Proton-transfer-reaction time-of-flight mass spectrometry (PTR-TOF-MS)-Based Emission Profiling of the CESAR1 Solvent: First Insights from the 2025 AURORA Project at TCM

PCCC-8

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The Aurora project

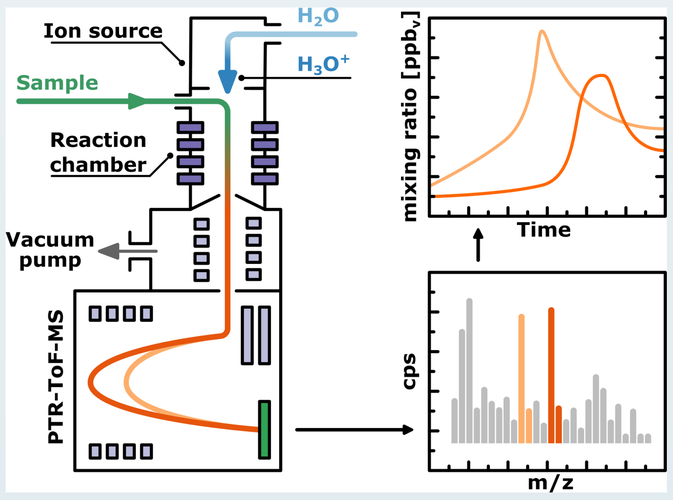
The AURORA project (Accelerated Deployment of Integrated CCUS Chains based on Solvent Capture Technology; https://aurora-heu.eu) is an EU-funded initiative dedicated to advancing post-combustion CO_2 capture through the optimization and commercial qualification of CESAR1 – a non-proprietary, aqueous solvent blend of 2-amino-2-methylpropan-1-ol (AMP) and piperazine (PZ). CESAR1 has emerged as a leading alternative to conventional amine systems due to its superior energy performance and capture efficiency. One of the core objectives of the AURORA project is to demonstrate that CO_2 capture using the CESAR1 solvent can be achieved with minimal environmental impact, placing particular emphasis on the identification, quantification, and mitigation of amine emissions and their degradation products.

As a key partner in the AURORA project, Technology Centre Mongstad (TCM) – the world's most advanced open-access CO_2 capture test facility – provides a critical platform for large-scale testing and environmental qualification. Since its establishment, TCM has consistently prioritized the use of advanced emission monitoring technologies. As part of this effort, it has engaged the University of Oslo to implement proton-transfer-reaction mass spectrometry (PTR-MS), which is regarded as the most sophisticated real-time emission monitoring technique for amines and amine degradation products available today. PTR-MS offers unmatched sensitivity, capable of detecting a broad spectrum of volatile and semi-volatile compounds – including parent amines and degradation products – at concentrations ranging from ppm down to single-digit ppt, with a temporal resolution of one minute. The PTR-MS technique was initially introduced at TCM over a decade ago as a research-grade tool and has since evolved into a routine monitoring method used at post-combustion carbon capture sites around the world.

In the AURORA campaign (April–August 2025), a PTR-MS instrument was deployed at TCM to conduct comprehensive, high-resolution emission monitoring during CESAR1 operation. Building upon previous work during the ALIGN-CCUS campaign, the study will target real-time quantification of AMP and PZ, as well as of key degradation products (*e.g.*, formaldehyde, acetaldehyde, acetonitrile, methylamine, formamide, morpholine, nitrosopiperazine). The resulting dataset – focusing on emission profiles, short-term variability, and implications for mitigation – will be shared openly with the research community. These insights are vital for informing regulatory frameworks, and supporting the safe, large-scale deployment of CESAR1.

PTR-TOF-MS: general principle, advantages and limitations

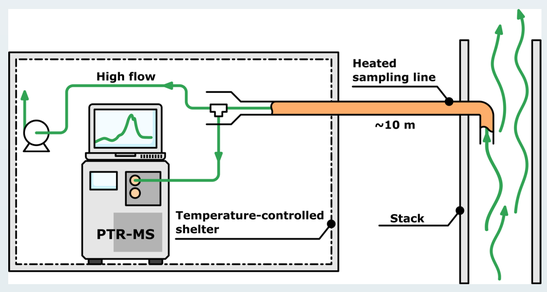
Proton-Transfer-Reaction Time-of-Flight Mass Spectrometry (PTR-ToF-MS) combines sensitivity, speed, and robustness, making it the leading technology for online monitoring emissions of amines and their degradation products.



