Demonstration of ship-based carbon capture on LNG fuelled ships

Webinar, June 25th 2024, Introduction

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The EverLoNG project is funded through the ACT programme (Accelerating CCS Technologies, Horizon2020 Project No 691712). Financial contributions have been made by the Ministry of Economic Affairs and Climate Policy, the Netherlands; The Federal Ministry for Economic Affairs and Climate Action, Germany; the Research Council of Norway; the Department for Business, Energy & Industrial Strategy, UK; and the U.S. Department of Energy. All funders are gratefully acknowledged.

Agenda

- 12:00 Welcome & housekeeping
- 12:05 CO_2 capture demonstration onboard SEAPEAK ARWA: Juliana Monteiro & Jasper Ros
- 12:45 Q&A
- 13:00 End

Objectives

Objective of EverLoNG is to accelerate the implementation of Ship Based Carbon Capture (SBCC) technology by:

(i) demonstrating SBCC on-board of LNG-fuelled ships;

(ii) optimising SBCC integration to the existing ship infrastructure;

(iii) facilitating the development of SBCC-based full CCUS chains;

(iv) facilitating the regulatory framework for the technology.

→ **Today we focus on the demonstration of carbon capture onboard a ship**

Partners

Acknowledgement

Accelerating CCS Technologies

- ACT funding partners

Supported by:

Federal Ministry
for Economic Affairs
and Climate Action

on the basis of a decision
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The Research Council
of Norway

Department for
Energy Security
& Net Zero

Ministerie van Economische Zaken
en Klimaat

U.S. DEPARTMENT OF
ENERGY

WP1 Demonstration updates

Campaign onboard the Seapeak Arwa LNG carrier

Jasper Ros and Juliana Monteiro, TNO

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This webinar will cover

- Overview of the demonstration campaign
- Calculated CO_2 capture rates
- Operation stability and effect of ship motion
- Exhaust gas measurements
  - NO_2 content
  - Emissions of amine and ammonia
- Solvent degradation

The Seapeak Arwa

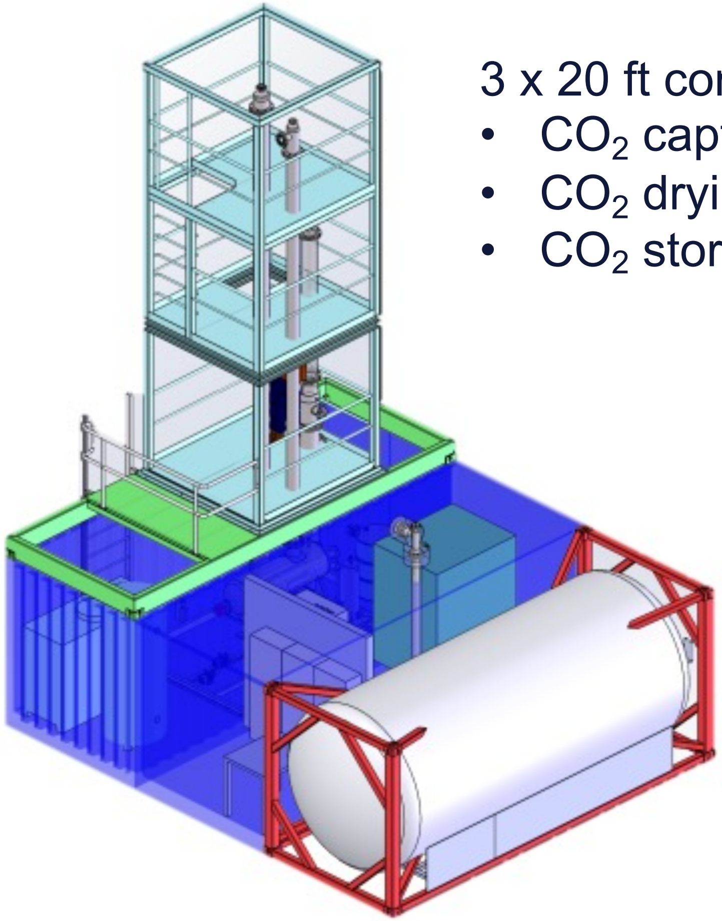
Seapeak Arwa LNG tanker, chartered by TotalEnergies

Additional information:

- Main engines:
  - 3 x Wartsila 12V50DF (4-stroke)
  - 1 x Wartsila 6L50DF (4-stroke)
- Power 39.9 MW
- Year of build: 2008
- Length: 286 m
- Beam: 43.4 m
- Draught: 12.1 m
- LNG: 163.285 m³

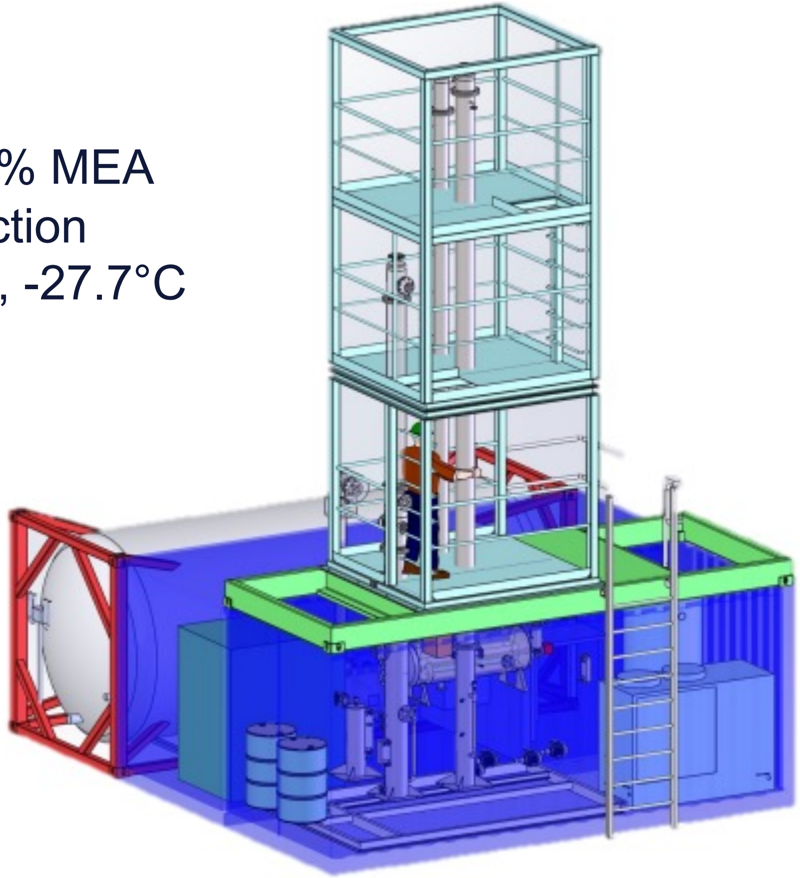
Carbon capture system was connected to AE2, LNG fuelled engine, running on boil-off gas

The EverLoNG prototype



3 x 20 ft containers

- CO_2 capture with 30 wt% MEA
- CO_2 drying and liquefaction
- CO_2 storage at 15 bara, -27.7°C



The campaign

Duration: 22-10-2023 until 03-02-2024 (2475 hours)

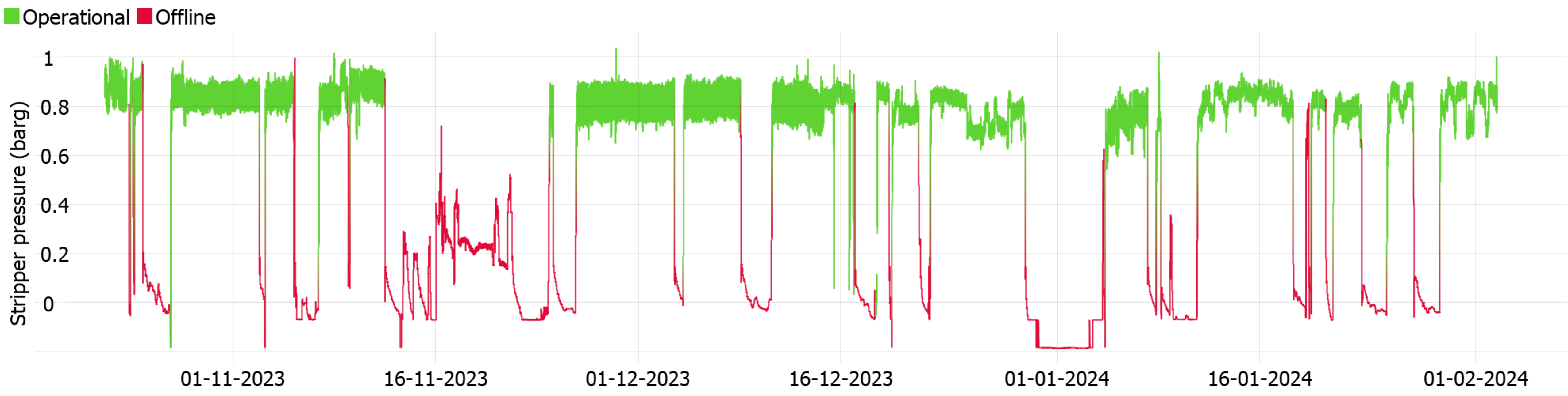
- This campaign focused on the capture system

Solvent of choice: 30wt% aqueous solution of mono-ethanolamine (MEA)
First-generation solvent, well described and understood

Data available for evaluation:

1. EverLoNG prototype → All sensors
2. Exhaust gas → Continuous emission data on outlet of capture system (FTIR)
3. Ship data → Motion, engine load, wind speed etc.
4. Solvent → Comprehensive sample analysis

