does not have the same evaporation characteristics as fuel so that only limited quantitative information of the amount of fuel in the engine oil can be obtained. [7, 8]

Instead of measuring oil dilution there are also methods to calculate the amount of fuel in the engine oil as for example described in [9]. Here fuel desorption and evaporation into and out of the oil is determined by calculating lambda and fuel balances. The accuracy of such calculations is mainly based on the quality of the measured values the used functions are based on. Generally it can be said that most of

the mathematical methods to determine oil dilution have a limited accuracy and are mostly used to analyze high amounts of fuel in the oil.

For the online detection of the fuel proportion in engine oil and in particular to examine the fuel in oil sorption and desorption processes up to now there is no system available that meets both the technical as well as the economic requirements. Hence at the University of Applied Sciences Regensburg a new measurement technique has been developed that allows both the online analysis of the quantitative fuel proportion in the engine oil as well as the specific fuel in oil sorption and desorption processes. Due to its high precision and low detection limit this measurement technique facilitates the analysis of very small amounts of fuel in the engine oil. [10]

A NEW TECHNIQUE FOR ONLINE OIL DILUTION MEASUREMENT

The developed measurement technique allows online a quasi- continuous analysis of volatile fuel components in the engine oil. The determined concentrations of these single fuel molecules are directly a measure for the fuel portion in the engine oil so that no additional tracer substance is necessary. The measurement method is applicable to gasoline engines running with gasoline and fuels containing ethanol as well as to diesel engines running with regular diesel fuel or biodiesel blended fuels. The technique is particularly suitable for the analysis of transient engine operation such as motor start and warm up.

The measurement setup for the quasi-continuous analysis of oil dilution consists of three main tasks:

- Extraction of a representative oil sample from the engine
- Separation of the volatile fuel components from the liquid oil sample
- Determination of the concentration of the evaporated fuel components

Figure 1 shows the schematic experimental measurement setup of the online oil dilution measurement:

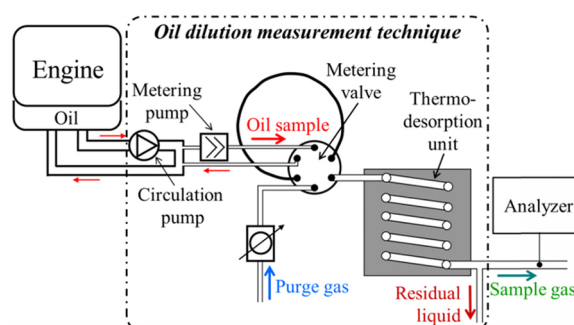


Figure 1. Schematic setup of the online oil dilution measurement technique [10]

For the extraction of representative oil samples from the engine a circulating pump is connected to the oil pan. This pump is operated in a bypass circle from the oil pan directly back to the engine in order to provide a homogenization of the engine oil. From this bypass circle a metering pump is fed with a representative oil sample. The metering pump operates a smaller bypass circle and feeds the oil through a metering valve. For the execution of an analysis the oil sample that is located inside the sample loop of the metering valve is led to the thermo-desorption unit of the measurement technique. The amount of oil needed for one analysis is 0.1 ml so that a huge number of analyses can be performed without influencing the oil balance of the engine.

In the second part of the measurement setup the oil sample is injected into the thermo-desorption unit in which the volatile fuel components of the oil sample are separated from the oil. The gaseous fuel components are then fed with purge gas from the thermo-desorption unit into the analyzer. Simultaneously the residual liquid is discharged separately into an intercepting tank and the thermo-desorption unit is purged in order to enable the performance of multiple analyses in short time intervals.

For the analysis of the fuel proportion in the engine oil two different analytical devices are used. For a selective detection of individual hydrocarbons a mass spectrometer (MS) that works with chemical ionization (IMR) and thus enables a measurement of the components mostly without fragmentation is used [11]. For the analysis of total hydrocarbons a flame ionization detector (FID) is applied.

