Influence of Nitrogen Compounds on PEMFC: A Comparative Study

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Cyclic voltammetry, electrochemical impedance spectroscopy and current distribution measurements are employed at single cells and a fuel cell stack to reveal the differences and interrelations of ammonia, nitrogen oxide and nitrogen dioxide. It is shown that both nitrogen oxides are adsorbed at the catalyst as NO. The adsorption of NO_2 is weaker and therefore leads to a lower and slower degradation. Moreover, all gases cause inhomogeneous stress of the MEA, which can lead to an accelerated degradation of the fuel cell. NH_3 shows a combined reaction by partly being adsorbed as a nitric oxide and partly reacting with the perfluorosulfonic acid groups of the ionomer.

Within the framework of climate protection and the protection of the population against pollutants, electromobility is becoming increasingly important worldwide. Polymer-Electrolyte-Membrane Fuel cell technology (PEMFC) plays a key role since it includes high driving ranges with short refueling times. For a successful market introduction, however, costs must be further reduced and the durability of the systems must be further increased. In this context, it is known that several air pollutants lead to a short-term loss of power and reduce the durability of fuel cells in the long term.

Nitrogen compounds are of special interest due to their high concentrations in urban traffic. Diesel vehicles are responsible for a majority of NO_x-emissions in urban areas. But also a medium-sized vehicle with gasoline engine and three-way catalytic converter can easily emit 2 ppm NO_2 at 120 km/h. For that reason and especially because of stricter legislation, there will be an increase of cars with SCR catalytic converters (selective catalytic reduction) to reduce NOx emissions in the future. Selective catalytic reduction generally names the reduction of NO_x by NH_3 to water and N_2 by the help of a selective catalyst. This technique has been used in combustion plants for several years. For more than 10 years, SCR-systems for passenger cars are in use as standard-production application. In vehicles, the NH_3 for the reduction is converted out of urea stored in an extra tank. The SCR-system is an effective way to reduce NO_x in the vehicle exhaust. On the one hand, only the use of SCR methods currently enables compliance with the Euro 6 and Tier 2 Bin 5 standards for NO_x. On the other hand, it was shown that there is significant NH_3 slippage during the SCR-process in vehicles. To ensure a nearly complete conversion of NO_x to N_2 the dosing of NH_3 has to be hyperstoichiometric. Furthermore, it is assumed that NH_3 reacts as NH_4^+ with the perfluorosulfonic acid groups of the ionomer especially in the membrane. As a result, inter alia, the proton conductivity is reduced and the water management is disturbed.

Because of the importance of the influence of nitrogen compounds on PEMFC, comparative experiments were executed employing cyclic voltammetry and electrochemical impedance spectroscopy. Additionally, current distribution measurements on short stacks with ten cells were executed. This is of special interest because fuel cell stacks for automotive applications contain several hundreds of cells with large active areas and a uniform distribution of current density, temperature, water and gases is important for a stable operation and a long lifetime. It might be assumed that air contaminants can influence the distribution of voltage over the active area as indicated by the work of Reshetenko et al. They may also influence the distribution of voltage over the individual cells of the stack as shown by St-Pierre et al. In the present work current distribution measurements are executed for the first time with a short stack and the gases NO, NO_2 and NH_3. Those contaminants are of special interest because of their importance in urban areas. The goal of the experiments was to clarify the differences and the interrelation of NO, NO_2 and NH_3 and their mechanisms of influence on PEMFCs for automotive applications.

Experimental

Test benches.—Experiments were conducted on two different test benches. The first one was a subscale test bench for a single cell and hence was used for the cyclic voltammetry and electrochemical impedance spectroscopy measurements. The second one was a test bench for automotive short stacks with ten cells and was used for the current distribution measurements.
In the subscale test bench, single cells (hydrogen/air PEM) employing hardware by AFCC (Automotive Fuel Cell Cooperation) were used. This sub-scale test hardware was developed to assure good comparability to full-size hardware. It provides near-zero gradients conditions (iso-thermal, iso-baric, iso-potential) and by that simulates a well-supplied middle section of a full-size hardware without critical undersupply. The graphitic flow-field-plates have a parallel straight channel flow-field design. Membrane-electrode-assemblies (MEA) were also provided by AFCC with a loading of 0.4 mg/cm² Pt/C on the cathode and 0.1 mg/cm² Pt/C + RuO₂ on the anode. The gas diffusion layer (GDL) consisted of a non-woven substrate with hydrophobic treatment. Membranes consisted of a perfluorinated polymer with a thickness of 18 μm. The active area of the catalyst layer was 48.5 cm² and a clamping pressure of 6 bar was used. Humidification was realized using bubble humidifiers with automated water replenishment. Fixed relative humidities of 100% and 50% were used. The feed gases were supplied with high stoichiometry to prevent undersupply at each operating point. A pressure control of the company Alicat Scientific was installed behind the stack to adjust automotive test conditions with a constant absolute pressure. Constant flow rates of 12 l/min air at the cathode side and 2 l/min hydrogen at the anode side were used. The overpressure was 1.5 bar on the cathode side and 1.7 bar on the anode side.