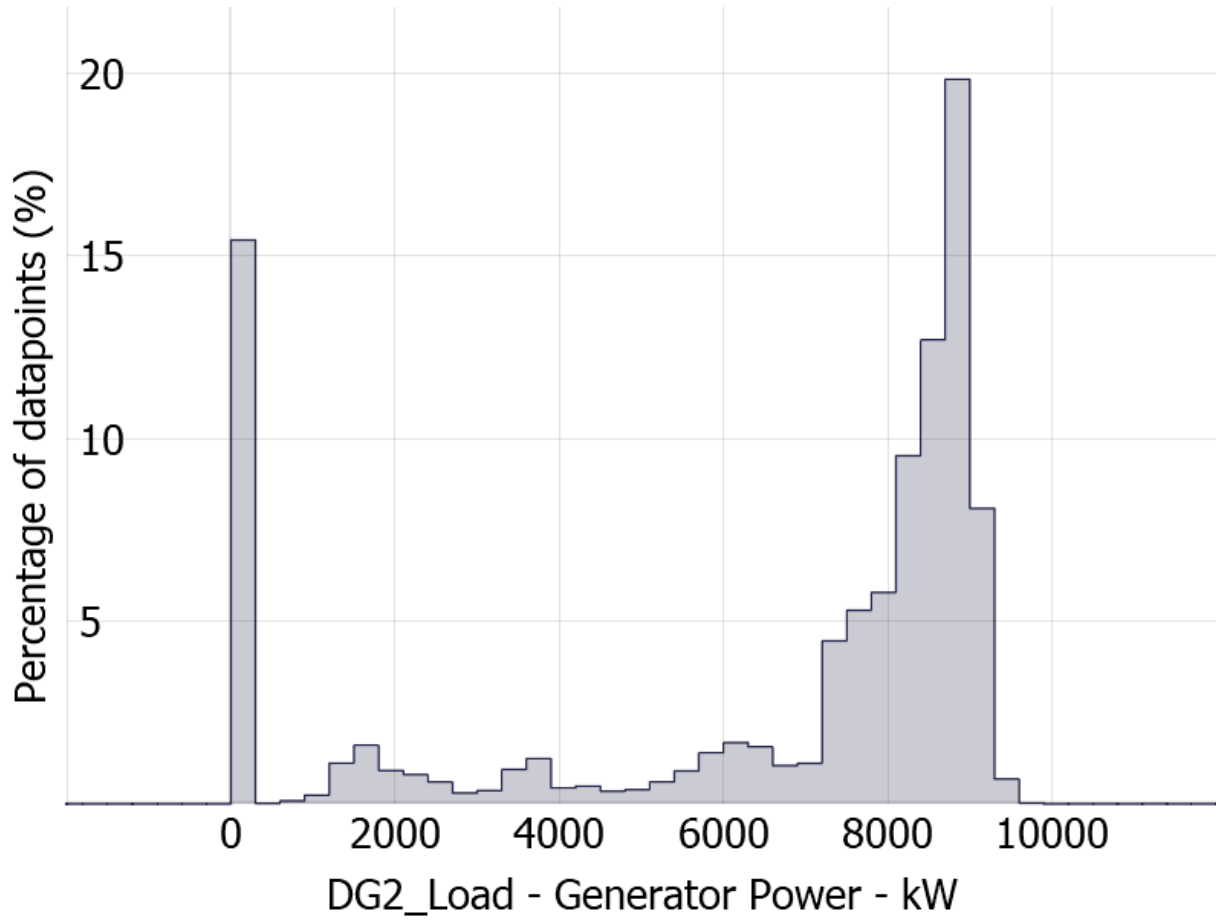
Overview of operation



Mode	Time (hours)	Time (%)
Operational	1539	62.2
Offline	936	37.8

Offline: LNG offloading, engine maintenance, non-availability of operators, prototype operational issues, etc.

Engine load histogram during campaign



Solvent concentration

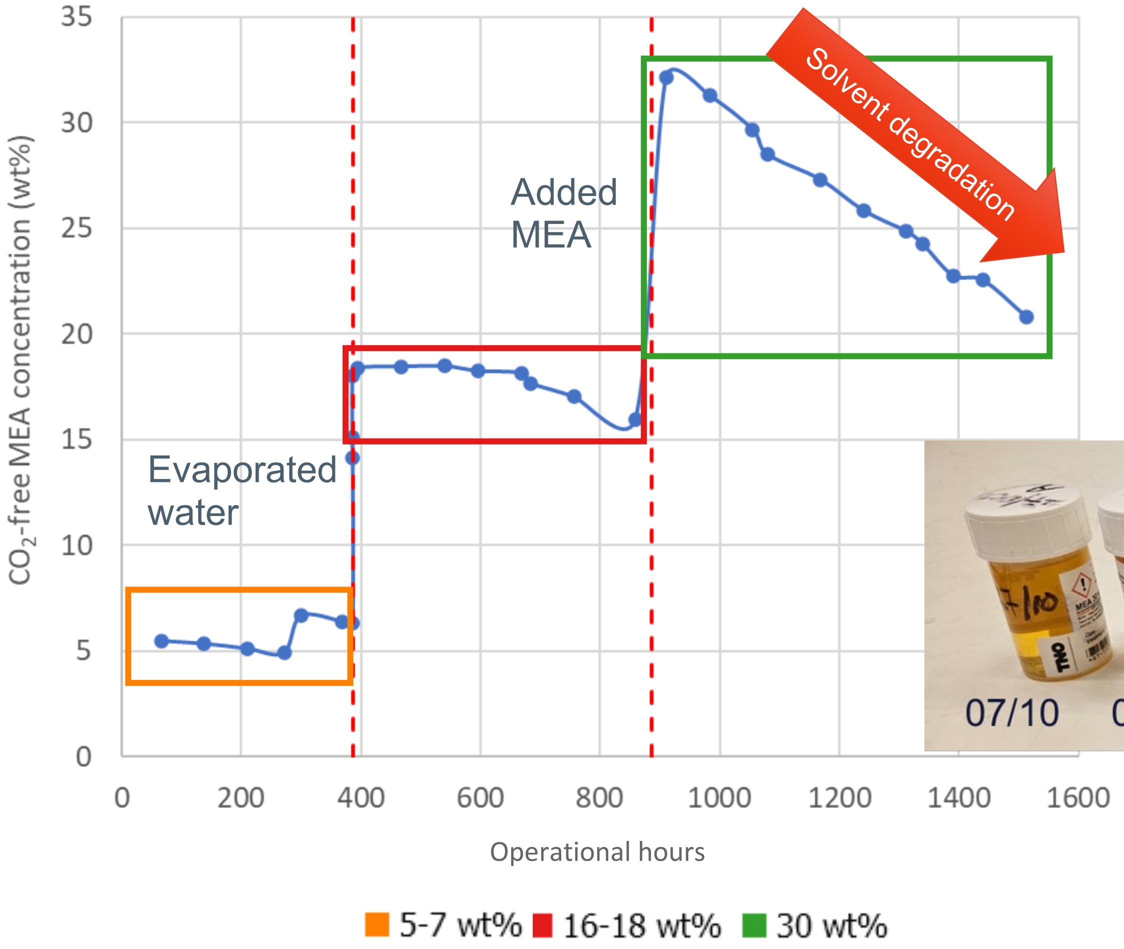
1st month, approx. 400 h, unit was in operation with 7% MEA concentration

2nd month, approx. 500 h unit was in operation with 17% MEA concentration

Last part of onboard testing, approx. 600 h, unit was in operation with 30% MEA concentration.

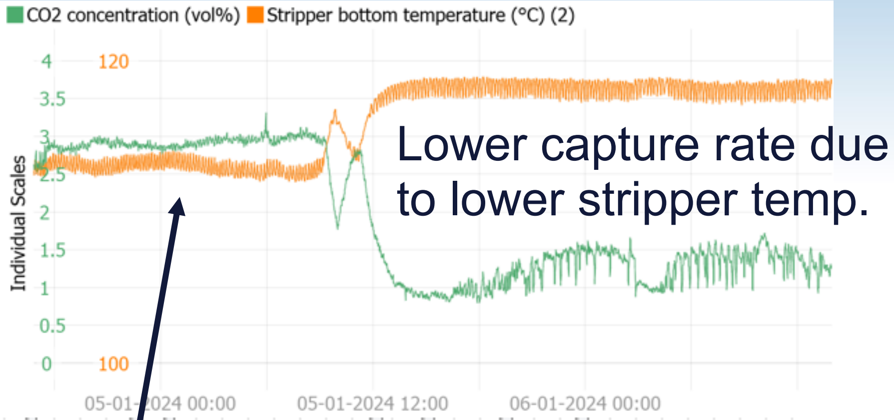
The differences in concentration have effect on CO_2 capture rate, which was monitored continuously

