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» Airbag Emissions: The Quantification of Gases, Dusts and Acoustics in Practice

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1. Abstract

The emissions of restraint systems - gases, dusts, and acoustics - are quantified in the industry using widely accepted methods such as AKZV01, SAEJ1794 and USCAR. This report gives an overview of the background concerning the analytic methods in use and comments on the given narrow specifications based on more than 20 years of experience in emission testing.

We use pyrotechnical buckle pretensioners (PBP's) of one single lot as a probe for the evaluation of the different influences on the results. Nitrogen oxide is chosen as the key gaseous component and we demonstrate the influences of the experimental set up - humidity and pressure - on the resulting concentration. For the dust analysis two methods are compared: the Andersen impactor and the laser particle counter. The acoustic emissions are distinguished in car and chamber results.

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2. Influences on the Gas Analysis: Example NO_x

For 25 years GWP has been examining gaseous airbag effluents. We have developed a unique method for the on line analysis of 16 gaseous components (compare the German AKZV01 since 1996, or other specifications i.e. SAE1794 or USCAR). Examples of the analytical subjective are reactive and “sticky” molecules like nitrogen oxide (NO_x) or ammonia (NH_3). They may react during the time of analysis over 30 minutes or adsorb due to their relatively high boiling points on walls, particles, and filters. Both mechanisms change the molecules’ initial concentration. Our method AV122 GasL assures the measuring of the actual concentrations using special materials, by heating the tubes, and filtering the gas in cascades before analyzing it with CLD (NO and NO_2 analysis), FT-IR, MS, and ND-IR.

Occasionally we have to comment on the deviations of external results on gas concentrations depending on the ignition and the series. We will show that especially for NO and NO_2 the experimental conditions for ambient pressure, humidity, and type of tank should meet the given specifications in the methods.

2.1. Influence of the Ambient Pressure

In the case of small tank measurements, e.g. 60 L or 146 L, the pressure before the ignition can be varied easily by filling the tank with compressed air or inert gas. Pressures above atmospherical pressure also have the advantage that a gas flow can - after the removal of airborne particles by suitable filtering - easily be fed into an array of analytical devices. Picture 1 shows the drastic influence of the pressure on the resulting NO_x concentration. In this figure, the relative NO_x concentration generated by one PBP decreases with increasing pressure. This shows a strong adsorption or condensation of NO_x molecules to walls and dust particles; this effect is enabled by a water content of about 50 % relative humidity.

Other components like CO and H_2 show different kinetics: the observed relative carbon monoxide concentration increases with increasing initial ambient pressure. Usually CO builds up one monolayer of adsorbed molecules to metals (and oxides) at room temperature and as soon as this capacity is filled all other CO molecules appear gaseous.

As a consequence the tank data on gas concentrations cannot easily be extrapolated for vehicle results.

2.2. Influence of Humidity

A relative air humidity of 50 % at e.g. 21 °C means an absolute water vapour concentration of approximately 1,22 vol%. Released reactive gases may change their chemical state because of the interaction with gaseous water or with the adsorbed water film on walls and particles. For the examination of this effect we adjusted different concentrations of water (or humidity) before the ignition of one PBP in a 60 L tank at 2 atm.

Picture 2 shows the influence of the variable humidity on the resulting gas concentrations. Due to the broad concentration range a logarithmic scale is used for this concentration.

Again, NO_2 shows a drastic dependency: with increasing water content the NO_2 concentration decreases. As the reaction of NO_2 with H_2O resulting in nitric acid (HNO_3) predominately appears on walls and particle surfaces, NO_2 is removed from the gas phase. NO shows a lower reactivity and thus a lower adsorption on the walls or particles. The less reactive components CO and H_2 alter on a lower scale. H_2 may be produced by water reduction due to high combustion temperatures, like H_2O + Red. -> H_2 + Ox..

2.3. NO reaction kinetics in the 2,5 m^3 chamber

Using the 2.5 m^3 tank at a constant, relative humidity of 50 % and a constant temperature of 21 °C we generated various, distinct concentrations of NO (500, 150, 100, 50 and 25 ppm) by loading a certain amount of pure, undiluted NO gas into the tank, employing a predetermined flow rate over a certain time. No fan was used for homogenization of the gas volume in the tank. This procedure represents the initial gas output of a module or gas generator.

