Ammonia Sensor For SCR NOX Reduction
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Agenda

- NH$_3$ Sensor Usage in SCR system
- Overview NH$_3$ Sensing Technologies
- Functionality of NH$_3$ Sensor
- NH$_3$ Sensor Design
- Test Results
  - Cross Sensitivity
  - Test results
- Close Loop Control of the SCR System with a NH$_3$ Sensor - System Advantages
- Summary
Diesel SCR System

Source of Ammonia: Urea through hydrolysis reaction
\[(NH_2)_{2}CO + H_2O \rightarrow 2NH_3 + CO_2\]

DeNOx Reaction: At favored temperature
\[4NH_3 + 2NO_2 + 2NO \rightarrow 4N_2 + 6H_2O\]
Non-equilibrium electrochemical sensing principle

- Proprietary NH3 sensing electrode materials
- Both sensing and reference electrodes exposed to the engine exhaust
- Solid oxide electrolyte used as the sensor body

\[ EMF \approx \frac{kT}{3e} \ln(P_{NH_3}) - \frac{kT}{4e} \ln(P_{O_2}) - \frac{kT}{2e} \ln(P_{H_2O}) \]

\( 3O^2^- + 2NH_3 \rightarrow N_2 + 3H_2O + 6e \)

\( O_2 + 4e^- \rightarrow 2O^2^- \)

(Heater circuit not shown)
Theory

- Semi-log output of EMF versus NH₃ concentration

\[ EMF \approx \frac{kT}{3e} \ln(P_{NH_3}) - \frac{kT}{4e} \ln(P_{O_2}) - \frac{kT}{2e} \ln(P_{H_2O}) \]

- Interference effect due to H₂O and O₂ concentrations changing due to combustion can be self-compensating
- The concentration of H₂O and O₂ vary in opposite directions as function of A/F ratio minimizing effect
Sensor structure

- **Planar structure**
  - Co-fired zirconia and alumina layers with NH3 sensing, platinum reference electrode and heater circuit

- **Key Features**
  - Integrated heater provides fast time to activity
  - Temperature sensor included
  - No air reference
  - Alumina layers provide electrical isolation between heater and sensor circuits
  - Porous protection provides excellent exhaust poison resistance
  - Small size
Sensing Element

- Finished sensing elements
  - Monolithic thick film multi layer composite substrate
    - Alumina / Zirconia composite
    - Alumina provides toughness - Zirconia electrolyte
    - Integral Heater and Temperature Sensor for heater control
    - Compatible with existing sensor packaging technology
- NH3 electrode material applied on substrate surface
- A poison protective material is applied over the NH3 electrode
- Finished sensing element looks like exhaust oxygen sensing element
Sensor package

- Based on proven robust production planar sensor packaging
- Package has capability beyond diesel exhaust temperatures
- Lower shielding can be modified according to customer application
NH₃ Sensor System Mechanization

- Mechanization
  - Early systems being developed for commercial vehicle applications
  - Stand-alone electronic interface with CAN link to vehicle
  - A-sample hardware shown below.
    » A-Sample systems provide either Analog or CAN message output

Advanced Development Hardware
NH₃ Sensor Performance Targets

- **Measurement range:** 0 – 100ppm NH₃
  - Tolerance: ± 5ppm NH₃ at 10 ppm NH₃.
  - Acceptable gas content without interference: NO, HC, CO, N₂O.
  - Acceptable gas content with cross sensitivity: O₂, H₂O.

- **Temperature range:**
  - Functional: 200 °C to 450 °C
  - Non functional: -40 °C to 700 °C

- **Durability target:**
  - 5,000 hours / 250,000km

- **NOx Exhaust gas content:**
  - 0 to 500ppm (sensor performance within spec)

- **H₂O exhaust gas content:**
  - 1% to 8% by mass (sensor performance within spec)

- **Response Time:**
  - \( T_{60} = 3 \text{ s} \)
  - \( T_{90} = 5 \text{ s} \)

- **Thermal Shock**
  - Two layers of protection
    1. Double layer protective shield
    2. System algorithm to disable sensor when liquid water is possible in the exhaust
  - Heated ceramic sensors must be protected from contact with liquid water to prevent damage due to thermal shock
NH\textsubscript{3} Sensor Interface Electronics

- **Environment**
  - Ambient Temperature (electronics): -40 °C to 105 °C

- **Electrical**
  - Sensor system compatible with either a 12V or 24V vehicle electrical system
  - Sensor system communicates to vehicle over a CAN bus

- **Mounting/Installation**
  - Sensor mounts directly to exhaust pipe via a M18x1.5 threaded boss
  - Sensor must be mounted 10 ° above horizontal to prevent pooling of water in shield
Water and oxygen interference effect

- Water and oxygen have opposite interference effect
- Self compensation effect is possible in a narrow range as shown in following figure (confirmed by lab gas bench too)
- Climate air humidity difference is a main concern but can be handled by calibration
- Model based correction is also possible if A/F ratio and air humidity information is available

![Graph showing interference effects](image-url)
NH₃ Output in the Presence of NOₓ

- Basic function demonstrated in gas bench testing
  - NH₃ signal free from NOₓ interference
  - Some interference below 10ppm set point
Sensor performance
cross interference

- NH₃ sensing accords to the theory prediction
  (semi-logarithms equation)
  - Data obtained at lab gas bench, 14% O₂, 1.5% H₂O
- Interference from NO, CO, and HC is negligent

![NH₃ cell only](image-url)
Sensor data
- Steady state performance on HD diesel engine
- Test stand fitted with SCR aftertreatment system
- Sensors tested at 200 C & 400 C steady-state exhaust gas conditions
- Ammonia slip between 0 and 50 ppm
- Chart shows sensor output plotted against LDS instrumentation NH3 output signal

Result
- Sensor accuracy within specification limits (+/- 5ppm at 10 ppm control point)
Engine Test Stand Performance
ESC Cycle

- NH₃ Sensor output during an ESC cycle on the engine test stand
  - NH₃ sensor output tracks LDS instrumentation over a dynamic test cycle

NH₃ Sensor Performance Test--Test 2b
ESC Engine cycle; 17-March-2006

No poison effects after 700h test cycle without DPF
Sample to Sample Variation

- 30 sensors
- Same conversion equation
- No water-oxygen adjustment
- No air humidity adjustment
- Red lines mark ±50% at 10 PPM NH₃
Exhaust Ammonia (NH₃) Sensor
- Optimized Performance of an SCR Converter

- Euro 4 limits can be achieved by using open loop control urea dosing
  - SCR efficiency approximately 65%

- The realization of maximum NOx conversion (without using a post oxidation catalyst) is only possible with closed loop controlled Urea dosing:
  - A NOx based SCR control does not enable the use of the maximum NOx conversion because of NH3 cross sensitivity of NOx sensor.
  - The NH3 based SCR control enables operation at the conversion limit of the catalyst:
    - >90% NOx conversion possible for highwa driving conditions
    - Minimal catalyst volume
Conclusion

- Sensor demonstration has been done
  - NH$_3$ sensing accords to concept
- Interference with NO, HC, CO is not significant
- O$_2$ and H$_2$O have opposite interference effect (minimum compensation through calibration)
- Air humidity and air to fuel ratio information is required for model based correction of the interference effects of O$_2$ and H$_2$O (only required if highest accuracy is demanded)
- Response time $T_{60} < 3$ second, $T_{90} < 5$ sec
- Sensors are built on existing Delphi exhaust oxygen sensor technology
- NH$_3$ Sensor provides an opportunity for improved SCR dosing control and system diagnosis
Thank You!