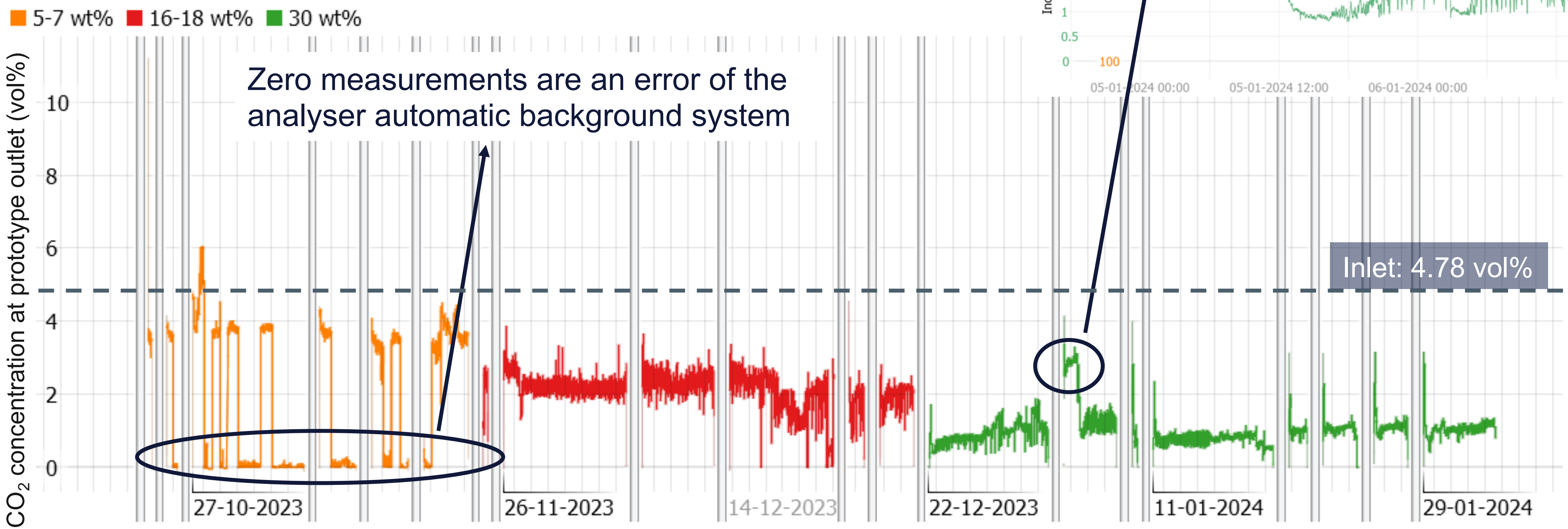
Solvent concentration



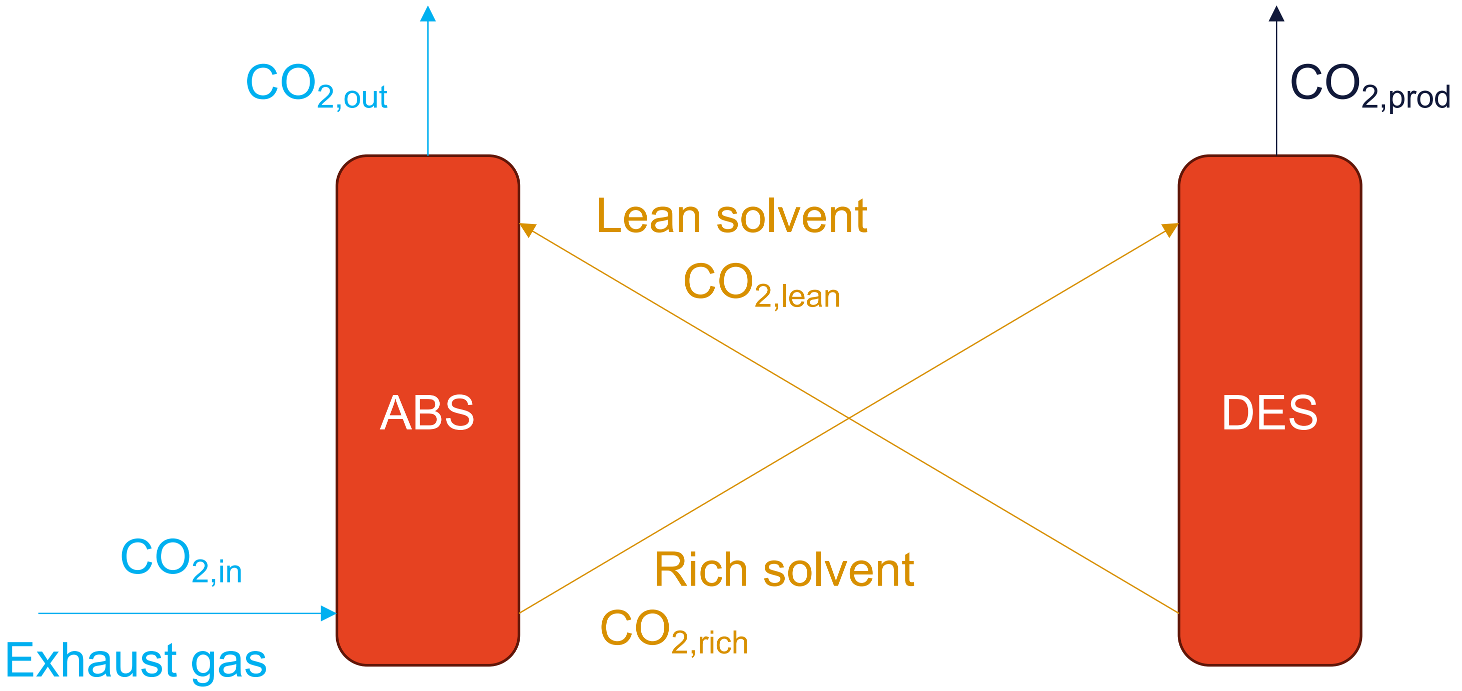
CO_2 capture rate

CO_2 concentration (data filter: operation only)





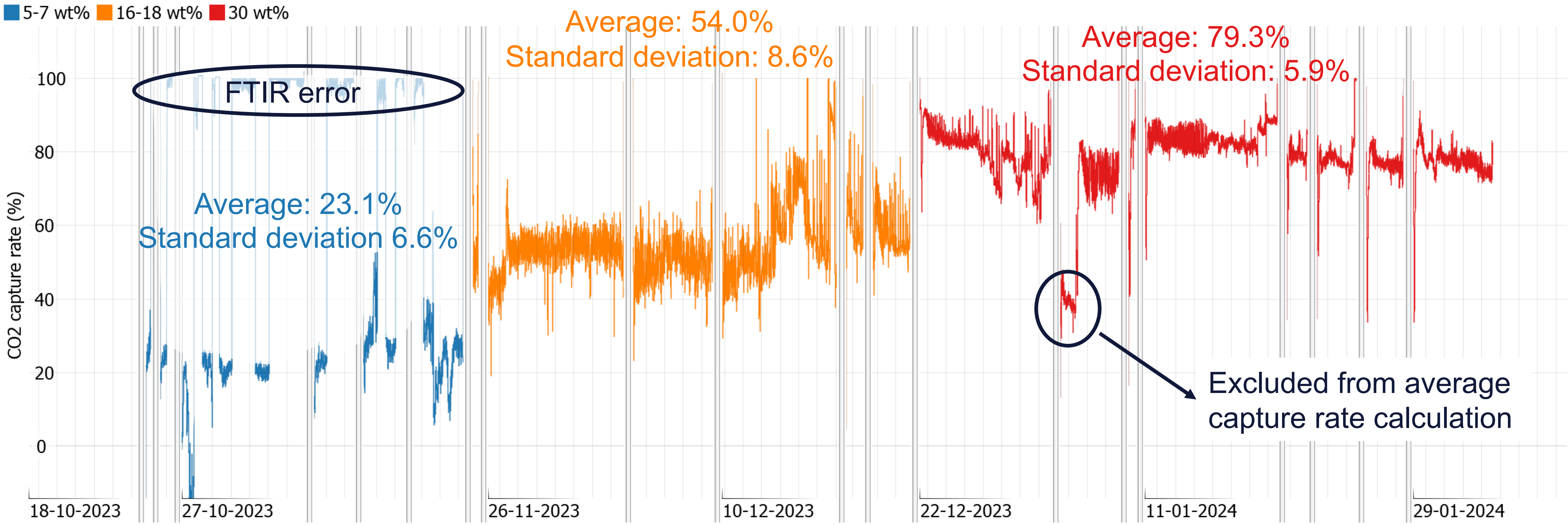
Calculating the CO_2 capture rate



Two methods:

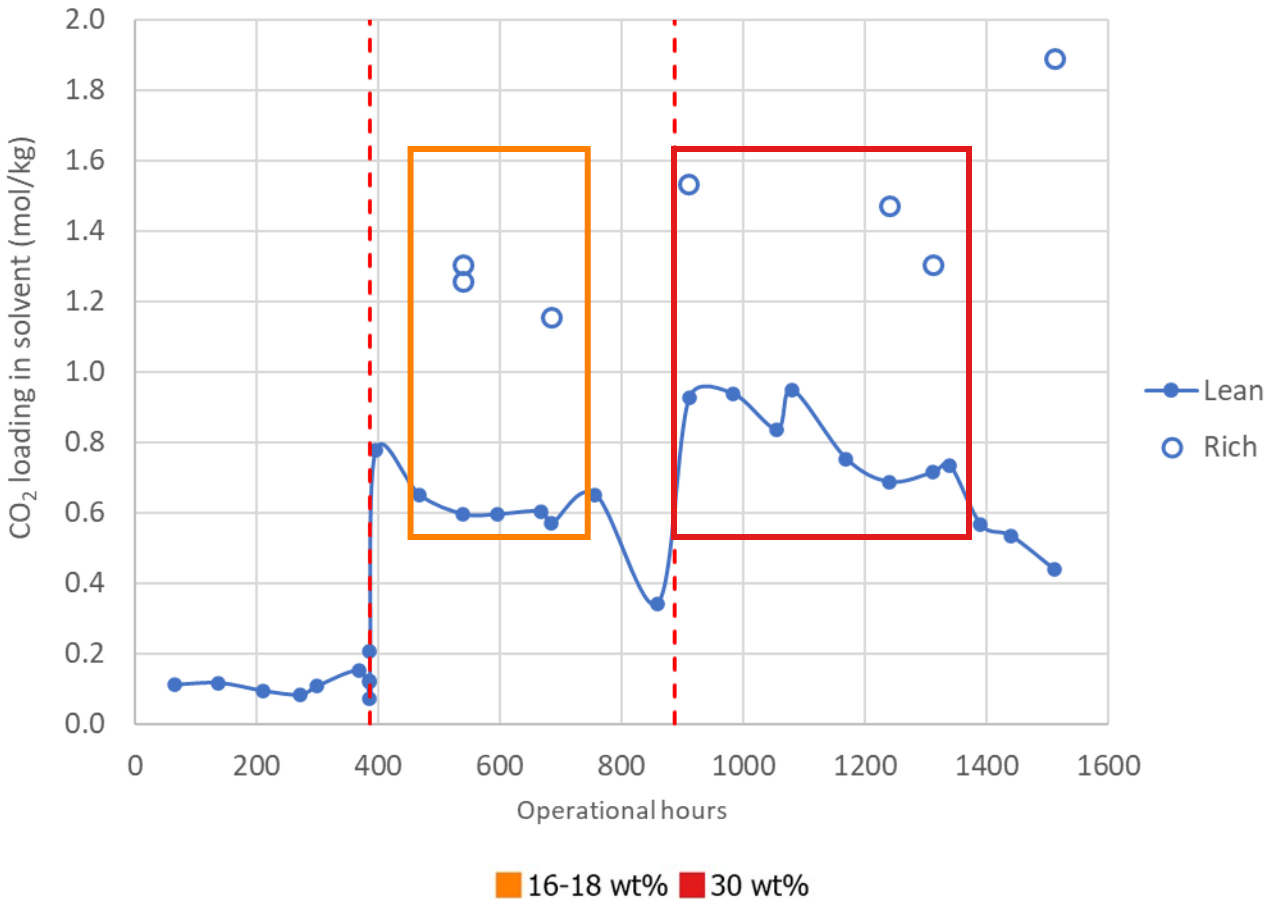
1. Exhaust gas side: $CO_{2,in}$ - $CO_{2,out}$
2. Solvent side: $CO_{2,rich}$ - $CO_{2,lean}$

CO_2 capture rate (exhaust gas side, method 1)



Assuming a stable inlet CO_2 concentration of 4.78 vol%

CO_2 capture rate (solvent side, method 2)



Summary of CO_2 capture rate calculations

16-18 wt%

Method	CO_2 captured, kg/h	CO_2 captured, %
1. Gas side	6.9 – 7.9	46.8 – 54.6
2. Liquid side	7.0 – 7.6	48.1 – 52.9