The experimentally observed kinetics of the concentration of the nitrogen oxide concentrations are shown in picture 3. The overall sum of both nitrogen oxides (NO_x) is decreasing with a declining rate (top curve). Initially, pure NO is loaded into the tank, but it is rapidly depleted by e.g. forming NO_2 or by adsorption. NO_2 is formed by NO oxidation and consumed by the mechanism discussed above. (All standard methods (AKZV01 or SAE1794) report only averaged gas concentration values over 20 or 30 minutes).

The decay rate of the NO concentration strongly depends on the NO concentration itself. With a higher initial NO concentration, a larger fraction of NO is depleted in a given time (Picture 4). This may reflect the underlying complex, partly self catalyzed decay mechanisms of NO to NO_2, nitrous acid (HNO_2), nitric acid (HNO_3) and other nitrogen oxides (NO_x). It also shows that neither simple linear extrapolation of gas concentrations to different volumes nor the utilization of simultaneously ignited PBP's (e.g. for enhanced detection of low concentrations of trace constituents) are recommended.

3. Dust Analysis

Particles generated by deployment are an important emission affecting passengers. This dust is emitted by most gas generators and has to be investigated according to the methods given. The determination of the total dust concentration (mg m^{-3}) often varies from ignition to ignition with about 20 % or more. To exclude systematic and large statistic errors, complementary methods should always be used simultaneously, i.e. Andersen impactor in addition to total particulate filter.

A standard device for the particle size distribution's measurement is the Andersen impactor. Impaction means the acceleration of a gas and particles through a nozzle and the deflection on a plate located vis-à-vis. On this plate heavy particles are not able to follow the deflected gas path but rather impinge on the plate. Different gas speeds are generated by different diameters of the nozzles on separated impaction stages and result in different deposited particle sizes. Finally, the plates are evaluated by weighing the dust gathered, resulting in a histogram of particle size vs. mass fraction. Picture 5 shows the result of a standard dust concentration measurement by an Andersen impactor. Particles with size over approx. 10 µm usually sediment fast, but small particles stay airborne much longer. Particle samples taken from an Andersen impactor are convenient for element analysis and for testing the morphology (fibers).

In picture 6, the results of the determination of particle density employing a laser particle counter are shown. There is a good correlation between these two complementary techniques regarding total dust content and identification of the fraction size with the prominent mass density.

For the evaluation of the dust's breathable fraction's toxicity the elemental composition is also important. Element analysis of the collected dust has to be done using an ICP-AES, or other related techniques, always requiring a certain mass of sample. The specifications of the methods for dust collecting result in a minimum mass for analysis. E.g. AKZV01, using a backup filter, 5 L min^{-1}, 30 min, with an expected dust concentration of 100 mg m^{-3}, will result in a total of 15 mg collected dust. This requires extreme detection limits for the analysis of elements like Pb, As, Cr, Ni ... Also, the acidity test is difficult employing such a low mass. Where possible we collect more dust material by additional filter lines.

Generally the experimental set up has to be chosen carefully and should take into account various parameters: necessity of particle size distribution, sedimentation of particles, run time and flow of impactors, impactor capacity, recirculation of sample air, additional filter lines for more dust collection, filter capacity, and requirements of the chemical analysis.