In contrast to the subscale test bench, the test bench for short stacks employed membrane humidifiers using deionized water in counter flow to provide up to 100% relative humidity. The operating conditions were set depending on the current, just as in a vehicle to ensure realistic conditions. At the chosen loadpoint of the present experiments (0.45 A/cm²), the relative humidity was set to 75% and 68% on the anode and cathode side, respectively. The temperature was 70 °C and the stoichiometry was set to 2 for both anode and cathode. Besides that, an operating pressure of 1.8 bara on the anode side and 1.5 bara on the cathode side were used. Since the flow rates were controlled by the current, only the needed amount of gas for a specific load point was fed in. For the current distribution measurements, a larger ten-cell stack short stack was employed. MEAs had a loading of 0.4 mg/cm² Pt/C on cathode and 0.1 mg/cm² Pt/C catalyst on the anode. Membranes consisted of reinforced polytetrafluoroethylene-based material (PTFE) with 30 μm thickness. The active area of the catalyst layer was 300 cm² and a gold-coated serpentine flow-field with a Z-shaped manifold was used. It consists of 11 channels with a depth of 0.4 mm and a width of 1.9 mm on both sides respectively. It is run in co-flow configuration. A picture of the bipolar plate is shown in Fig. 1. Even though the usage of a PEMFC with a different size and bipolar plate design limits the comparability of the results of the two test benches, it is necessary for the current distribution measurements. The larger active area and the serpentine flow field is important to display the distribution of the air pollutants in a PEMFC for automotive applications.

**Electrochemical measuring methods.**—To receive further information, a CV and EIS device from Zahner GmbH was integrated in the subscale test bench. CV measurements were used to analyze the catalyst activity and the hydrogen permeability of the membrane. Therefore, the cell was operated with different contaminant concentrations for one hour at a humidification of 100%. The tests were conducted with a constant voltage of 0.7 V or a constant current of 0.7 A/cm² at 87 °C. Subsequent, a regeneration with clean air for one hour was executed at the same conditions. After that the CV measurements were conducted to indicate remaining impurities that could not be removed by the operation with clean air. The cathode was flushed with 8 l/min nitrogen, while the anode was supplied with 2 l/min hydrogen, both gases with a humidification of 100%. The potential range was 0.1 V–1 V vs. the hydrogen reference electrode (HRE) and scan speeds of 2 and 100 mV/s were used. The measurements should show the presence of additional peaks due to any residuals of the pollutants on the catalyst. In addition, the relative change of the electrochemical active surface area of the cathode (EC/S/A) and the permeability of the membrane for hydrogen were examined. The H₂ permeation across the membrane (H₂ crossover) can be seen in the 2 mV/s CV measurement by a change of the mean value of the current at 450 mV. An increase of the current indicates an increase in permeation. An increase of 10% is regarded as a significant deterioration.

Furthermore, EIS measurements were carried out. Therefore, the cell was operated for at least 50 hours with 1 ppm NH₃ at a humidification of 50% with a constant voltage of 0.7 V and 70 °C. During this experiment impedance measurements were recorded automatically in even intervals. A frequency range of 1 kHz to 10 kHz was used and the amplitude was 1 A. Regardless of the decreasing current due to the negative influence of the air pollutants, the amplitude of 1 A is still sufficiently low to set a stable sine wave and keep the voltage response at values <10 mV at all resulting currents. The EIS measurements were carried out to evaluate the location of the impact of the contaminant. Therefore, the measurements were compared using a Nyquist diagram with its three characteristic ranges depending on the excitation frequency. The high-frequency range reflects the ohmic resistances, especially the membrane resistance. The medium frequency range shows the charge-transfer resistances, e.g. catalyst activity. The low frequency range shows the mass transport resistance and is often related to the water management of the cell. An enlargement of the respective arcs indicates an increase of the resistances.