Good agreement in CO_2 mass balances
Average capture rate for 17wt% MEA: ca. 50%

30 wt%

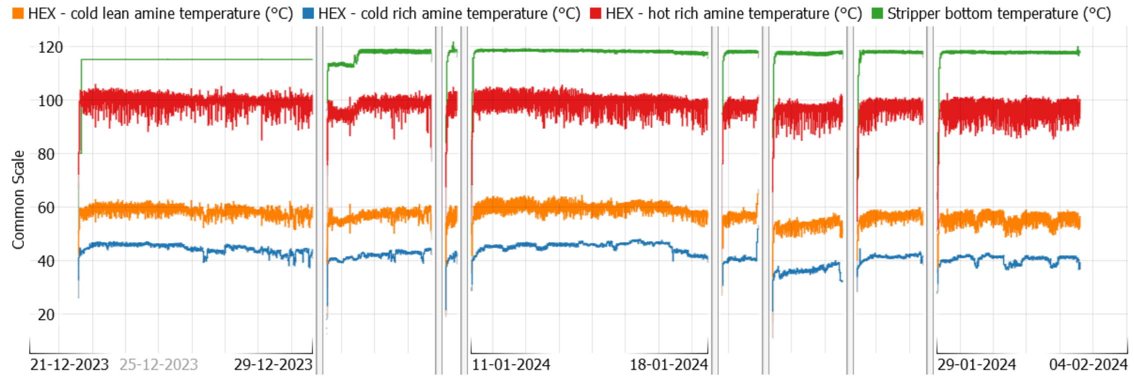
Method	CO_2 captured, kg/h	CO_2 captured, %
1. Gas side	12.0 – 13.9	85.1 – 88.5
2. Liquid side	7.3 – 10.9	51.8 – 65.8

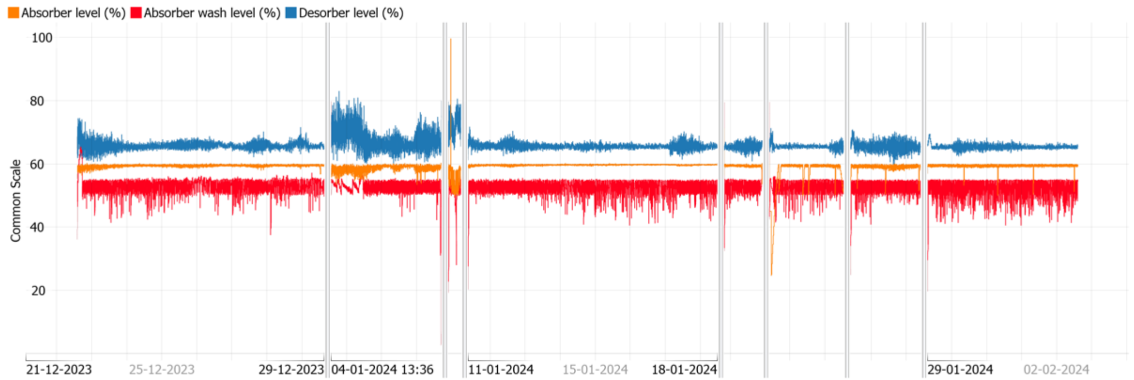
Bad agreement in CO_2 mass balances
Average capture rate for 30wt% MEA: ca. 85%

Sources of uncertainty: gas flowrate (not measured directly, but correlated from blower curves); CO_2 content in inlet gas (measured once, assumed constant); liquid flowrates (daily averages used); FTIR accuracy; liquid analysis (only 6 data points available so far, will be increased)

Operation stability and effect of ship motion

Operation stability – process parameters



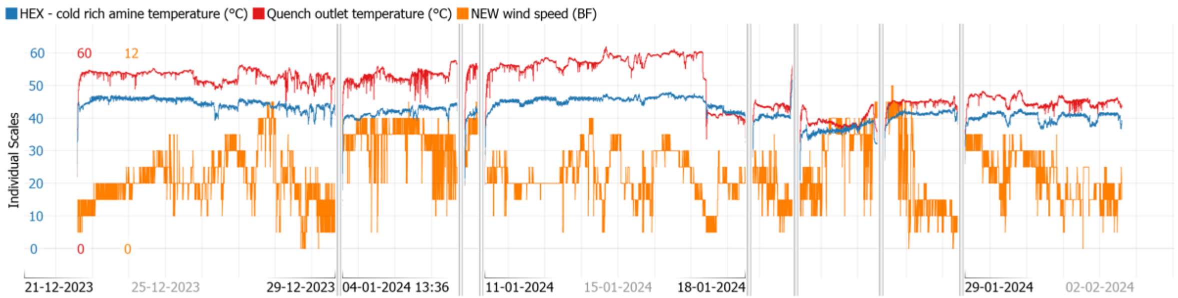


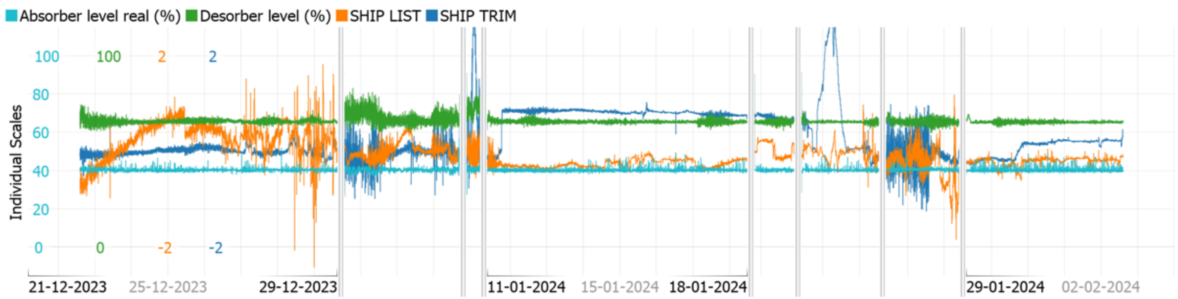
Stable operation during the campaign exemplified by temperatures around heat exchanger, and liquid levels in the sumps of the absorber, desorber and water wash

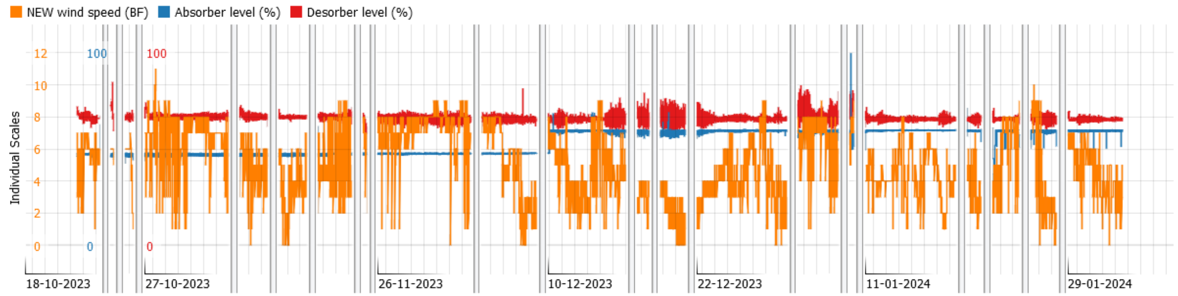
- ✓ Reliable process control system
- ✓ Robust technology

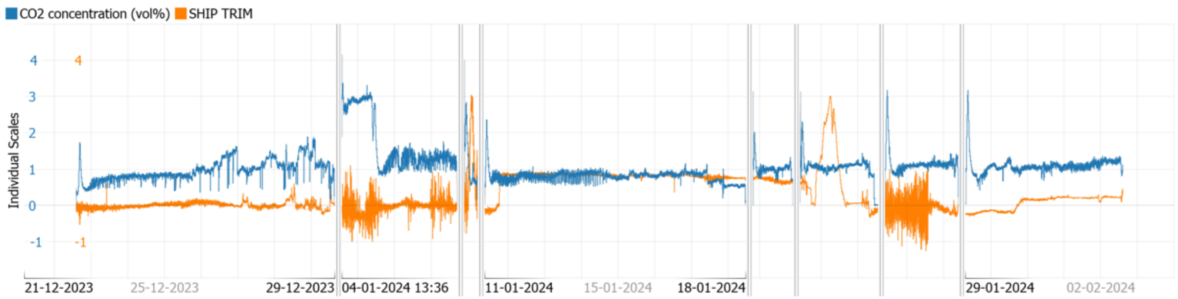
Effect of motion

Ship sea movement or rolling evaluated throughout the campaign
Periods with strong wind speed (up to Beaufort 10, or above 24.5 m/s)









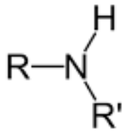
Ship motions had **no measurable effect** on CO_2 capture rate or other process parameters

Exhaust gas measurements NO_2

Why discuss NO_2?

NO_2 reacts with amines causing oxidative degradation (affects costs and system performance)