4. Acoustics

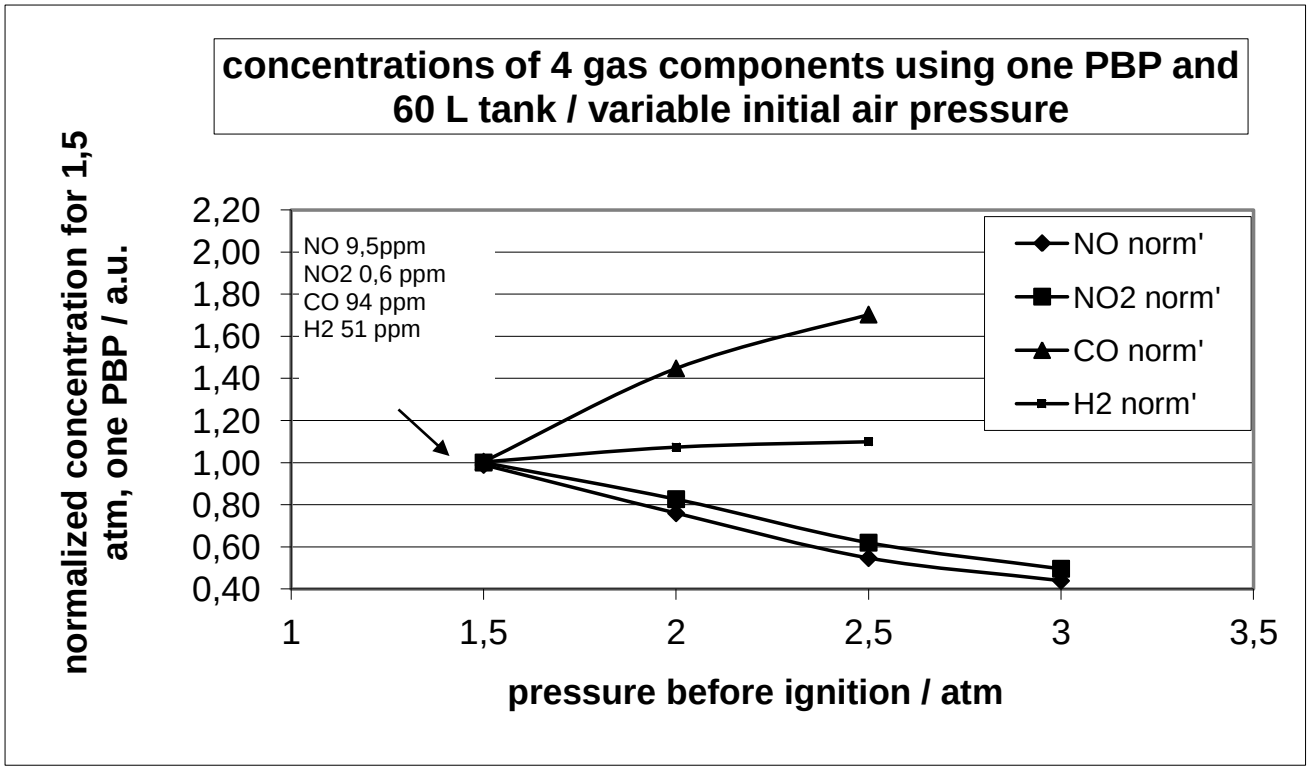
The consideration of acoustic emissions is an important component in air bag development. Although a car crash itself may reach sound levels up to 140 dB, acoustic emissions of air bag releases can easily exceed sound levels which may cause inner ear damage. The methods for emission tests, such as AKZV01 or SAE J247, define a detailed method for the measurement using special equipment to record highly dynamic impulse noise. This method can be applied to vehicle measurements (see picture 7) and also to chamber measurements in an alpha cabin with low acoustic reflections, if no vehicle is available. Gas and dust results can be extrapolated from chamber to vehicle under special conditions, but acoustic results may not be extrapolated due too many influencing and barely known parameters. Nevertheless, chamber tests are necessary to get results in an early stage of a project.

Validation and assessment of results still prove a challenge in acoustic measurements. The US Army defined the Human Ear Model as a method for the reproducible validation of the complex function of a human ear. This model sums up many mechanisms in the ear and calculates a number in “auditory hazard units” (ahu). Thus the complex validation is reduced to an easily manageable numeric result, so that a limit for the maximum expose can be defined, e.g. 500 ahu.