**Current distribution measurements.**—In case of automotive fuel cells with relatively large active areas there can be an inhomogeneous distribution of the current due to a maldistribution of reactants, temperature and water. It could be shown that air pollutants can increase these inhomogeneities. In order to achieve a better understanding of the degradation mechanisms of the nitrogen compounds current distribution measurements were examined.

Therefore, a custom made segmented measurement plate called “current scan lin” of the company S++ was employed. It has 15 × 44 = 660 measuring segments on an area of 10.7 cm × 30.9 cm = 331 cm². Therefore, some of the outer segments are not active during tests because the active area of the MEA is only 300 cm². The plate is integrated behind the cathode end plate of a ten-cell stack. Thus, the segmented plate is able to create a highly dissolved 2D view of the current distribution of the cell.

Measurements were conducted at constant 0.45 A/cm² and 70 °C for variable durations without contaminant and with 10 ppm of NO, NO₂ and NH₃, respectively. Experiments were repeated at least twice. The exact sequence was:

- 15 minutes conditioning without contaminant
- 15 minutes/1 hour/3 hour contaminant supply
- 15 minutes/1 hour/3 hour regeneration without contaminant

Due to the galvanostatic operation, the sum of all segments is fixed and always 150 A, only the distribution of the current changes.

**Results and Discussion.** In all experiments a different behavior of all three nitrogen compounds can be seen as displayed in Fig. 2. As a result of constant 0.7 A/cm² the voltage decreases strongly during the supply of NO and NO₂. After some time it reaches an equilibrium stage where no further decrease is taking place. In comparison to NO, NO₂ shows a slightly different progress with a slower voltage decrease. In addition,
a stronger damage by NO at low concentrations could be observed. At 1 ppm NO2 causes no damage to the fuel cell. In contrast, the addition of 1 ppm NO causes an average voltage decline of 33% (also compare).9

Lemaire et al. already reported a split degradation due to NO2 contamination.32 They suggested that the first steep loss of power is a result of the adsorption of NO2 at the platinum. There it dissociates and releases oxygen which leads to a short term increase of the ORR and therefore an increase of power.

In comparison to the amount of oxygen in the air the amount of released oxygen is comparatively negligible. However, it is generally believed that NO2 is dissociated at platinum catalysts and adsorbed as NO (e.g.,33,34) It was observed that the adsorbed NO converted of NO2 is less stable than the direct adsorbate of NO. This is presumably due to the additional adsorbed oxygen in the immediate vicinity, causing increased adsorbate repulsion effects.33 Moreover, as the NO2 coverage increases, the previously favored bridge position of NO is converted to atop bonding as it reduces the repulsive effects with adjacent adsorbates.33 Therefore, for a short time more NO2 could be adsorbed without further Platinum places being occupied. It has also been shown that the released oxygen of NO2 is bound to the catalyst by dissociation in a different structure than in the case of direct addition of O2. The altered structure can lead to higher degrees of surface coverage of platinum with oxygen.34 In addition, it can be expected that the high potentials of the cathode lead to the undissociated adsorption of a part of the NO2 and further oxidation. Thus, it can be assumed that a mixture of the described effects leads to a delayed or reduced effect of NO2 compared to NO, which explains the observed difference. In the displayed experiment in Fig. 3, the effect of NO2 only shows a delay in comparison to the effect of NO and reaches the same voltage level after some time. This observation affirms the slower dissociation of NO2 to NO and its subsequent adsorption at similar Pt sites.

NH3 shows a different behavior with a more constant voltage decrease without an equilibrium stage within 50 minutes. This indicates different mechanisms of degradation, which is examined in detail with additional methods in the following sections.

**Figure 2.** Comparison of the effect of 10 ppm NO, NO2 and NH3 at constant 0.7 A/cm².

**Figure 3.** Three CV measurements after experiments at 87°C and 0.7 V with 8 ppm NH3, 15 ppm NO2 and without contaminant as a reference.

**Figure 4.** a. EIS measurements at 50% rH during the addition of 1 ppm NH3 (blue curves) and subsequent regeneration (gray curves) – 90 hours. b. EIS measurements at 50% rH without contaminant as reference – 200 hours.

