ON-BOARD REAL LIFE AMMONIA MEASUREMENTS FOR VEHICLES WITH RECENT EMISSION CONTROL TECHNOLOGY

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ABSTRACT
Ammonia emissions of modern petrol fuelled cars are of raising concern especially in the city. As to heavy duty (HD) diesel vehicles the possible use of urea in the Selective Catalytic Reduction (SCR) of nitrogen oxides can result in ammonia slip.

In the development or evaluation of vehicles equipped with recent or new emission control technology an on-board measuring system capable of determining ppm level emissions of ammonia is used. This system features the latest in laboratory grade Tuneable Diode Laser (TDL) analysers. The simultaneous retrieval of engine and vehicle parameters together with the measurement of regulated exhaust emissions allow for a quick link to relevant parameters of the emission control system.

The system consists of a novel Norsk Elektro Optikk TDL analyser with the transmitter and receiver mounted on the opposite sides of a compact measurement cuvet. This system is mounted on the exhaust piping measuring under full flow conditions. Extensive testing in the laboratory and on-board a HD test vehicle yielded sub ppm zero stability and detection limit.

A real life on-board evaluation is executed on a SCR and particulate trap equipped city bus. The ammonia slip is found to be dependent on engine, urea dosing and catalyst parameters.

Keywords: ammonia, emissions, on-board, real life, SCR

INTRODUCTION
Road transport is known as a major source of exhaust pollutant emissions. Some of these have been regulated in many countries i.e. carbon monoxide (CO), total hydrocarbons (THC), nitrogen oxides (NO_x) and particulate matter (PM). Others are the so called non regulated emissions. They include e.g. carbon dioxide (CO_2), nitrous oxide (N_2O), speciated hydrocarbons (e.g. benzene, polycyclic aromatic hydrocarbons) etc. Also ammonia (NH_3) is one of these emissions.

Ammonia is an aggressive gas to the eyes, skin and respiratory trajectory. It has a maximum allowable concentration in air of 20 ppm. This is also the level at which it can be smelled. Ammonia can react with nitrate and sulphate in the exhaust gas and form respectively ammonium nitrate and sulphate that are emitted as secondary particles.

At present ammonia is emitted from petrol fuelled cars. It is an unwanted side effect of the introduction of the catalytic converter on these vehicles. In a Californian study on 39 vehicles [1] of different emission categories widely varying ammonia emissions from 4 to 177 g/mile were found. The study was executed along different routes driven on chassis dynamometer. In future ammonia will also be emitted from HD diesel fuelled vehicles if they make use of SCR to reduce their NO_x emissions to below the 2005/2008 upcoming Euro 4/5 legislative limits of 3.5 and 2.0 g/kWh respectively.

To determine the on-road real life ammonia emissions an on-board measurement is needed as in an emission lab not all conditions can be simulated. This is especially the case for SCR equipped vehicles as SCR is dependent on many parameters that can not all be reproduced on dynamometer. The use of an on-line on-board system capable of assisting in on-the-fly engine calibration would accelerate the development process. The results are directly available whilst the vehicle is driven on the road. In the following the realisation of such an on-board system is described together with an application on a SCR equipped city bus.

GOAL

The aim of this study is the development of an on-board ammonia measuring system capable of:

1. the on-line determination of ppm levels of NH_3 in full flow exhaust gas;
2. resisting harsh on-the-road conditions especially regarding shocks and vibrations;
3. making the link to engine, vehicle and emission control parameters;
4. being applied on a SCR equipped city bus.

THE AMMONIA ANALYSER

For the measurement of ammonia in exhaust special care has to be taken to the sampling. The normal way of retrieving a part of the exhaust gases, conditioning it and delivering it to the analyser installed inside the vehicle has serious drawbacks given the reactivity of ammonia. To prevent the loss of ammonia due to the formation of ammonium nitrate and sulphates the sampling line must be heated to 250°C. The use of an infrared analyser usually requires the removal of exhaust water which if done in a cooler will form NH_4OH. Even if other solutions are applied here the salt formation remains a problem. Therefore the direct in situ determination over a Tuneable Diode Laser (TDL) is chosen. This is also the fastest sampling technique as the measurement occurs immediately in the exhaust gas stream itself.