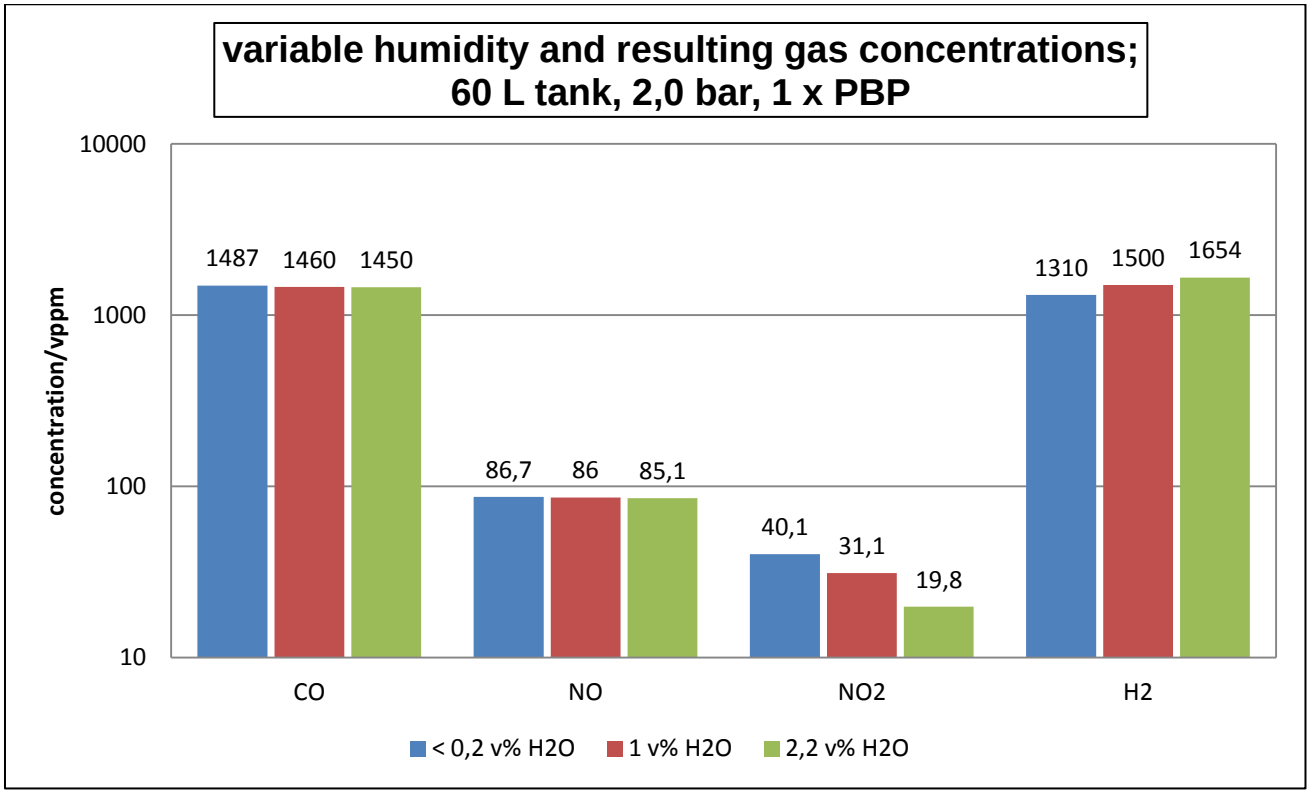
In cooperation with our partner lab, GWP offers acoustic assessments of complete vehicle restraint systems *in situ* in the passenger cabin using state of the art electro acoustic instrumentation.