**Electrochemical measuring methods.**—Fig. 3 displays three CV measurements with a scan rate of 100 mV/s after contamination of the cell with 8 ppm NH3, 15 ppm NO2 and without contaminant as a reference.

The voltammogram of the reference test with clean air shows the typical pattern for a PEMFC with the different typical sections representing for example platinum oxidation and reduction. Both voltammograms of the experiments with NO2 and NH3 exhibit an additional desorption peak at about 0.7 V. Peaks at 0.7 V are often related to the desorption of nitric oxides of the catalyst.20,21,35 The voltammograms therefore reveal the adsorption of nitric oxides at the cathode catalyst. Furthermore, the results indicate that part of the NH3 is oxidized to a nitric oxide as assumed and in this form also leads to a spontaneous decrease of power by competing with the ORR.21

Besides that, the evaluation of the ECSA (not shown) does not show a permanent degradation of the catalyst after the regeneration with clean air for one hour for any of the three contaminants. The ECSA is slightly decreasing in all experiments even without contaminant. The evaluation of the H2 crossover does not show an influence of the contaminants either. This means, that no thinning of the membrane occurred in this experiments. These results confirm the good reversibility of the influence of NO, NO2 and even NH3 after a short contamination time (one hour contamination and one hour regeneration).

In addition, the EIS measurements show an increase in membrane resistance due to the addition of 1 ppm NH3 over 50 hours. This can be seen in Fig. 4a by the shift of the intersection of the curves with the x-axis to higher values. Fig. 4a displays several subsequent EIS measurements after different durations of the experiment with 1 ppm NH3. As a reference several measurements without contaminant at the same conditions are displayed in Fig. 4b.
Contrariwise, larger cations are transported by the vehicle mechanism, additionally impedes the water management of the cell. Since NH3 a change in the transport mechanism. H+ Ions are mainly transported across the membrane by the Grothus mechanism, whereby the protons tunnel through dissolution and formation of hydrogen bonds between the water molecules and only briefly form an oxonium ion (H3O+). Contrariwise, larger cations are transported by the vehicle mechanism, which is much slower. Furthermore, Hongsirikarn et al. have shown a decrease in thickness of the membrane by the uptake of NH4+. This is explained by the formation of hydrogen bonds between NH and adjacent H2O molecules, resulting in a tighter and more compact structure. As a result a significantly reduced water content of the membrane due to NH3 is detected.20,24

Due to these results, it can be assumed that the negative effect of NH3 is a mixture of different degradation mechanisms. Ammonia is reversibly adsorbed on the catalyst and is oxidized to a nitrogen oxide compound. This process is concentration-dependent and especially at high ammonia concentrations leads to a relatively spontaneous reduction of the cell performance by partly occupying the catalyst. As a result of the lower quantity of nitric oxide, this effect is not as strong as in case of NO or NO2. Furthermore, ammonia reacts with the perfluorosulfonic acid groups of the ionomer. This reaction takes place in the ionomer of the catalyst, as well as in the membrane and thus increases the charge transfer resistances by adversely affecting the catalyst-ionomer interface in the medium term. In the long term, the mass transport resistance is increased by a disturbed water management, especially in the membrane. The different durations until a clear visibility of the effects depend on the NH3 concentration, but also on the amounts of ionomer in the catalyst and membrane. In the long term also the hydrophobicity of the gas diffusion layer is reduced which additionally impedes the water management of the cell. Since NH3 attacks the membrane, it can be assumed that this is mainly caused by decomposition products of the perfluorosulfonic acid groups, such as hydrofluoric acid and sulfuric acid.

This collective effects result in an approximately linear decrease of the cell performance at low NH3 concentrations comprising a reversible and an increasingly irreversible proportion. It can also be seen from the EIS-measurements that after 200 hours irreversible damage to the membrane does not occur since the membrane resistance completely recovers.

Current distribution measurement.—The current distribution measurements provide an inside into the distribution of the contaminants over the surface of the MEA. For that reason, MEAs with a larger active area of 300 cm² like in automotive applications were used.

Fig. 5 shows three visualizations of the current distribution of the start, the middle and the end of a measurement without contaminant as a reference. Air is fed on the lower left side as the arrow indicates. The single segments have a current of 0.228 A on average with a minimum of 0.125 A and a maximum of 0.313 A. High currents are displayed in red, low currents in green. The standard deviation is 0.032 A and is displayed in the lower part of the diagram. Furthermore, the resulting potential in V is displayed in the middle section.