A TDL uses as measurement principle the absorption of infra red light over a measurement path according to Lambert-Beer’s law. The light is generated in the transmitter and detected in the receiver. A TDL offers several advantages to the measurement: it is component specific by the use of monochromatic light, it measures ammonia to the ppm level, it is fast and it is of rigid construction. However, at the start of the project commercially available analysers used a large main cabinet housing the laser and/or electronic components. This limits the suitability for on-board use although Siemens mounted their LDS3000 analyser on-board a SCR equipped HD truck [2]. Therefore a near commercial Norsk Elektro Optikk (NEO) Lasergas II NH_3/H_2O monitor was used. It has no main cabinet as all of the laser, optical and electronic components are integrated in the transmitter and receiver housings. This instrument is now commercially available. It features an additional water measurement capability. Next to the knowledge of water concentration in the exhaust gas this allows to correct the ammonia measurement for water interference on its selected spectral line (infrared absorption due to water is present in a large part of the infrared spectrum). The NEO analyser can also apply an exhaust gas temperature correction to the measured ammonia spectrum.

The on-board setup is shown in Figure 1. The transmitter and receiver are mounted and aligned on the opposite sides of a measurement cuvet that has a similar diameter as the exhaust piping it is connected to. The measurement path length is 1.295 m.

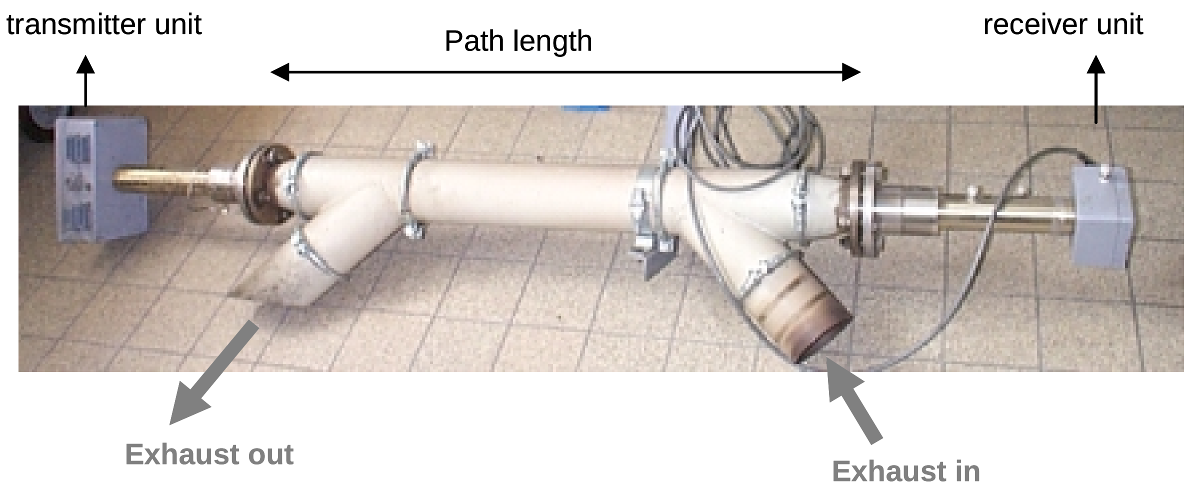

Figure 1: Setup for on-board use of the NEO Lasergas II analyser

The analyser was tested in the laboratory and then installed on a Mercedes Atego HD truck for on-board performance checking. First the zero stability was investigated by driving while measuring on normal exhaust gas. As can be seen from Figure 2 the zero stability is 0.5 ppm. For comparison it is 0.3 ppm in a stationary laboratory setup. The water concentration and the light transmission vary widely but do not influence the readings. The transmission started of at 0.76 -from 1.00 at the beginning of the day- and decreased slowly due to PM deposits on