Zorneding, 30.03.2017

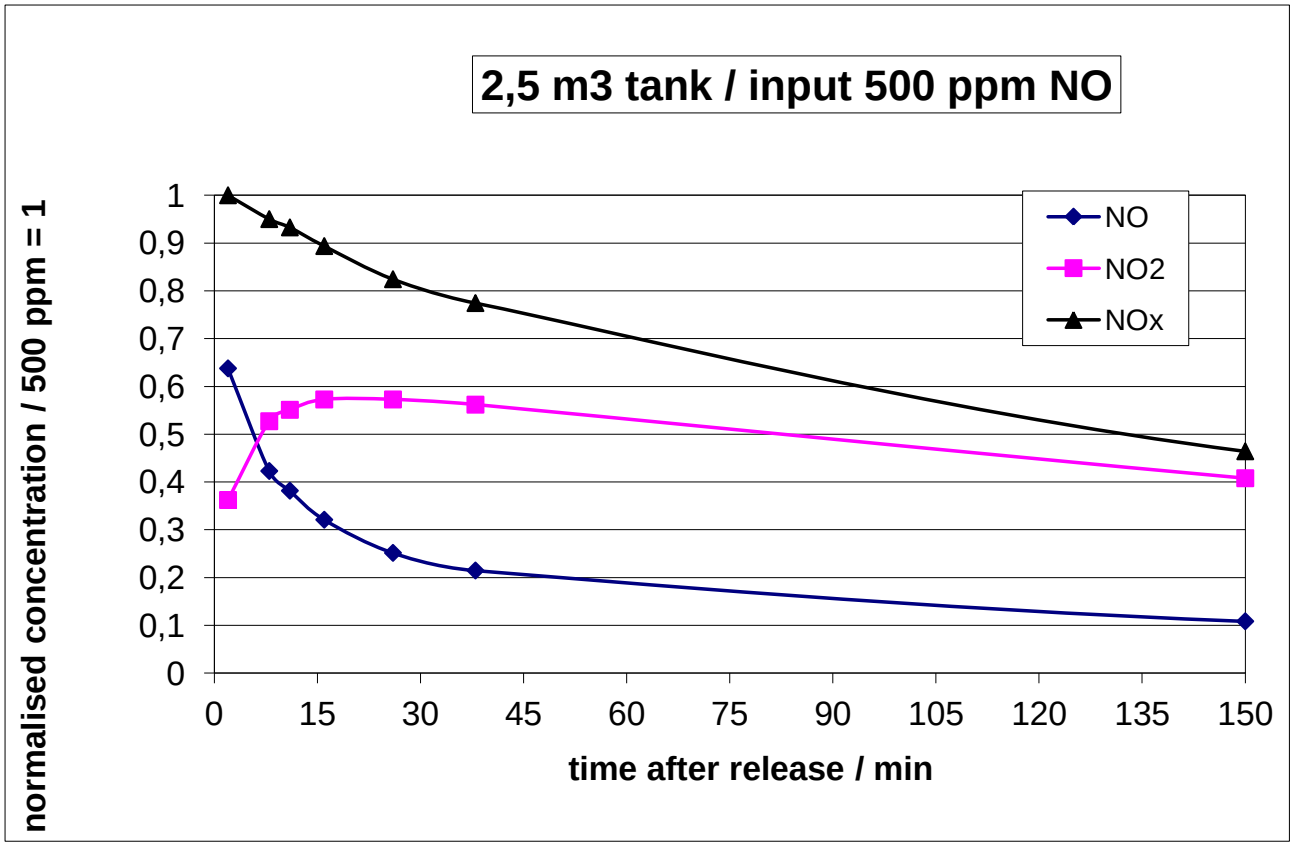
Dr. J. A. Nickl



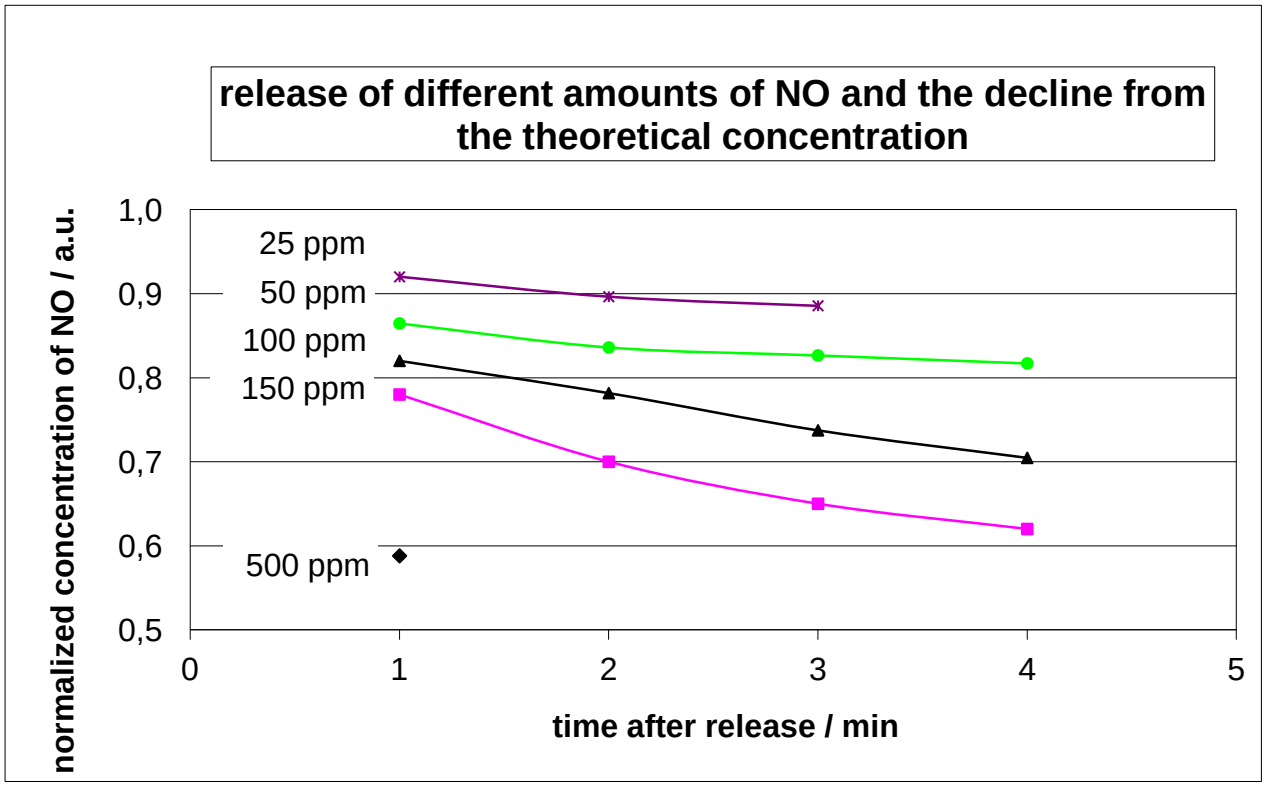
Picture 1: **Influence of the initial ambient air pressure on the resulting gas concentrations per PBP. NO and NO2 diminish from the gas phase by raising pressure, while the relative CO concentration rises with initial pressure. Hydrogen (H2) is not strongly influenced.**