There is a clear gradient of the current with high values at the inlet and decreasing values in the direction of the outlet. This inhomogeneity, even without contaminants, is due to the suboptimal design of the laboratory bipolar plates with a nonhomogeneous distribution of air and H2. Thus, the voltage at the inlet section of the MEA is higher as in direction of the outlet section, where a significant fraction of the reactants is already consumed. Nevertheless, the resulting voltage is nearly constant for six hours and also the standard deviation of the single segments is constant.

Fig. 6 shows a comparison of four measurements of the current distribution without contaminant and with 10 ppm NO, NO2 and NH3 for three hours, respectively. The upper part of the diagram displays the resulting voltage; the lower part displays the standard deviation of the segments as a degree for the homogeneity of the current distribution.

It can be seen that the contaminants are leading to a more homogeneous distribution of the current. This is due to the stronger effect of all contaminants at the air inlet where the former high current is reduced. This is counterbalanced by a higher current at the rear end of the cell whereby the overall homogeneity is increased.

In case of NH3 the standard deviation roughly follows the course of the voltage with a slow decrease during the contaminant supply and a slow regeneration in the subsequent phase with clean air. NO and NO2, on the other hand, show a very different progress of the standard deviation with two low points and a subsequent equilibrium at the level of the reference during contaminant supply. During the regeneration, there is a short but significant increase in inhomogeneity above the reference level. This progress of the standard deviation can be seen in all measurements with NO and NO2.

Fig. 7 displays the standard deviation in case of 10 ppm NO and the corresponding visualization of the current distribution over the active area at the marked positions. The first visualization shows the initial status without contaminant at the end of the conditioning phase with a strong gradient of current over the area of the MEA. The second visualization at the first low point of the standard deviation shows the occupancy of the catalyst by NO and the resulting decrease in activity of the air inlet part of the MEA. The subsequent increase in standard deviation is due to the stronger activation of the rear area of the MEA near the air outlet as can be seen in visualization 3. The second low point displayed in visualization 4 is caused by the slow reactivation of the catalyst at the air inlet region. After about 1.5 hours the equilibrium stage and the initial status of distribution is reached as shown by visualizations 5 and 6. Directly after stopping the contaminant supply the inhomogeneity increases strongly due to an above-average activation of the catalyst area at the air inlet region. Again, after about 1.5 hours the distribution of the current is normalized to its initial status.

Thus, it can be seen that the nitrogen oxides are leading to a dynamic equilibrium. They adsorb in particular at the active parts of the catalyst. This is due to the positive conditions like a balanced humidity in these areas. Because of the occupancy of the formerly active areas of the catalyst the positive conditions move toward the rear end of the cell. There the oxygen reduction reaction (ORR) increases until this part is also occupied by the nitrogen oxides. This process takes about 30 minutes with this specific hardware and conditions but it is not necessarily transferable to other applications.

After the second low point the initial status is slowly retrieved showing an equilibrium of adsorption and desorption of the nitrogen oxides over the whole catalyst area. The subsequent strong reactivation of the stack inlet region during the regeneration without contaminant is most likely a result of the nitrogen oxides having occupied also difficult to access platinum particles and activated them. If these places are suddenly released after contamination they are temporary available for the ORR leading to an increased current density in this area. This process is also the reason for the super recovery after contamination that has been observed before.30,37 This is most likely a result of the occupancy of the whole MEA-area by catalyst oriented contaminants. Due to the parallel reaction of contaminant and oxygen, difficult-to-access platinum sites are reached and temporarily activated.38
The shift of ORR activity in the direction of the outlet of the cell might be a reason for the formerly observed irreversible degradation of fuel cells after long-term tests with NOx. The degradation mechanisms without contaminants are more pronounced at the stack outlet due to the higher temperature and are further accelerated by the more intensive ORR. This inhomogeneous stress of the MEA might lead to an accelerated aging of the cell. It can be assumed that this phenomenon occurs with all catalyst oriented pollutants like hydrocarbons.

The current distribution in case of NH3 (not shown) exhibits a successive deactivation of the MEA at the air inlet and an increased activity at the rear side. After the contaminant supply the initial status is slowly retrieved.