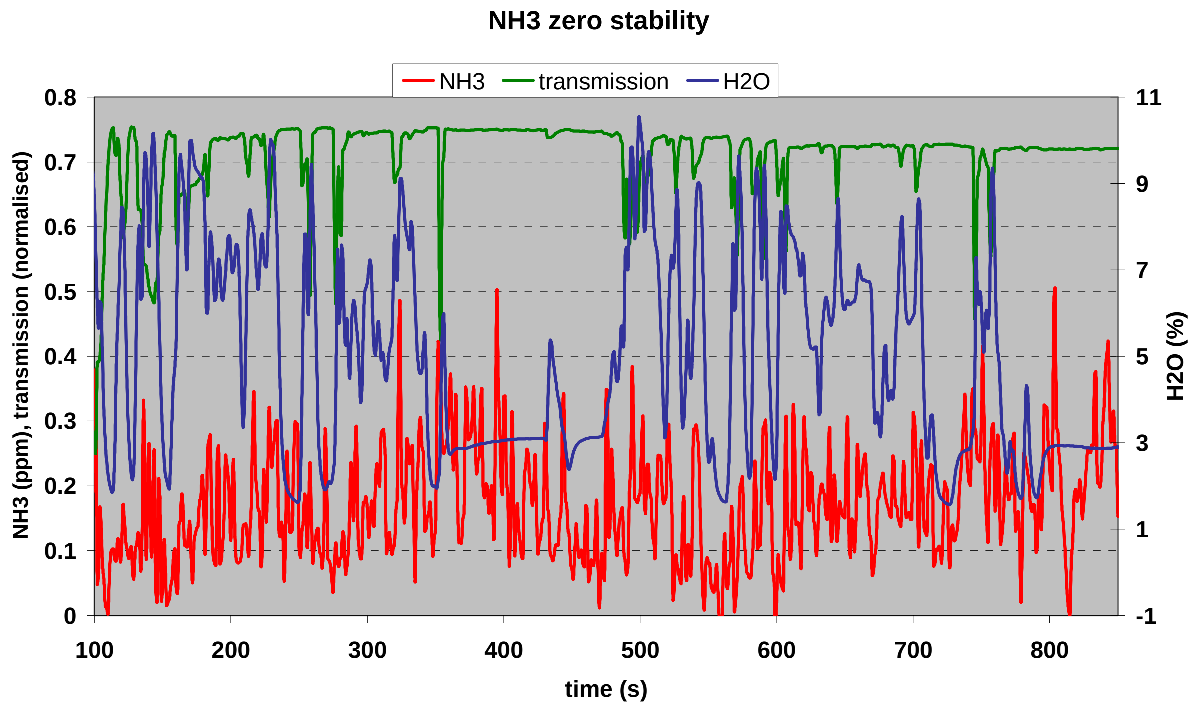

Figure 2: Ammonia analyser zero stability on-board a HD truck

the analyser windows. The transmission drops during vehicle acceleration due to exhaust PM load. Meanwhile the water concentration rises as the air to fuel ratio gets smaller. Figure 3 gives part of Figure 2 for a better view.