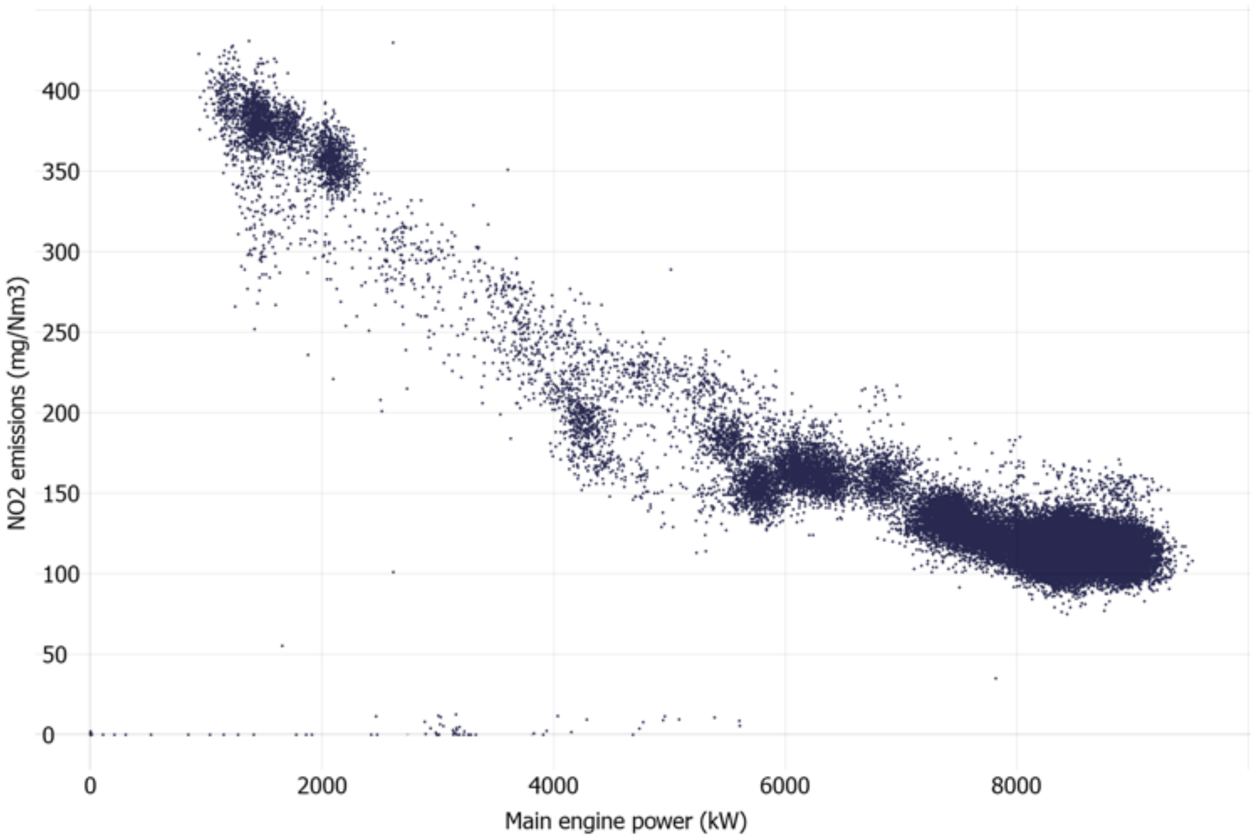
NO_2 reacts with secondary amines, forming nitrosamines (safety concern)



Secondary amine

Example: piperazine (present in the CESAR1 solvent)

NO_2 emissions as a function of engine load

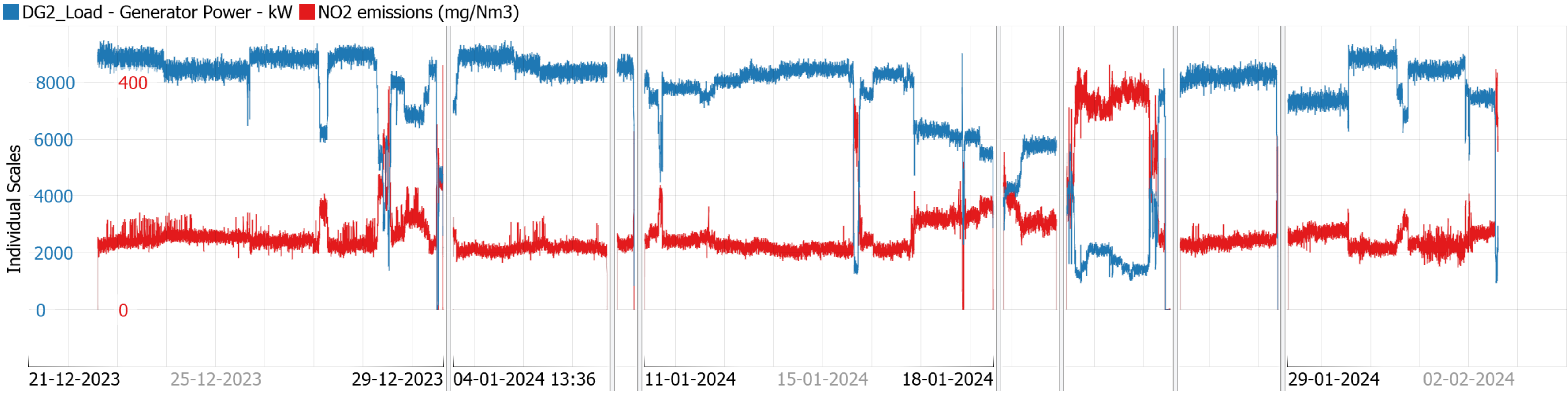


Clear correlation between NO_2 concentration and the engine load

NO_2 emissions in the range of 100-400 mg/Nm^3 (outlet of capture plant)

In land-based systems, amines are typically exposed to 2-5 mg/Nm^3 of NO_2 (inlet of capture plant)

NO_2 emissions as a function of engine load



NO_2 measurements (FTIR measurement) follows the engine load (ship data) closely, showing the consistency between the ship's data and the FTIR measurements

What to do?

- Solvent choice: consider avoiding secondary amines
- Consider NOx emissions reduction (far beyond IMO requirements)
- Evaluate if cost and safety consequences can be accepted

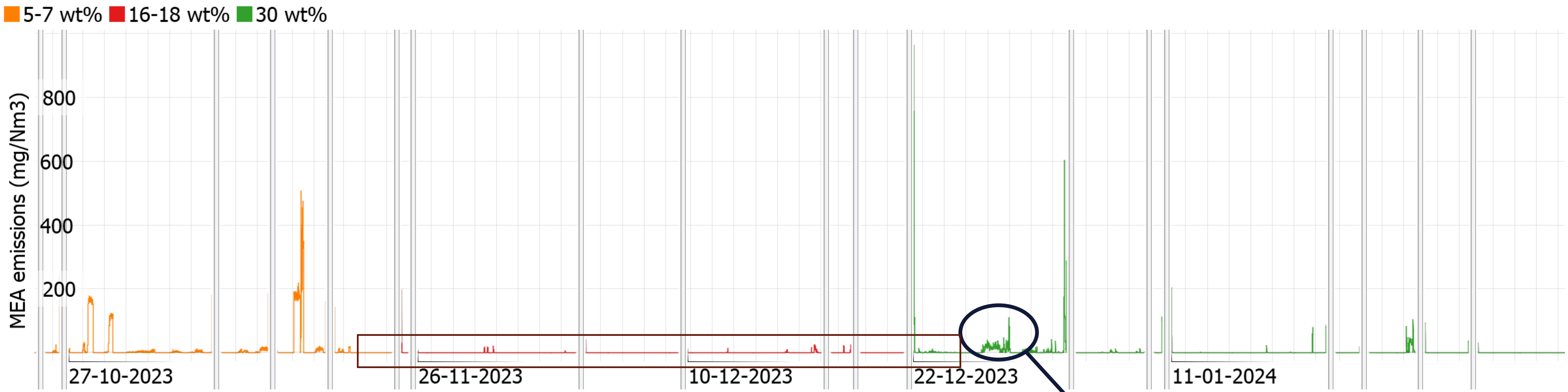
Exhaust gas measurements
MEA and ammonia

MEA emissions

Average: 12.4 mg/Nm³
Standard deviation: 46.9 mg/Nm³

Average: 0.12 mg/Nm³
Standard deviation: 1.3 mg/Nm³

Average: 2.1 mg/Nm³
Standard deviation: 14.8 mg/Nm³

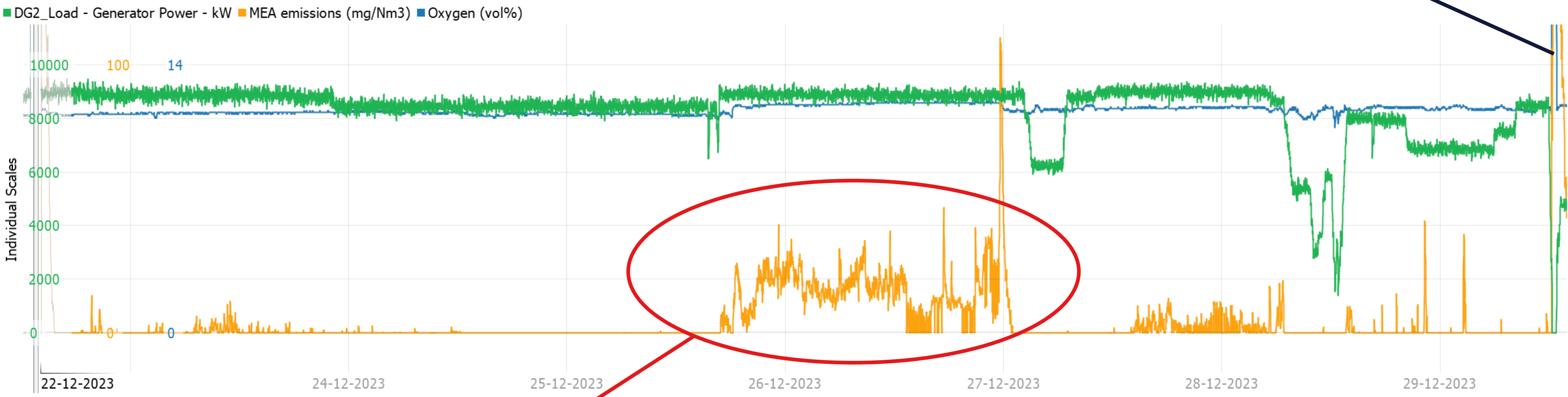


Discussed on next slide

Most of the times, very low amine emissions
Efficient design and operation of water wash

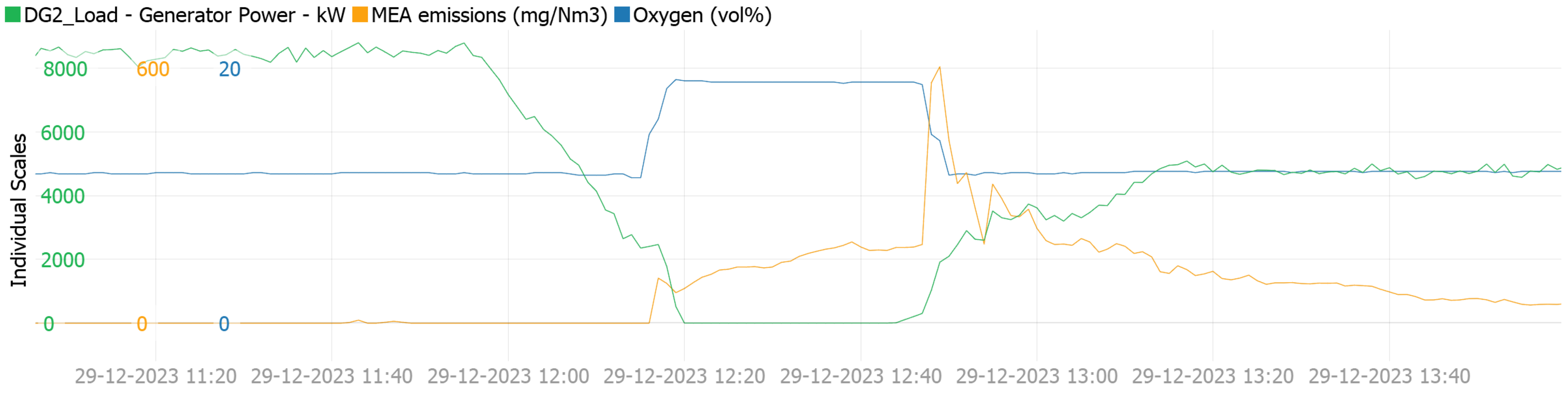
MEA emissions (30 wt% MEA section)