These results confirm the formerly assumed degradation mechanisms of NH3. The part of the NH3 which is oxidized at the catalyst to a nitrogen oxide causes a slow shift of the ORR toward the outlet of the cell. As a result of the lower quantity of nitric oxide, this effect is not as strong as in case of NO or NO2. On the other hand, NH3 reacts with the perfluorosulfonic acid of the Ionomer and leads to an increase of mass transport resistance. This reaction is much slower and results in a longer shifting of the ORR toward the air outlet some time after the end of contaminant supply.

In summary, it can be determined that it is most likely that a non-uniform distribution of damage due to air pollutants will occur in automotive fuel cells in urban areas. This effect can be referred to the different local conditions like temperature and relative humidity of the cell. Beyond that, the contaminants are also causing a shift of the cell potential at galvanostatic experiments. This could lead to different reactions configurations of adsorption of NO and NO2, since Nitrogen can react in several different ways. However, this effect is most likely to be the reason for an increasing irreversible damage caused by of NO and NO2.
**Single cell voltages in the short stack.**—For a differentiated analysis of the distribution of air pollutants, the single cell voltages of the short stack were evaluated. Therefore, the current was fixed at 0.7 A/cm² at the beginning and at the end of the tests with and without contaminants. At the beginning of the experiments, the cell voltage distribution without contaminants and with NO, NO₂ and NH₃ is very balanced and also the level of the overall stack voltage is similar, as Fig. 8 shows.

In the course of the experiments the average cell voltage of the whole stack decreases due to the negative influence of the contaminants, as can be seen by the parallel shift of the curves in Fig. 9. Besides that, a slightly unequal distribution of the single cell voltages occurs. The two outer cells have a lower performance in almost all tests even without contaminant. Especially the first cell on the anode side in case of operation with pollutant shows a little higher performance degradation, as can be seen in Fig. 9.

Differences of the single cell voltages without addition of pollutants are an indication of problems with the media supply, especially of an uneven temperature distribution. The temperature of the outer cells is often smaller than of the inner cells. This leads to a decreased

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**Figure 6.** Comparison of four current distribution measurements by the resulting voltage in the upper part and the standard deviation of the currents of the single measuring fields in the lower part.

**Figure 7.** Current distribution during and after the addition of 10 ppm NO. Upper part: standard deviation of the current. Lower part: visualization of the current distribution at the marked positions of the experiment.

**Figure 8.** Average single cell voltages at 0.7 A/cm² at the beginning of the test with NO, NO₂, NH₃ and without contaminant as a reference.

**Figure 9.** Average single cell voltages at 0.7 A/cm² at the end of the test with NO, NO₂, NH₃ and without contaminant as a reference. A slight non-uniform distribution can be seen at the first cell on the anode side.
reaction rate and therefore a shortened performance. In the case of pollutants, this is an indication of unevenly distributed degradation. This is probably not caused by an uneven air supply and more contaminant by an enhanced performance of this cell, which is not the case as shown by the reference curve in Fig. 9. Yet, the feeds of all media (H₂, air, cooling water) are located on the anode side and are routed parallel through the stack in this hardware. The supply of all media on the anode side leads to a pronounced cooling on this side, the cathode side is relatively more isolated.

St-Pierre et al. observed in their experiments with a 36-cell stack a heavily unequal distribution of single cell voltages due to the use of 50 ppm propene. This is also mostly pronounced on the side of the stack in this hardware. The supply of all media, including water and air, is rather insignificant, even more because of the large number of cells. Moreover, the phenomenon is not heavily pronounced even in these experiments with a not optimized stack hardware. Therefore it is supposed to be almost negligible in commercial applications.

Summary

Cyclic voltammetry, electrochemical impedance spectroscopy and current distribution measurements were employed to receive further information about the kind and location of the negative influence of ammonia, nitrogen oxide and nitrogen dioxide. It was demonstrated that the nitrogen oxides are adsorbed at the catalyst as NO whereas adsorption of NO₂ is weaker and therefore leads to a lower and slower degradation. Both also cause inhomogeneous stress of the MEA, which can lead to an accelerated degradation of the fuel cell. NH₃ causes a partly irreversible damage to the fuel cell due to a combined reaction mechanism. It is partly adsorbed as a nitric oxide at the catalyst and partly reacting with the perfluorosulfonic acid groups of the ionomer. This causes a slow but long-lasting shift of the ORR toward the end-section of the MEA.

Furthermore, it could be shown that a non-uniform distribution of the negative influence of the contaminants over the area of the MEA is more important than a non-uniform distribution over the individual cells of the short stack.

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