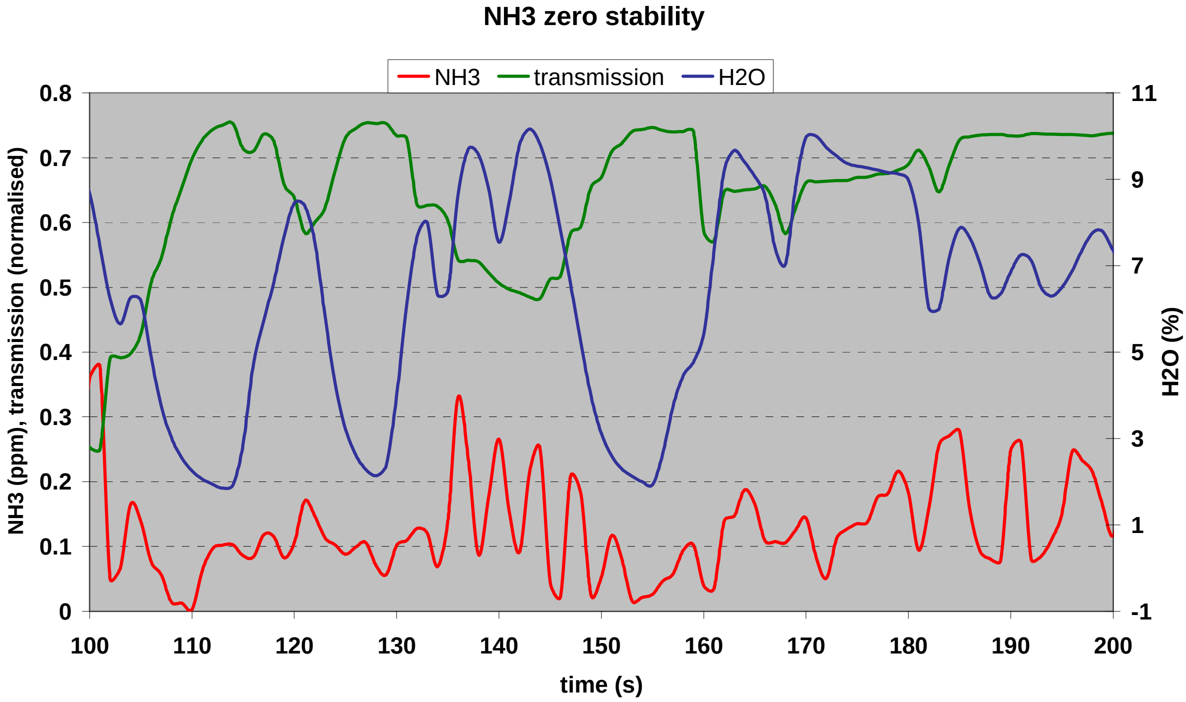

Figure 3: Ammonia analyser zero stability on-board a HD truck; part of Figure 2

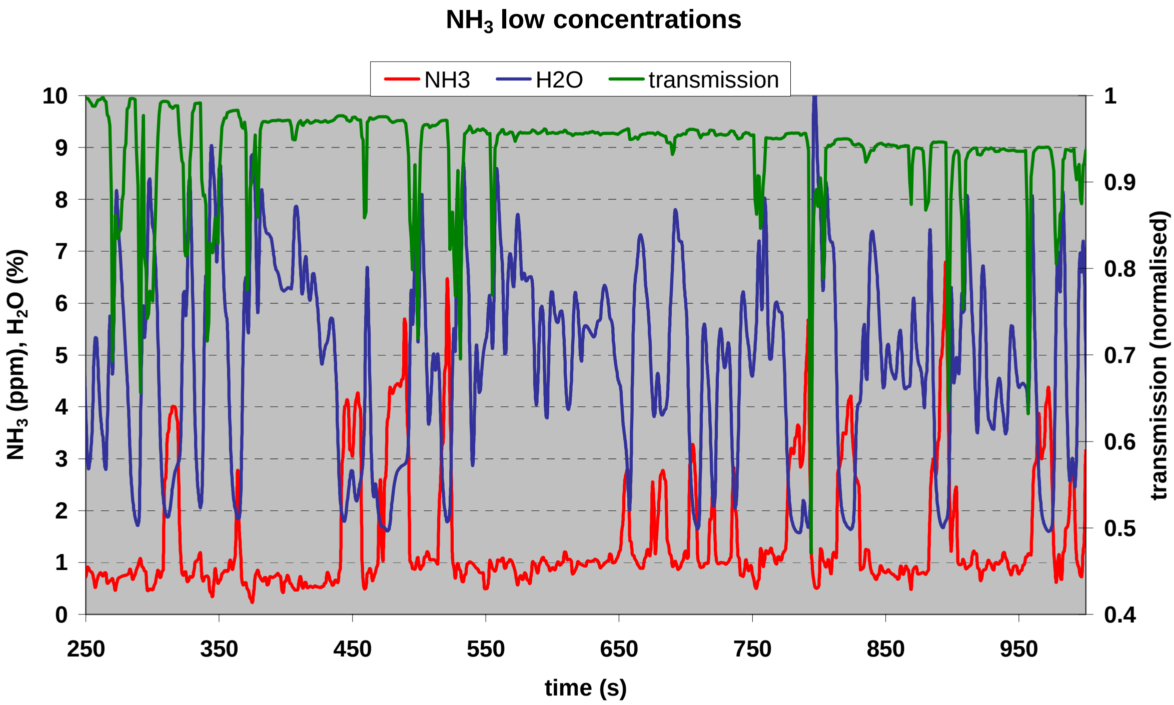

Figure 4: On-board low concentration ammonia measurement

In a next step ammonia was admitted to the exhaust using fixed settings of a mass flow controller connected to a bottle of 5% NH_3 in nitrogen. Due to the changes in exhaust flow the actual ammonia concentration varies too. Figure 4 presents the results for low concentrations (0.5 to 7 ppm) and Figure 5 for higher ones (up to 40 ppm). Figure 4 shows the ability to measure down to the 1 ppm level. Figure 5 shows the ability to measure quickly changing concentrations.