High peak
Discussed on next slide



Some engine load changes seems to cause emissions

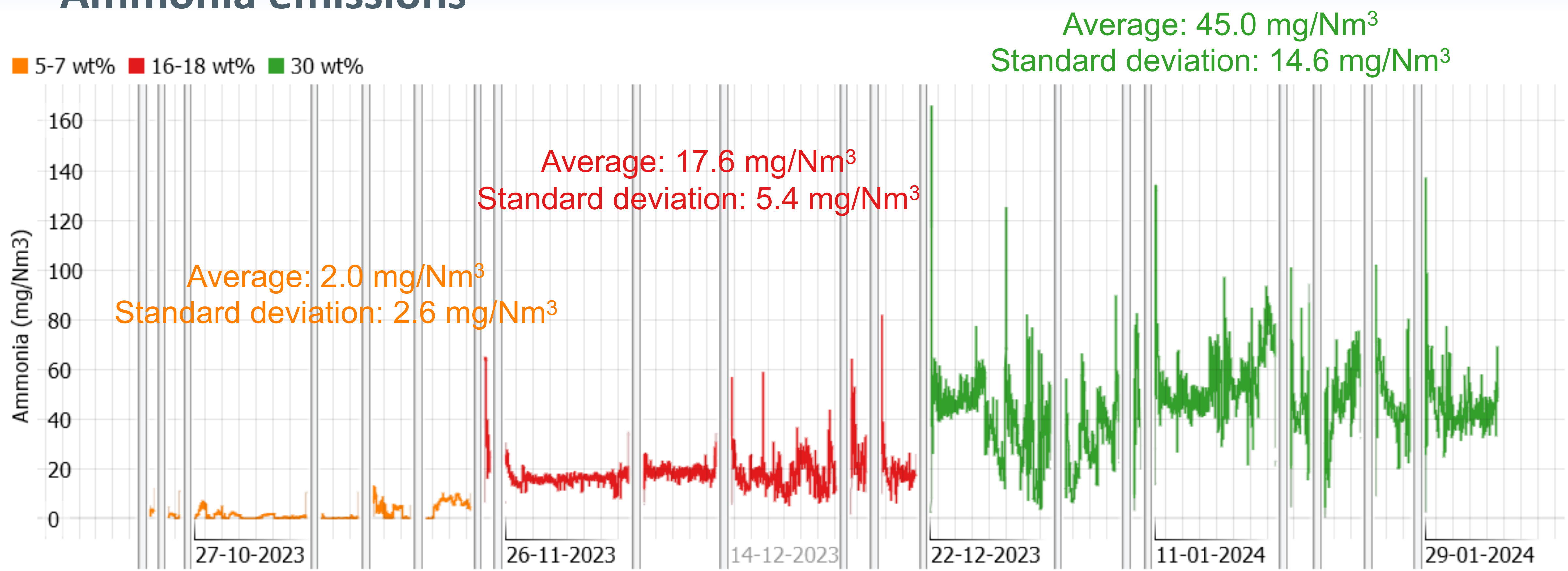
MEA emissions (during load change)



Very high amine emissions observed during rapid load change of main engine → indicates aerosol emissions could be present - Amine emissions are probably not acceptable in this range → In full-scale system, temporary bypass could be a solution

Note: ambient air was sucked through the capture system when engine was offline

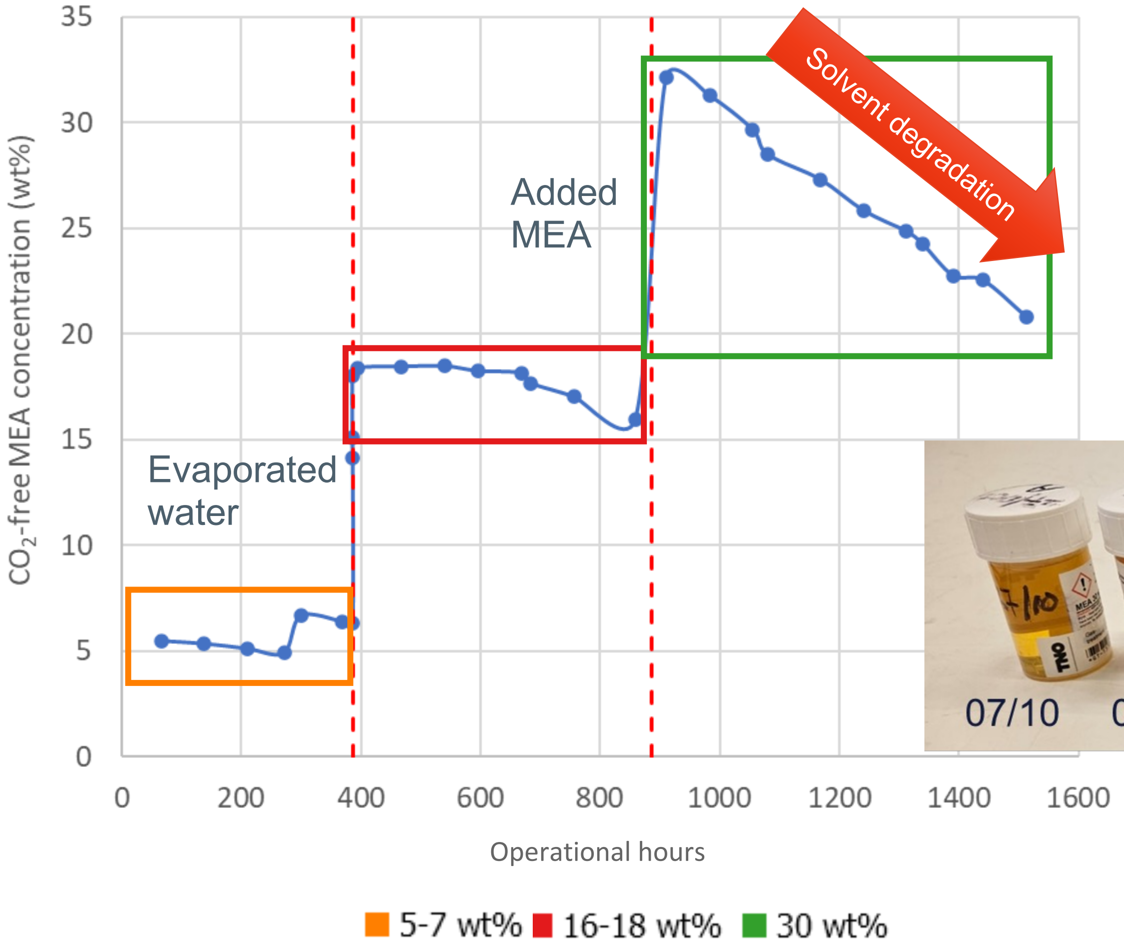
Ammonia emissions



Ammonia emissions at design MEA concentration (30 wt%) are **high relative to other campaigns,** and indicate high solvent degradation rates. To be quantified further with solvent analysis

Solvent Degradation

Solvent concentration



Estimated loss:
3.5 to 4 kg_{MEA}/ton_{CO2}

Estimated solvent loss – comparison with literature

Comparison against TCM campaign

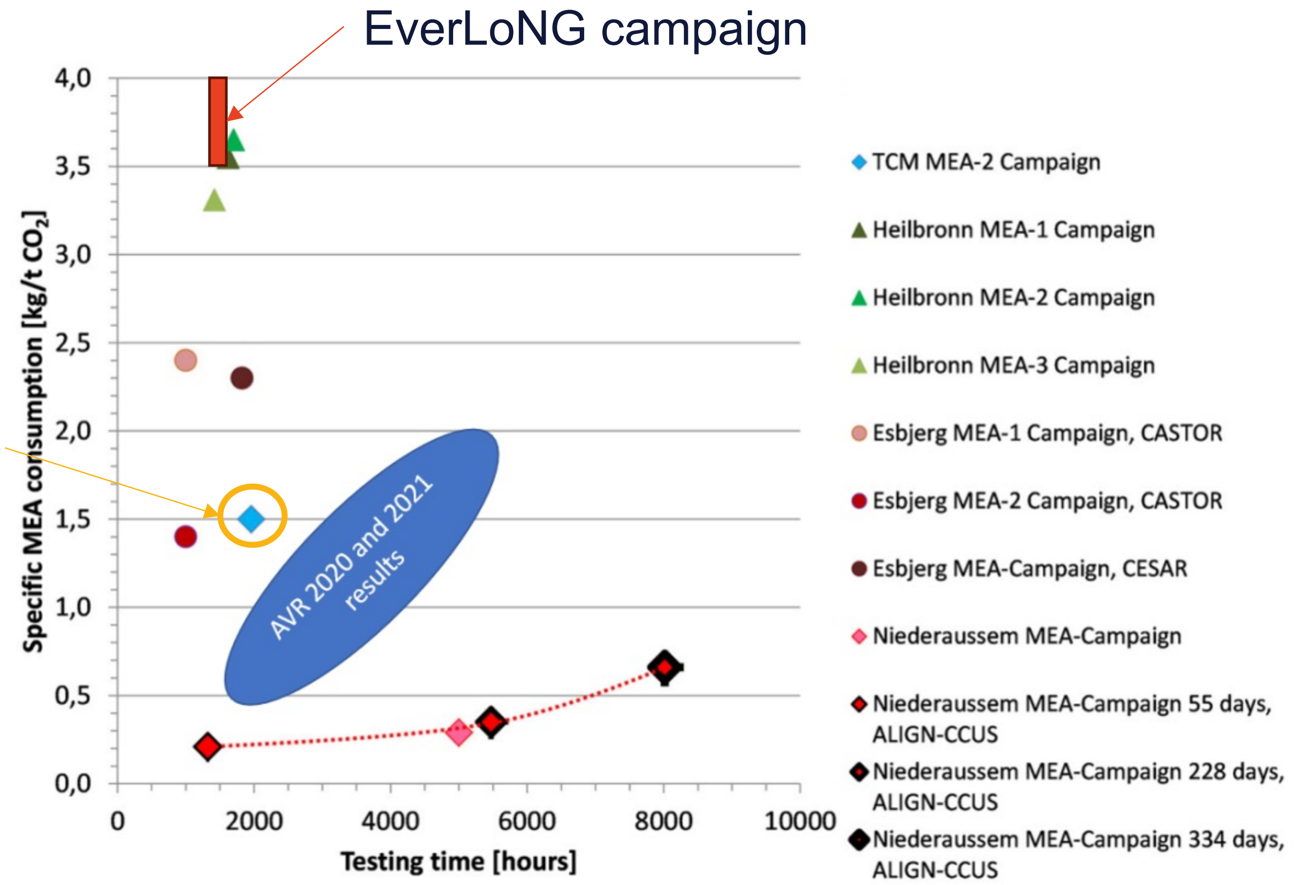


Figure 12, specific MEA consumptions in different (pilot) campaigns, including the results from AVR represented as a range. Figure taken from Moser et al. [5]