Key Advantages

- **Real-time, online analysis**
  – Direct sample introduction (no preparation or pre-concentration)
  – Continuous monitoring with minute-level time resolution
- **Wide dynamic range**
  – Sensitive from low ppt (parts-per-trillion) to ppm (parts-per-million) levels
- **Time-of-Flight (ToF) – MS detection**
  – Essential for resolving complex mixtures
  – Full mass spectrum acquisition with high mass resolution and accuracy;
  – Outperforms quadrupole-based IMR-MS and SIFT-MS, which cannot reliably analyze high-complexity samples
- **Industrial-ready instrument options**
  – **PTR-TOF 8000** (used in this study, now replaced by **PTR-TOF 3000**)
  – Optimized for the analysis of complex mixtures such as amine-treated flue gas
  – Simplified ion chemistry facilitates complex mixture analysis, unlike RF-field–enhanced systems (e.g., VOCUS PTR) which are too sensitive and generate more complex ion chemistry
  – Designed for robust and reliable operation in industrial environments
- **Proven reliability and versatility**
  – Successfully deployed in multiple amine-based CO_2 capture plants (e.g., TCM, NCCC, and several pilot facilities)
  – Demonstrated stability for continuous, long-term operation

Specific configuration, developed tools and performance

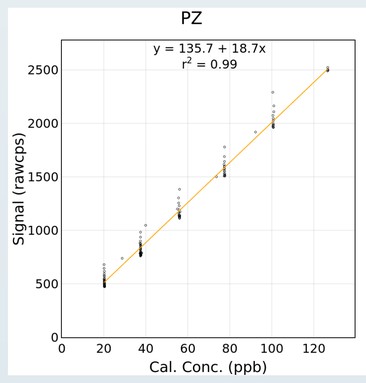


At TCM, the PTR-ToF-MS instrument is installed in a temperature-controlled shelter at the top of the absorber.

- High-flow sample extraction directly from the stack
- Short, heated, passivated stainless steel sampling line
- Minimizes sampling artifacts, which are otherwise common in this application

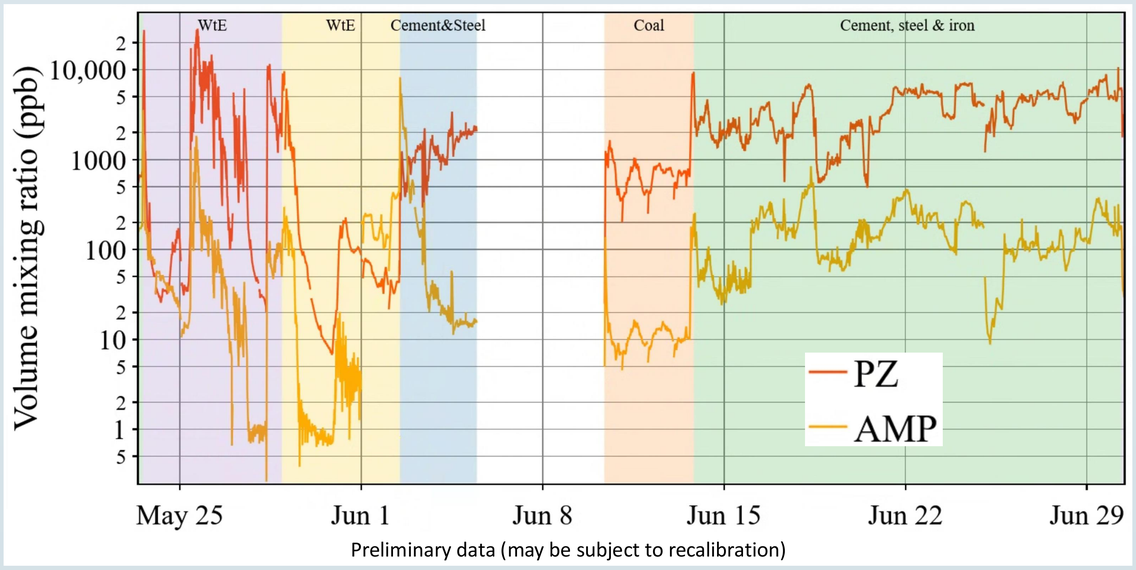
Calibration curve

Target compounds such as piperazine (PZ) are calibrated using the Liquid Calibration Unit (LCU).The LCU evaporates aqueous standard solutions into a clean carrier gas stream. This enables the generation of precisely defined gas-phase standards over a wide concentration range.