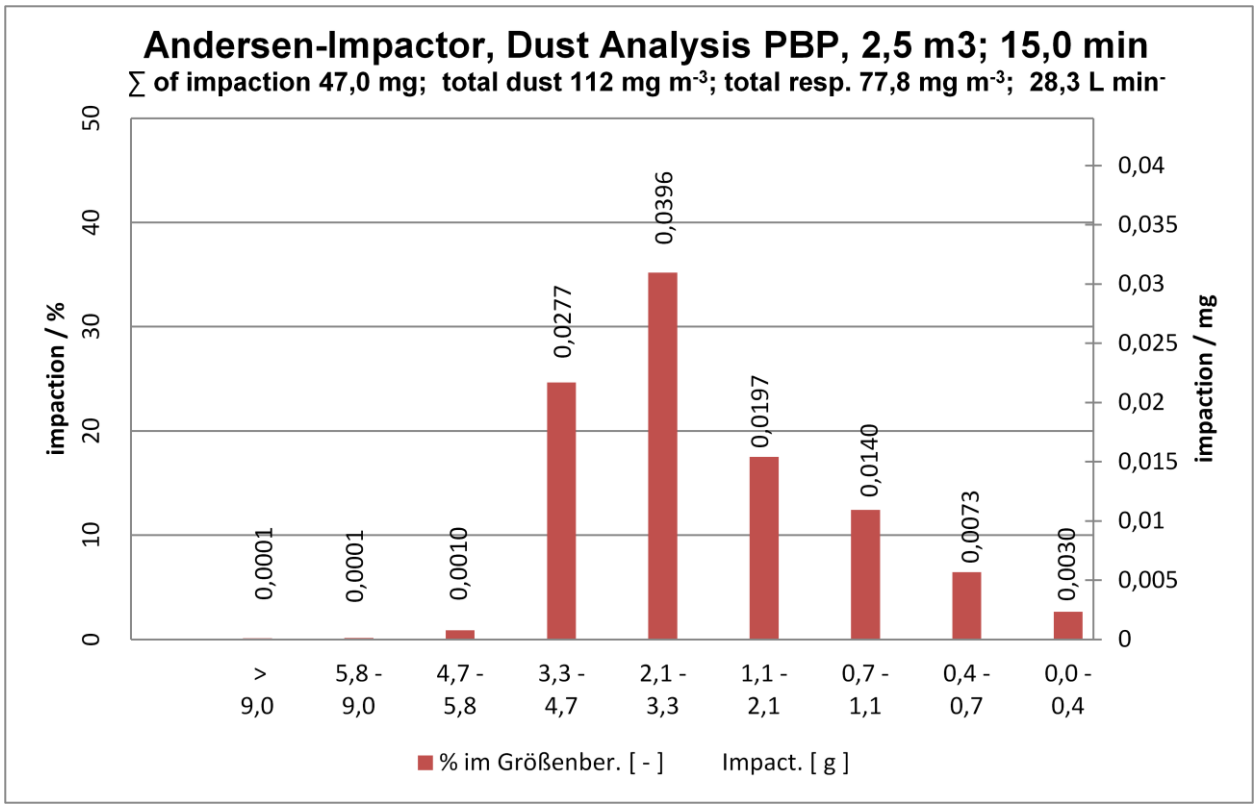
Picture 2: **Influence of the initial water partial pressure, or humidity, on the resulting gas concentrations per PBP. CO and NO concentrations do not alter significantly, NO2 diminish from the gas phase by increasing humidity drastically, and H2 shows a positive dependence on the water content.**