High degradation rate, but not off the charts

EverLoNG flue gas:
O_2 concentration: 11.6 vol%
NO_2 concentration: 69.2 ppm

TCM CHP flue gas:
O_2 concentration: 14 vol%
NO_2 concentration: 0.5 ppm

Comparison against TCM campaign

Test Center Mongstad (TCM, Norway)

One of the largest post-combustion CO_2 capture test centres in the world. Flue gas streams of up to 60,000 Sm^3/h (ca. 400 times larger than EverLoNG prototype)

Campaign:

July to October 2015

30wt% MEA

3.5% CO_2

Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia
Energy Procedia 114 (2017) 1245 – 1262

13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland

Degradation and Emission Results of Amine Plant Operations from MEA Testing at the CO_2 Technology Centre Mongstad

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Abstract

In 2015, the CO_2 Technology Centre Mongstad (TCM DA), operated a test campaign using aqueous monoethanolamine (MEA) solvent at 30 wt%. The main objective was to demonstrate and document the performance of the TCM DA Amine Plant located in Mongstad, Norway. This paper will present several aspects concerning degradation of the solvent and atmospheric emissions from amine based CO_2 removal processes. The work aims to; (1) quantify the amounts and compositions of the degraded solvent (2) report results from atmospheric emissions measurements of amines and amine based degradation products; and (3) present Ambient Air measurement done during a 2 month campaign.

Peer-review under responsibility of the organizing committee of GHGT-13.

Keywords: Monoethanolamine, MEA, Amine, Emission, Degradation, CO_2-capture

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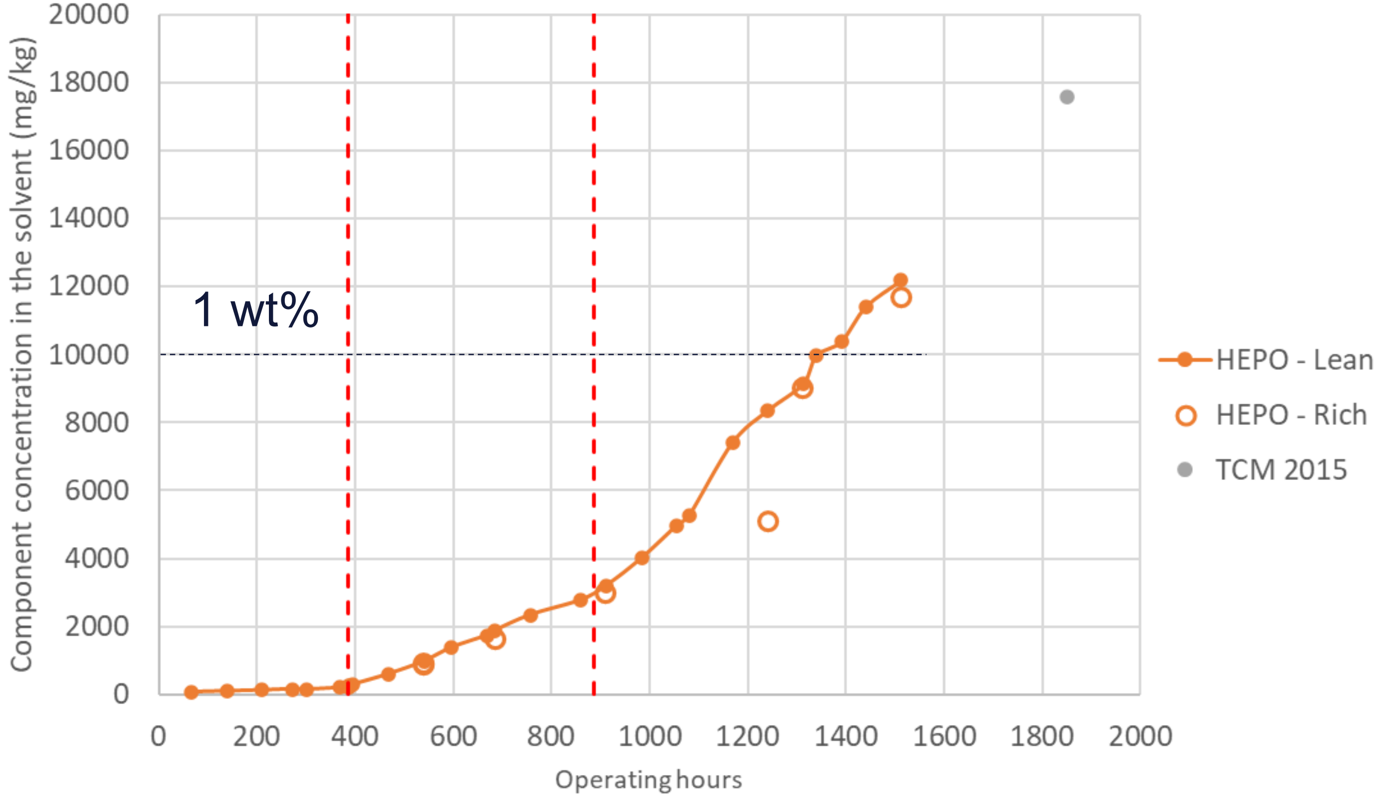
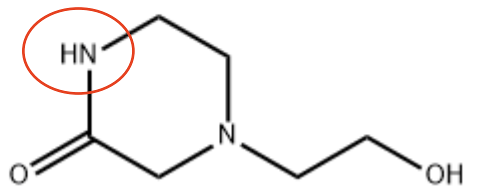
Main degradation products - HEPO



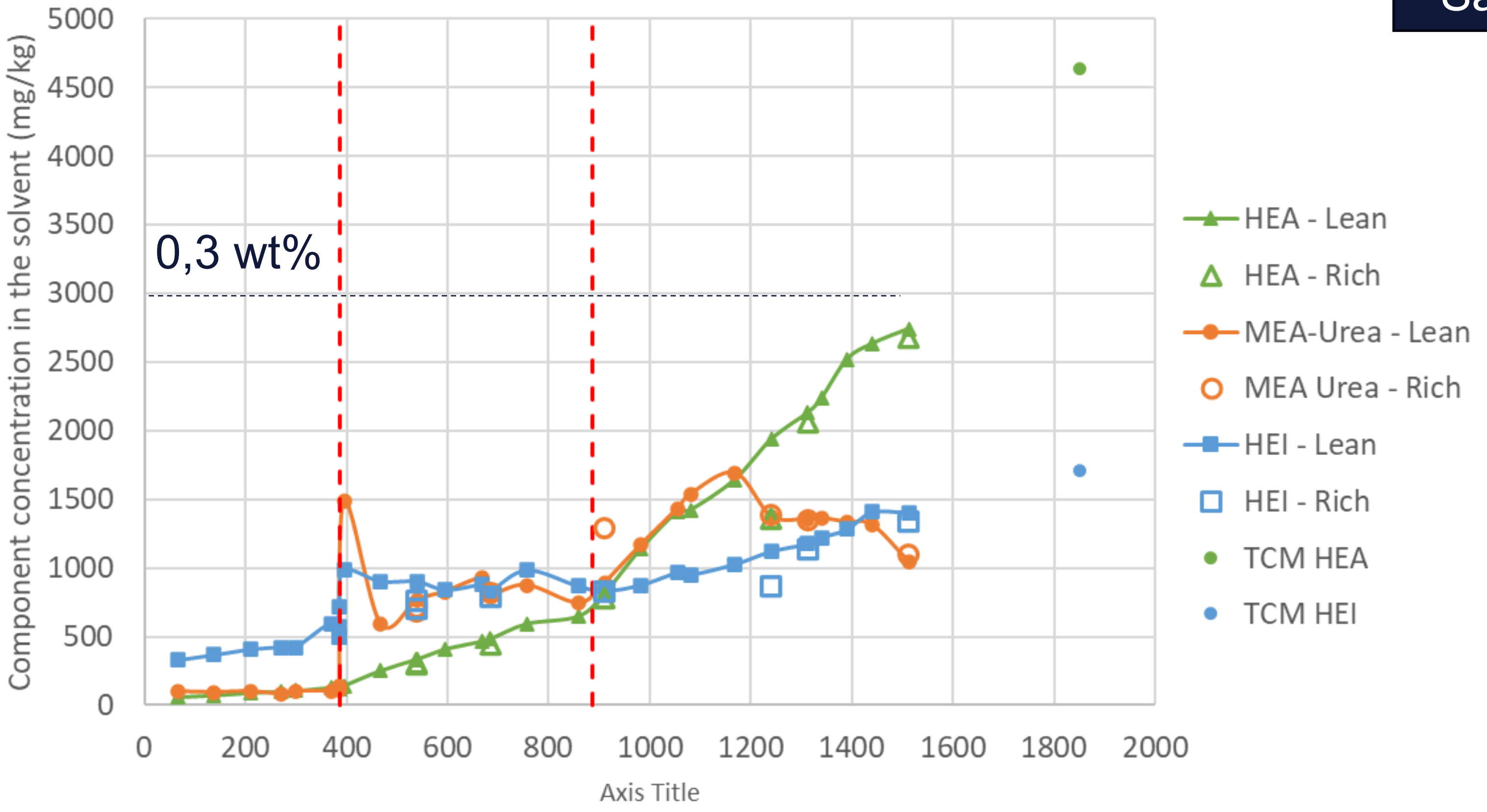
Secondary amine group



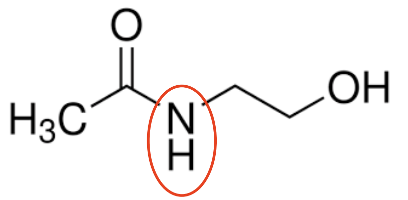
HEPO is the main degradation product. Same order of magnitude as TCM