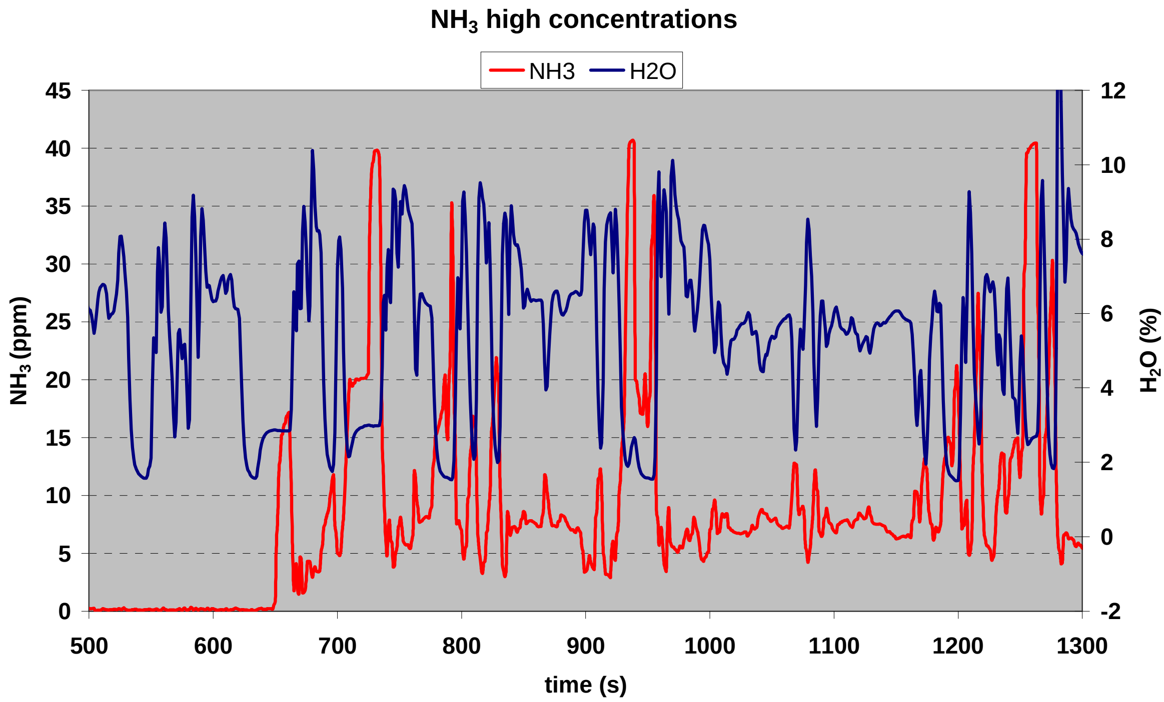

Figure 5: On-board high concentration ammonia measurement

APPLICATION ON A SCR EQUIPPED VEHICLE

The ammonia measurement system was installed on a city bus equipped with a combination of particulate trap and SCR; see Figure 6. An on-board measurement system for gaseous emissions 'VOEMLow' and engine and vehicle parameters [3] was also installed.