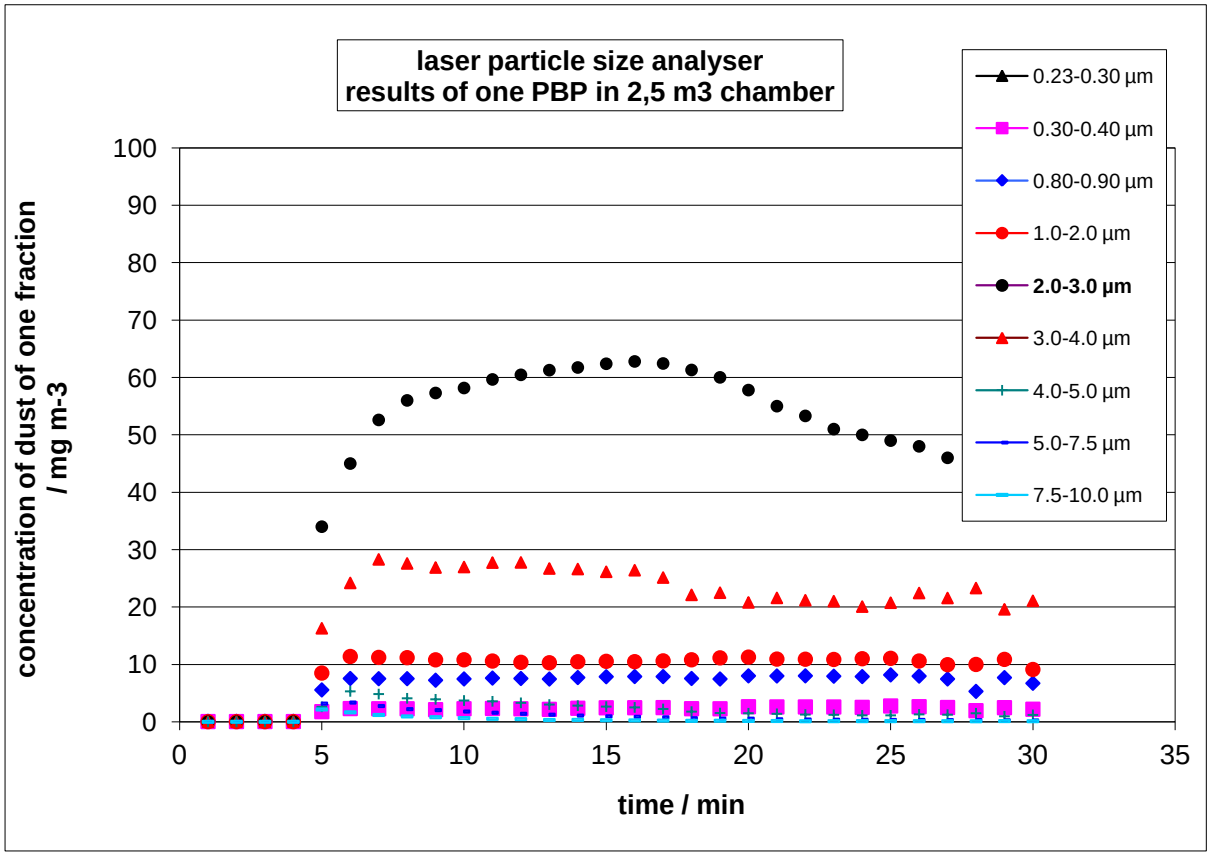
Picture 3: **Reaction kinetics of released NO gas in a realistic chamber (50 % rH, 21 °C)**