The analysis of the fuel proportion with the MS is done via the individual components that are characteristic for fuel. For this purpose hydrocarbon molecules are selected that are contained in significant quantities in the fuel and in the oil only in trace amounts. Additionally molecules with different physical properties are to be considered because these are determining the desorption behavior of the fuel components from the engine oil.

For the selection of the target components the pure fluids fuel and oil as well as fuel/oil-mixtures with varying fuel quantity are examined by headspace technique with the mass spectrometer. The figures 2 and 3 show measurement signals of the MS in "counts per second" (cps) for engine oil and gasoline respectively diesel fuel.

Based on the mass spectra measured by headspace technique the molecules ethanol (C_2O_5OH), benzene (C_6H_6), toluene (C_7H_8) and xylene (C_8H_{10}) are selected for the oil dilution analysis for gasoline and ethanol containing fuels.

For the analysis of the diesel content in oil the hydrocarbons C_4H_{10} , C_5H_{10} , C_5H_{12} and C_8H_{16} are selected based on the measured mass spectra because these signals show significant differences between diesel and engine oil.

Due to the different physical properties of the chosen molecules for gasoline and diesel fuel the bandwidth of the sorption and desorption behavior of the different fuel components can be investigated.

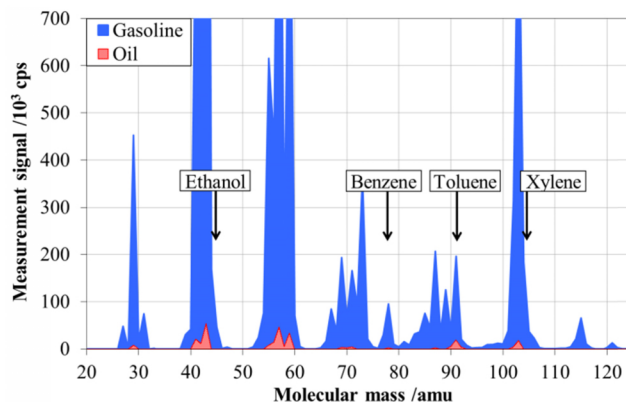


Figure 2. Mass spectra of gasoline and oil

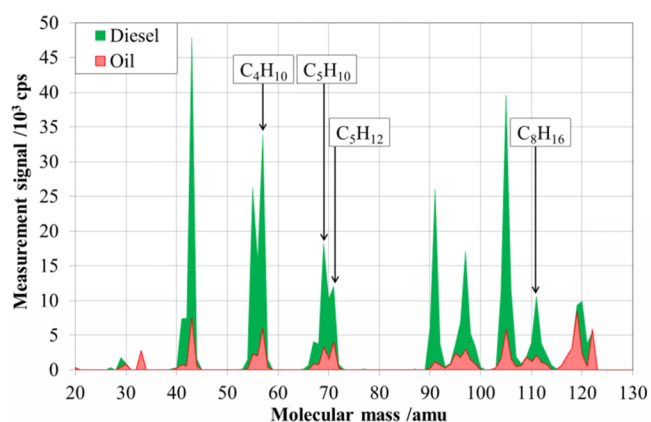


Figure 3. Mass spectra of diesel and oil

The quantitative calculation of the fuel concentration in the engine oil is done via calibration curves. These are created with calibration solutions of known composition from 0 % up to 15 % fuel content in the engine oil. Using these calibration curves the precision and the detection limits of the measurement technique are determined according to DIN 1319-3 (Table 1). [12]

Table 1. Precision and detection limits of the online oil dilution measurement technique

	Diesel	Gasoline
Precision /% fuel	± 0.18	± 0.05
Precision /g fuel (for 6 l oil volume)	± 9.0	± 3.0
Detection limit /% fuel	0.33	0.17
Detection limit /g fuel (for 6 l oil volume)	16.5	8.5

