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NH_3 sensor measurements in different engine applications

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Abstract

In this study the exhaust gas ammonia (NH_3) concentrations from different exhaust sources were measured with ammonia sensor. Aim of the study was to find out if NH_3 sensor has potential to be used for monitoring and control purposes for SCR systems. Measurements were performed in laboratory and field conditions and comparison against Fourier Transform Infrared (FTIR) and Laser Diode Spectrometer (LDS) measurement techniques were carried out.

With heavy-duty vehicle, a comparison between LDS, FTIR and NH_3 sensor was performed on a heavy-duty chassis dynamometer. Measurements were performed on steady speeds and using World Harmonized Vehicle Cycle (WHVC) and Braunschweig test cycles. The urea injection rate for SCR system was varied for generating different ammonia levels on the exhaust gas.

On large cruiser ships the NH_3 measurements with FTIR and NH_3 sensor were performed using heavy fuel oil (HFO) and marine gas oil (MGO) as fuels. Also a long-term trials on two cruiser ships were conducted using heavy fuel oil and low sulphur (S<0.1%) residual fuel.

Results indicate that the NH3 sensor has potential to be used in different applications for monitoring and controlling the SCR system. Measurement results with the sensor were in good correlation with LDS and FTIR techniques and in dynamic measurements the sensor response was very fast.

Introduction

The current NO_x emission limits set by the legislation e.g. in U.S. and Europe, force vehicle and engine manufactures to use emission control systems for limiting NO_x emissions. This is applies to heavy- and light-duty diesel vehicles as well as for the non-road diesel engines and ship engines.

Selective catalytic reduction (SCR) is used for heavy-duty engine applications for controlling the NO_x emissions. Also some light-duty vehicles use the same NO_x reduction strategy. The SCR is based on injecting water-urea solution (AdBlue, hereafter urea) in exhaust gas before a SCR catalyst element. The injected solution decomposes under high temperatures to ammonia (NH_3) which reacts in the catalyst and the nitrogen monoxide (NO) and nitrogen dioxide (NO_2) are reduced to nitrogen (N_2) and water (H_2O). The actual chemical reactions in SCR are more complex and in real operating conditions the reactions can be incomplete.

SCR systems need complicate control system for reducing the nitrogen oxides (NO_x) emissions in the most efficient way and without feeding excess amounts of urea to the exhaust gas. Excessive urea feed causes NH_3 emissions (NH_3 slip) after the catalyst. Therefore the system needs to operate in controlled way under dynamic operating conditions. NH_3 slip is unwanted, since the NH_3 is a precursor of secondary inorganic aerosol [1]. In environment the NH_3 causes acid deposition, coastal eutrophication and productivity of freshwaters, marine waters, and terrestrial ecosystems [2]. In small concentrations the NH_3 is not dangerous to human health but it can be irritating. The occupational health exposure limit for 15 minutes time period is is 50 ppm [3].

Measuring NH_3 from the exhaust gas is mandatory for heavy-duty engine certification in Europe and recommended in U.S. In Europe the allowed average NH_3 concentration during the test cycle is 10 ppm for heavy-duty on-road and non-road mobile machinery (25 ppm for locomotive engines) [4, 5]. In U.S. the EPA has been thought to set 10 ppm limit value for average NH_3 concentration over the test cycle [6]. In Europe the approved NH_3 measurement methods for heavy-duty vehicle engine type approvals are Fourier Transform Infrared (FTIR) and Laser Diode Spectrometer (LDS) and for non-road mobile machinery also Non Dispersive Ultra Violet Resonance Absorption (NDUV) [7,8].

The European heavy-duty engine type-approval procedure includes in-service conformity testing. The first in-use test should be performed at the time of type-approval testing. Portable emissions measurement system (PEMS) is used for the measurement, which is performed on-road according to specified driving pattern. At the moment testing doesn't cover the NH_3 emissions.

As mentioned the chemical reactions of SCR catalyst are complex and sensitive to exhaust gas conditions (temperature, flowrate) and catalyst ageing can cause decreasing efficiency of NO_x reduction. According the European regulations the emission durability requirement for Euro VI heavy-duty vehicles is 500 000 km / 7 years [9]. In U.S. the corresponding requirement for HHDDE category is 435,000 miles / 22,000 hours / 10 years [10]. The U.S. and European legislation also set requirements for on board diagnostics (OBD) system, which needs to detect malfunctioning emission control devices.

The heavy-duty vehicles use NO_x sensors for controlling the SCR system and for the OBD system requirements related to SCR. NO_x sensors are accurate way of controlling SCR and measuring the NO_x emissions before and after SCR catalyst. However, NO_x sensor has cross-sensitivity with NH_3 since NH_3 forms NO inside the sensor. When NH_3 is present in the exhaust gas after the SCR the NO_x