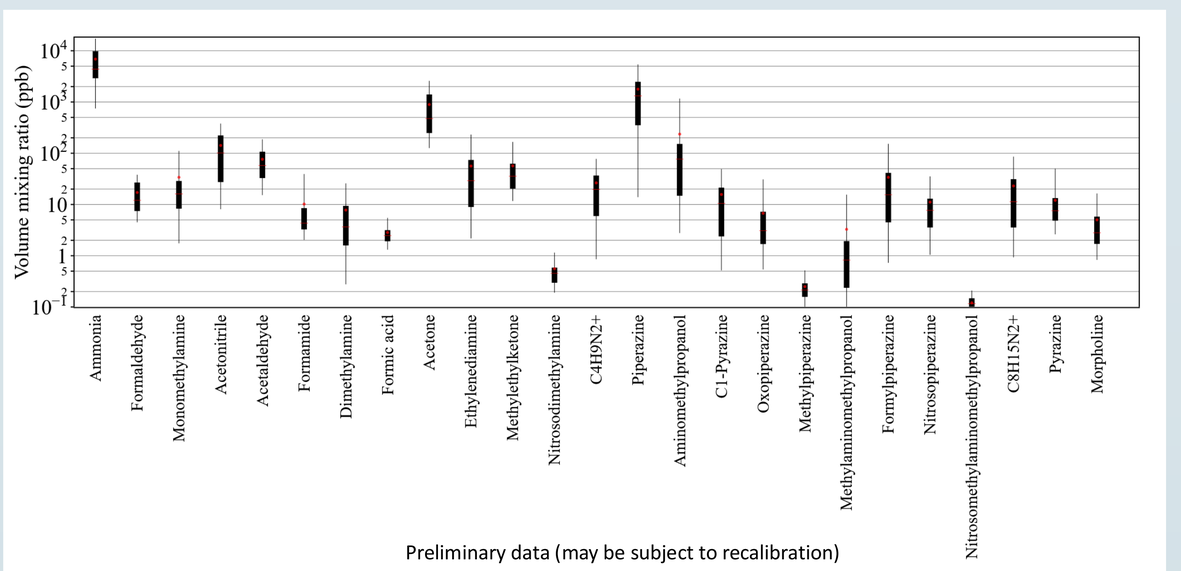
High-resolution MS data are processed in real time and made available through a web-based graphical user interface (Live Data Viewer, LDV).
Enables immediate visualization of measurement results
Supports process optimization and real-time emission interventions
Accessible remotely for continuous monitoring and decision support
Data are also manually post-processed and quality-assured.

Measured levels of PZ, AMP and degradation products



During the AURORA campaign, emissions of AMP and PZ were monitored under various flue gas compositions designed to mimic:

- Waste-to-Energy (WtE) applications
- Cement and steel production
- Coal combustion
- Cement, steel and iron production



Volume mixing ratio distribution of the most abundant compounds detected by the PTR-MS during the entire campaign. Boxes represent 25th and 75th percentiles, the red line is the median, and the red dot is the mean. Whiskers represent 5th and 95th percentiles.

Conclusion

The Aurora campaign was conducted for four months at the Technology Center Mongstad, Norway. This allowed to extensively study emissions from the non-proprietary Cesar-1 solvent. Various plant conditions were tested with flue gas CO_2 concentration ranging from below 2% up to 20+%. This resulted in different emission regimes. PZ and AMP, the constituents of the solvent, were detected from single-digit ppb to ppm levels. About 20 extra compounds were measured; the highest being ammonia, acetone, acetonitrile, methylethylketone and acetaldehyde.

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