MINIATURIZED GAS COMPOSITION SENSOR

EMPIR LNG2/LNG3 | Arjen Boersma & Huib Blokland
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ABOUT TNO

Mission and Strategy
The research organisation TNO connects people and knowledge to create innovations that boost the sustainable competitive strength of industry and well-being of society.

Organisation
TNO was founded by law in 1932 to enable business and government to apply knowledge. As an organisation regulated by public law, we are independent: not part of any government, university or company. 2600 FTE

Roles
DRIVERS FOR GAS COMPOSITION SENSING

Source: De rol van gas en Gasunie in de duurzame energievoorziening, Gasunie 2016
PRODUCTION

- Fermentation
  - slurry, waste water
  - 40-70% Methane
  - Upto 2% H2S

- Gasification
  - Wood, solid biomass
  - <50% Methane, also higher HC’s

- Measure composition in the process and at feed-in to the grid
- More cost-effective (mainly for small plants)
- Complex mixtures
GAS GRIDS

- New gasses in the grid: monitoring gas quality
- Use as input for gas network modelling
- Results to be used for maintenance and long term asset management decisions

- Cost-effective
- In-line and in combination with flow and pressure
END-USERS

- Household consumers
  - Billing for Energy, high accuracy
  - Large quantities, ultra low-cost

- Industry
  - Burner control
  - Fast response, lower accuracy

- Transport (LNG)
  - Motor management: fast response, lower accuracy
  - (Methane) emission: very low concentrations
STATE-OF-THE-ART

- Wobbe index meter / calorimeter
- Combustion of the calorific gasses
- Gas chromatography
- FTIR / NDIR
- Combination of NDIR, photoacoustics, thermal conductivity, viscometry (EDGaR project)

General draw backs
- Large (dm$^3$ - m$^3$)
- Expensive (10 -50 k€)
- Influence on gas flow / not inline
- Slow (minutes … hours)
TNO APPROACH

- Reduce size and costs of gas sensing solution to:
  - Small (< 10 cm³)
  - Low-cost (< €200)
  - Fast (< 10 s)
  - Inline

- Achievable by combining capacitive electrodes and multiple responsive coatings
DEVELOPMENTS

Sensor for monitoring gas quality in distribution gas grid
GAS EXPOSURE EXPERIMENTS

- Chips are connected to PCB and placed into pressure vessel
- Simultaneously read-out of chips
- Exposed to gas mixtures
RESPONSE TO METHANE

Pressure is 100 mbarg; Temperature is 24 °C; Carrier gas is nitrogen
RESPONSE TO ETHANE

Pressure is 100 mbarg; Temperature is 24 °C; Carrier gas is nitrogen
RESPONSE TO PROPANE

Pressure is 100 mbarg; Temperature is 24 °C; Carrier gas is nitrogen
RESPONSE TO CO$_2$

Pressure is 100 mbarg; Temperature is 24 °C; Carrier gas is nitrogen
CROSS SENSITIVITY

However, every coating responds to more than 1 gas
MATRIX CALCULATIONS

- Calculations started with only CH\textsubscript{4}-C\textsubscript{2}H\textsubscript{6}-C\textsubscript{3}H\textsubscript{8}-N\textsubscript{2} mixtures
- All measurements have been used to derive relations between gas composition and chip responses → use matrix calculations → response matrix [M] and [N]

\[
\begin{pmatrix}
\text{Chip 1} \\
\vdots \\
\text{Chip n}
\end{pmatrix}
= \begin{pmatrix}
M_{11} & M_{12} & M_{13} & M_{14} & M_{15} \\
\vdots & \ddots & \vdots & \vdots & \vdots \\
M_{n1} & M_{n2} & M_{n3} & M_{n4} & M_{n5}
\end{pmatrix}
\begin{pmatrix}
\text{CH}_4 \\
\text{C}_2\text{H}_6 \\
\text{C}_3\text{H}_8 \\
\text{CO}_2 \\
\text{N}_2
\end{pmatrix}
\]

\[
\begin{pmatrix}
\text{Chip 1} \\
\vdots \\
\text{Chip n}
\end{pmatrix}
= \begin{pmatrix}
N_{11} & \ldots & N_{1n} \\
N_{21} & \ldots & N_{2n} \\
N_{31} & \ldots & N_{3n} \\
N_{41} & \ldots & N_{4n} \\
N_{51} & \ldots & N_{5n}
\end{pmatrix}
\begin{pmatrix}
\text{CH}_4 \\
\text{C}_2\text{H}_6 \\
\text{C}_3\text{H}_8 \\
\text{CO}_2 \\
\text{N}_2
\end{pmatrix}
\]

- Matrix [N] will be used to calculate composition of gas mixtures
FIRST RESULTS OF PROTO DEVICE

- Only methane concentration has been varied
FIRST RESULTS ON PROTO DEVICE

Average errors:
- Methane: 3.0 vol\%
- Ethane: 0.3 vol\%
- Propane: 0.001 vol\%
- Nitrogen: 2.6 vol\%

CV: 0.9 MJ/m$^3$
CONCLUSIONS

- An array of coated interdigitated electrodes enables the measurement of the calorific value from the gas composition
- Gas response of six sensitive coatings enables the calculation of the composition
- Laboratory results:
  - Error composition measurement <3%
  - Error in CV measurement <2.5%
- Field test of sensors in distribution grid are ongoing
PREVIEW ON LNG3

Smart sensor development and lab testing (WP3)
- Modify sensor for inline application in the gas fuel line of an LNG engine
  - Main challenges:
    - Higher HydroCarbons: Butane, Pentane, …
    - Fast response
    - Higher pressure
- Investigate the feasibility for Methane Slip measurement

Smart sensor validation and engine tests (WP4)
- Measure composition of LNG in the gas fuel line of an LNG engine
TNO CORE TEAM

Huib Blokland
Sensor development
PoC TNO (overall and WP3)

Arjen Boersma
Materials for Sensors

Cemil Bekdemir
Engine performance
PoC TNO (WP4)

Peter van Gompel
Engine performance