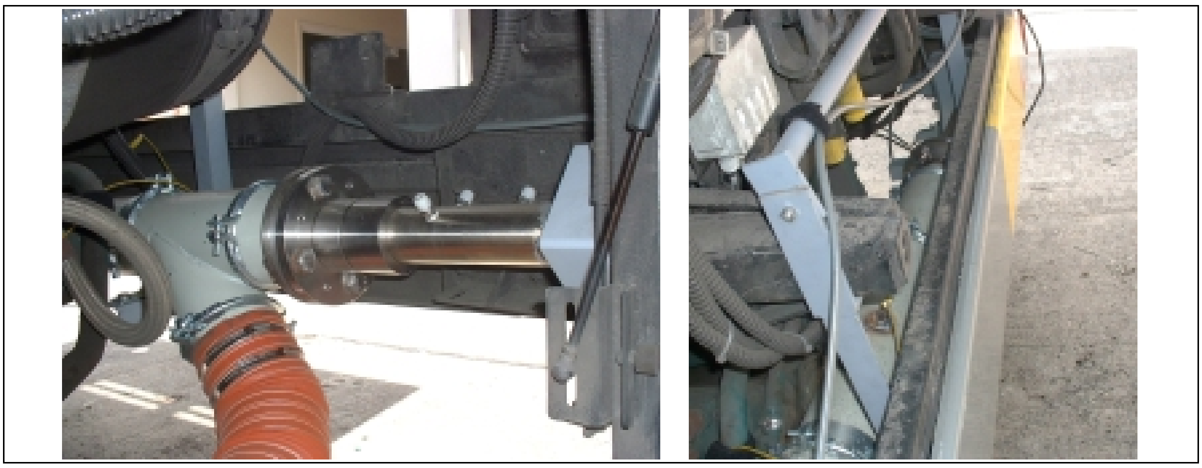

Figure 6: Ammonia measurement system installed on a SCR equipped bus

SCR utilises ammonia to reduce NO_x in exhaust gases. The main reactions are given as:

$4\ NO + 4\ NH_3 + O_2 \rightarrow 4\ N_2 + 6\ H_2O$ and

$6\ NO_2 + 8\ NH_3 \rightarrow 7\ N_2 + 12\ H_2O$

The ammonia in the tested vehicle is produced from an urea solution that is injected in the exhaust. The hydrolysis of this urea forms ammonia that reacts in a SCR catalyst with NO_x. As NO_x amounts vary fast the injection of urea needs to do so too. If not enough is injected the NO_x reduction rate is too small; if too much is added excess ammonia will be emitted as the so called ammonia slip. Figure 7 shows the ammonia slip together with NO_x before and after the catalyst measured on the Fige cycle. At first the ammonia slip is low but then it rises to a maximum of 30ppm. NO_x is significantly reduced. Figure 8 presents the ammonia slip together with the exhaust temperature before the SCR catalyst and vehicle speed for the same test cycle. Catalyst temperature is one of the parameters affecting the conversion efficiency and the results suggest that it might have an influence here. This application shows the potential of on-board ammonia slip measurement when making the link to engine, vehicle and emission control parameters.