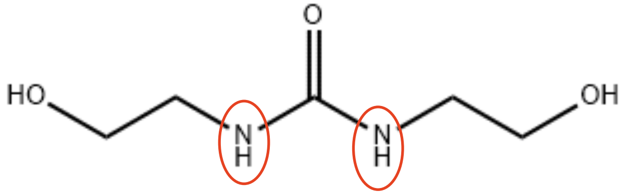
TCM data from Morken et al., 2017

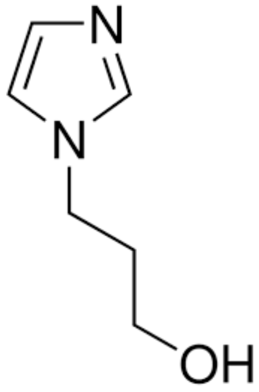
Main degradation products – HEA, MEA-urea, HEI



Same order of magnitude as TCM

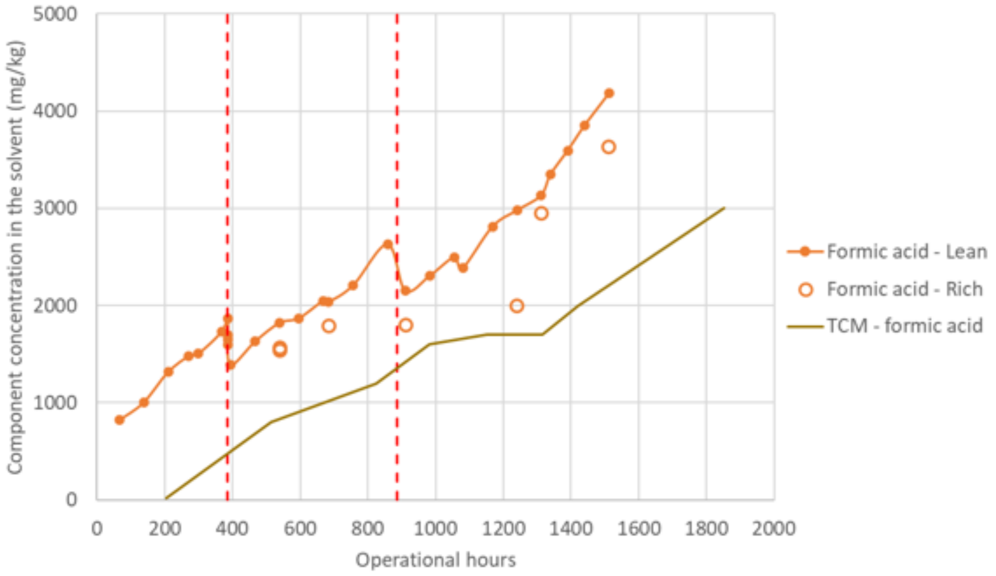


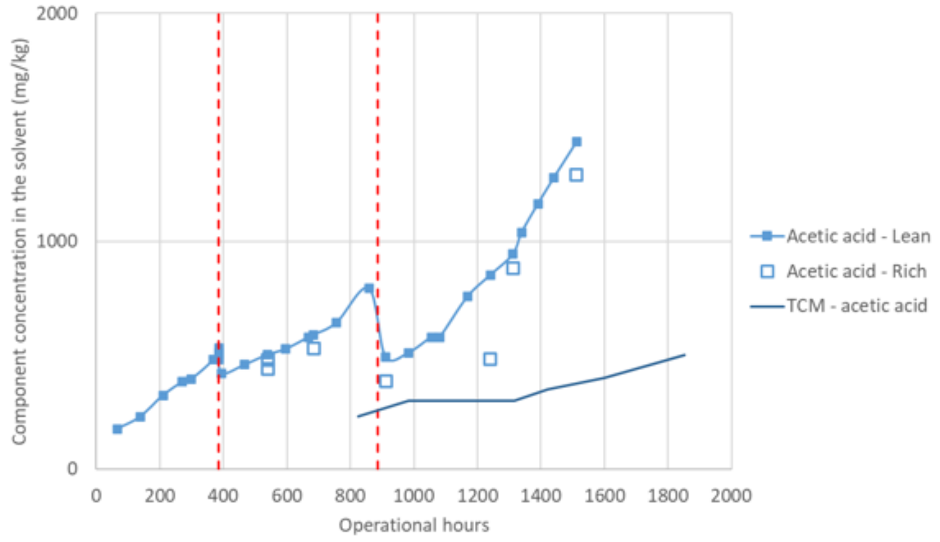


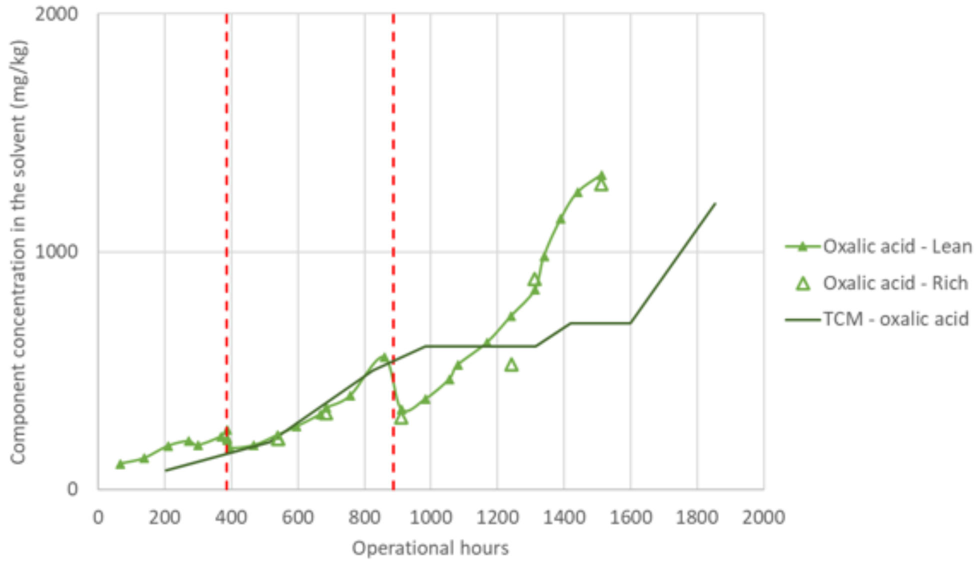


TCM data from Morken et al., 2017

Main degradation products – acids



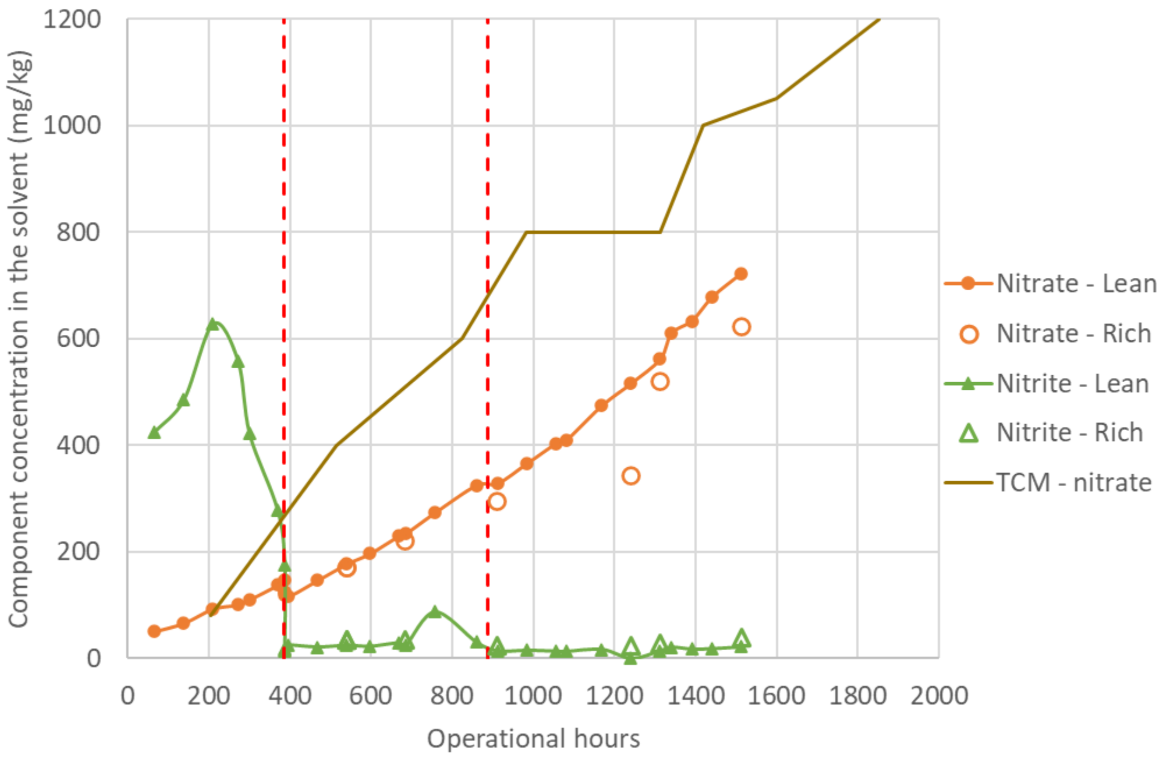




These products seem to accumulate at a higher rate than at TCM – indication of higher oxidative degradation

TCM data approximated from graphs presented in Morken et al., 2017

Main degradation products – nitrite and nitrate



Nitrite behaviour at 5-7wt% MEA: to be confirmed

Nitrate accumulates at lower rate than TCM

TCM data approximated from graphs presented in Morken et al., 2017

Conclusions

Successful demonstration of SBCC at TRL8, during 2475 hours. Stable operation, no measurable effect of ship motion

Average CO_2 capture rate at design solvent concentration: 79% (up to 88.5%)

- Uncertainties in calculations: carefully consider sensors needed to monitor capture rate in full-scale implementations!

Solvent degradation rate higher than most pilot operations in literature. Consequences on solvent lifetime and logistics of solvent replacement will be further evaluated within EverLoNG

- NO_2 content – point of concern (verify for other engines and ships and consider in design)

Thank you for listening

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