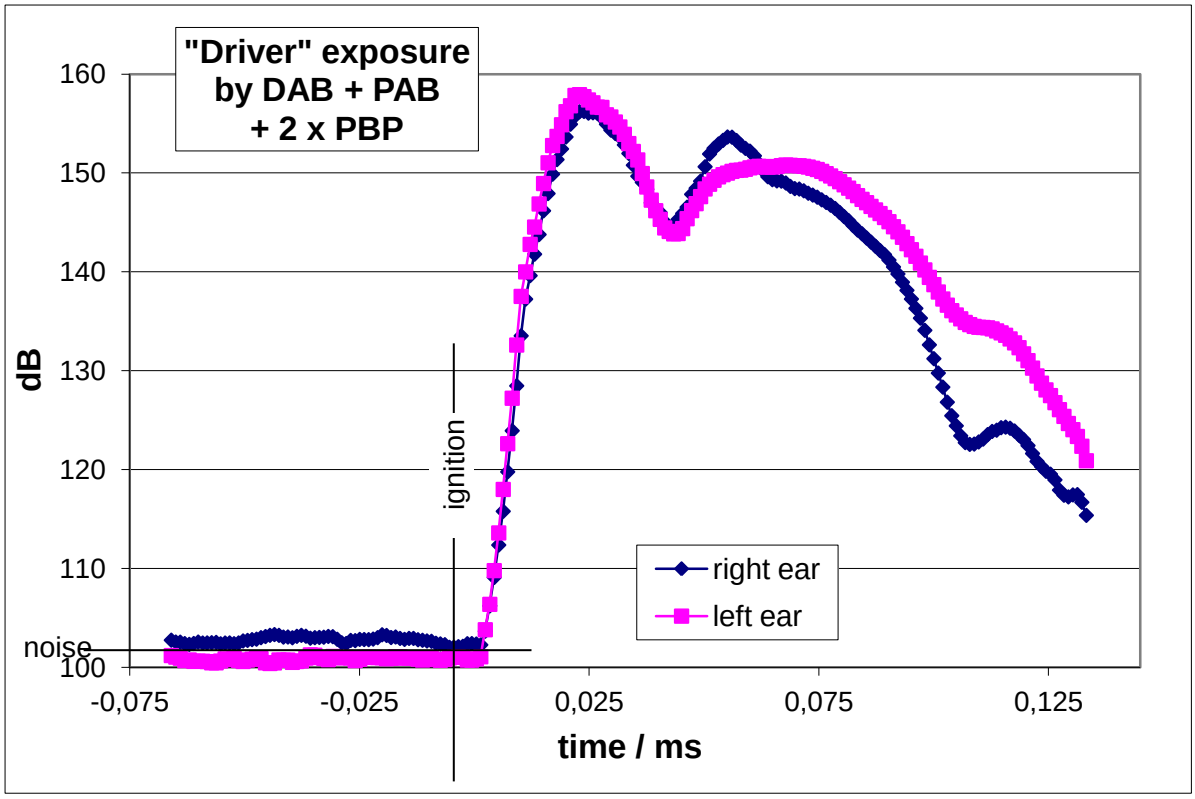
Picture 4: **Similar to picture 3, but using different initial NO concentrations. The reaction kinetics of the NO decline is dependent on the initial concentration.**



Picture 5: **Andersen impactor result of one PBP in a 2,5 m3 chamber.**



Picture 6: **Laser particle counter result of the dust analysis of one PBP in a 2,5 m3 chamber. For the first 15 minutes after deployment there is a good correlation of Anderen results and laser results. After 15 minutes the bigger particles start to sediment.**



Picture 7: **Acoustic measurement in a car using a complete front crash simulation. Position of the microphones: driver's ears. The „human ear model" calculates an "auditory hazard" of about 486 ahu.**

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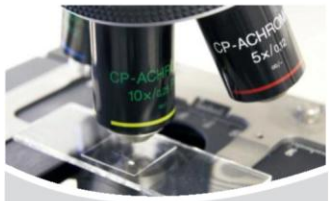

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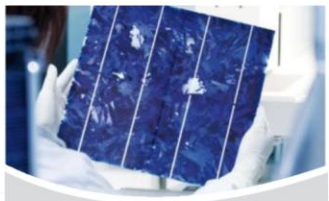
› Qualitätssicherung

› Schadensanalyse



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