APPLICATION OF THE ONLINE OIL DILUTION MEASUREMENT TECHNIQUE

Oil Dilution Measurement on Gasoline Engines

When using gasoline fuels containing ethanol the risk of fuel input into the engine oil increases particularly under cold start conditions due to the lower calorific value of ethanol a higher amount of fuel is required and the preconditions for mixture formation compared to regular gasoline are worse because ethanol has a higher evaporation enthalpy, a lower vapor pressure and no low boiling components. [13] Because of that the online measurement technique is implemented on a flex fuel vehicle for the investigation of fuel oil dilution during cold start and warm up phases of the engine at different environmental conditions and fuels with varying ethanol portions.

Experimental setup

The measurements with the online oil dilution measurement technique are carried out on a flex fuel vehicle with a 1.6 liter 4-cylinder engine with intake-manifold fuel injection (MPI) that can be operated with fuels containing 0 % to 85 % ethanol. Additionally the vehicle is equipped with a cold start system for the operation with E100 fuel. In order to connect the measurement technique to the test engine the oil drain plug of the engine is modified so that the engine oil can be pumped from the oil sump. After flowing through the measurement device the oil is fed back into the engine through the oil filler neck. Figure 4 shows the schematic experimental setup for the online oil dilution measurement on the flex fuel vehicle.

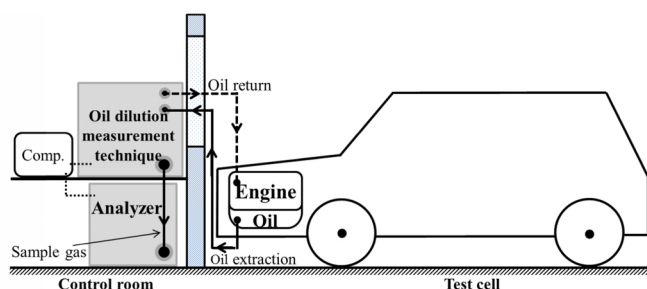


Figure 4. Schematic experimental setup for the oil dilution measurement on the flex fuel vehicle

The technical data of the flex fuel engine are summarized in [table 2](#).

Table 2. Technical data of the 1.6l flex fuel engine

Cylinder	4
Displacement	1.6 l
Fuel	E0 – E85
Emission standard	Euro 4
max. Torque	148 Nm at 4,500 rpm
max. Power	75 kW at 5,700 rpm

Experimental procedure

During the investigation of the oil dilution on the flex fuel vehicle fuels with different ethanol content were examined. Also measurements at varying environmental conditions and different engine start and warm up strategies were carried out. Engine starts were done with oil containing no fuel as well as with oil that already contains fuel that has been inserted during multiple prior engine cold starts without heating up the oil before the start procedure. In the shown engine start and warm up procedures the engine was operated for at least 60 minutes at idle speed after the start in order to heat the engine oil slowly. During all shown engine start and warm up tests oil samples were examined with the measurement technique at a measurement interval of 60 seconds.

Results

Analysis of cold start and warm up phases with fuels with varying ethanol content

Figure 5 shows the oil dilution measurement results of the ethanol analysis by the mass spectrometer for cold start and warm up tests with gasoline fuels containing 20 % (E20), 40 % (E40), 60 % (E60) and 75 % (E75) ethanol. In order to compare the different fuels the amount of ethanol in the oil sample is analyzed instead of the four selected components shown in [figure 2](#). In the diagram the integrated measurement signal of the MS (scps) is presented as a measure of ethanol amount in the engine oil. Additionally the oil temperatures are shown in the diagram. The oil temperatures before engine start are corresponding to the ambient temperatures and lay in the range of -6°C to $+8^{\circ}\text{C}$.

It is clearly seen that with rising ethanol content of the used fuel the amount of ethanol that enters the oil increases significantly. The reasons for that are on the one hand the higher ethanol content of the fuel that is absorbed by the oil and on the other hand the trend to higher fuel input into the oil during the engine start and warm up phase.