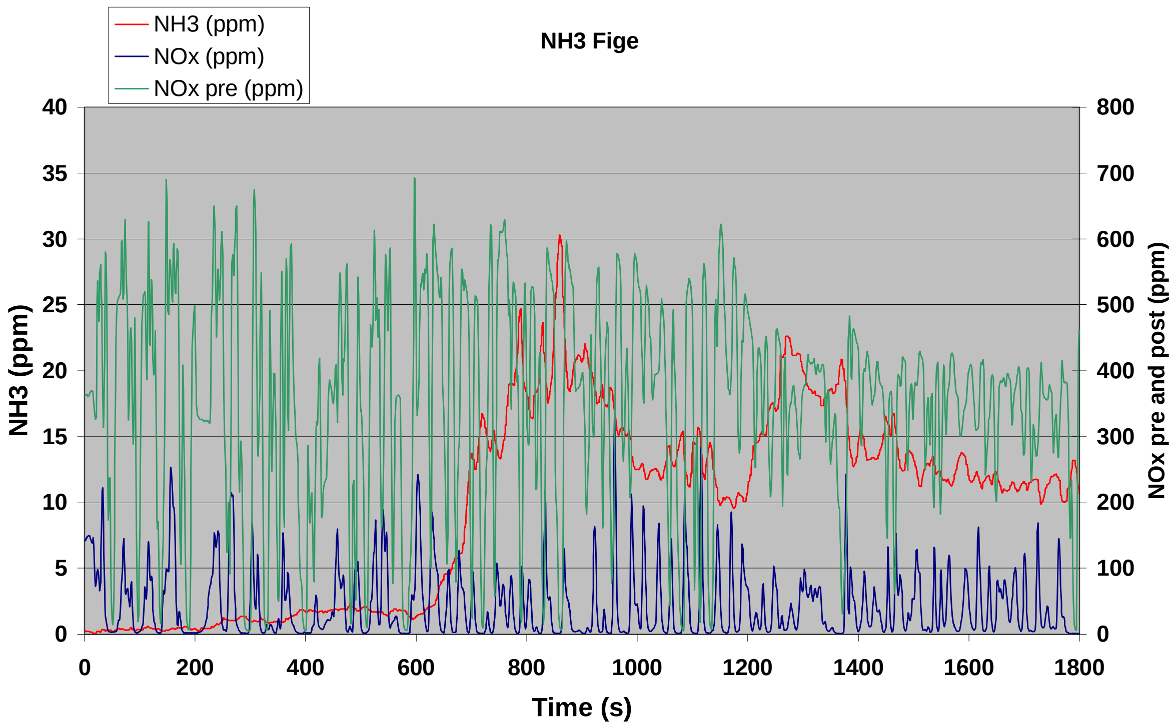

Figure 7: Ammonia slip, NO_x pre and post SCR catalyst on the Fige cycle

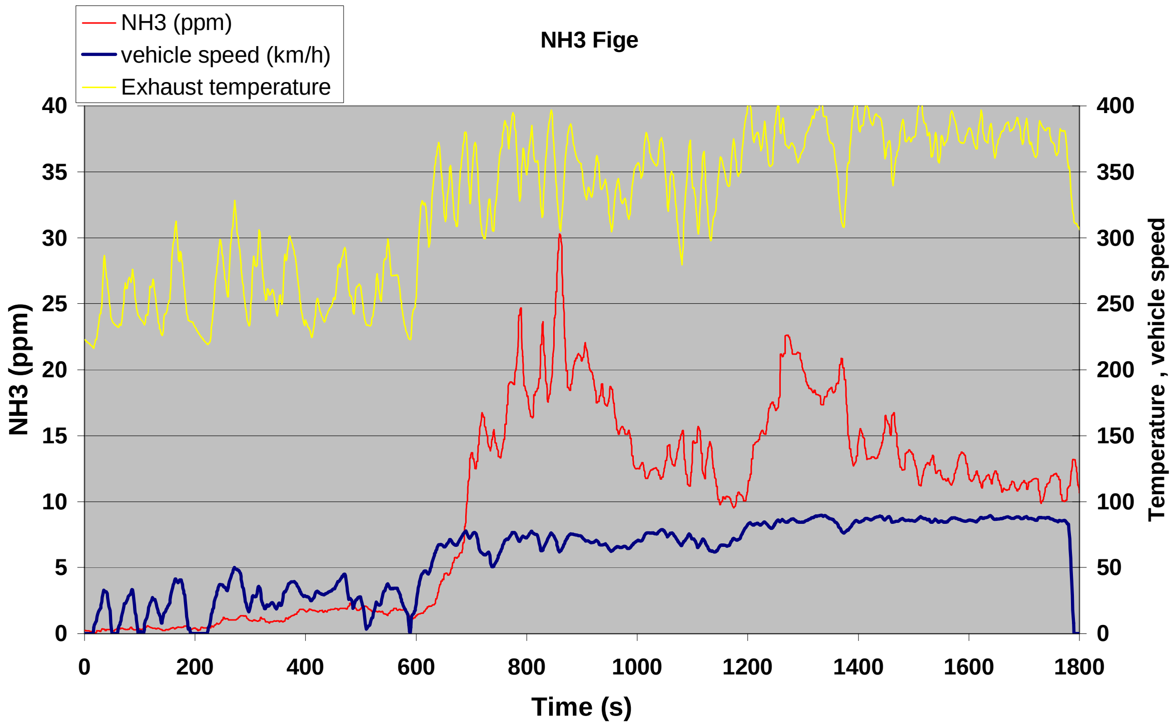

Figure 8: Ammonia slip, vehicle speed and pre SCR exhaust temperature on the Fige cycle

CONCLUSIONS

An on-board system capable of determining ppm emissions of ammonia is realised. The system consists of a novel Norsk Elektro Optikk TDL analyser with the transmitter and receiver mounted on the opposite sides of a compact measurement cuvet. This system is mounted on the exhaust piping measuring under full flow conditions. Extensive testing on-board a HD vehicle yielded sub ppm zero stability and detection limit.

The simultaneous retrieval of ammonia, engine and vehicle parameters together with the measurement of regulated exhaust emissions allow for a quick link to relevant parameters of the emission control system as shown in an evaluation of a SCR equipped city bus.

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