Peter Moser, Maxime François

SCOPE - Volatile and aerosol-based emissions of aged CESAR1 and their mitigation - measurement and simulation

TCCS 12

SCOPE

Project number 327341
ACT – Accelerating CCS Technologies

SCOPE - Volatile and aerosol-based emissions of aged CESAR1 and their mitigation - measurement and simulation

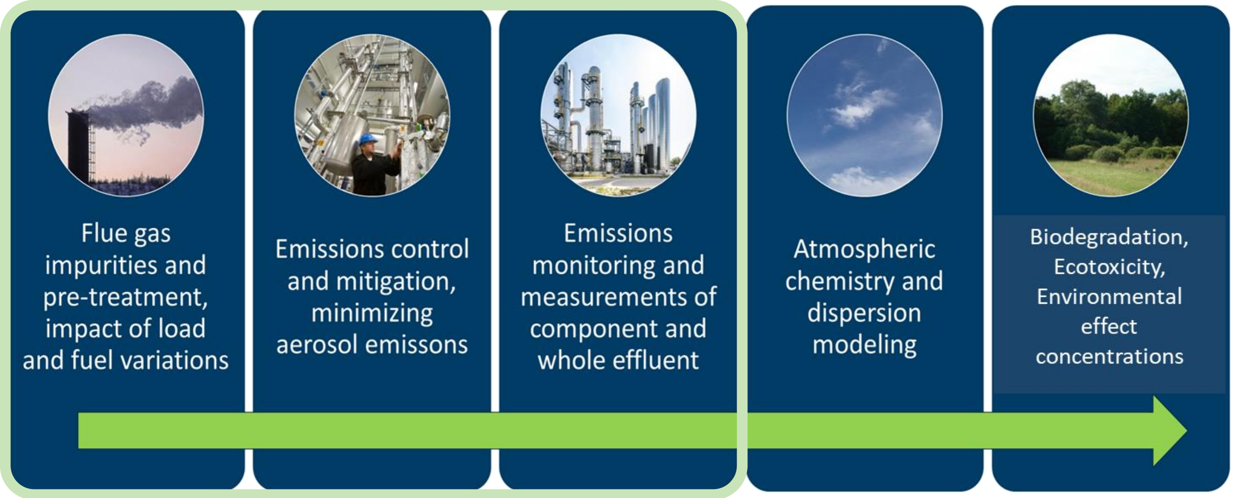
Peter Moser, Georg Wiechers, Marcel Busch, Knut Stahl, RWE Power AG
Susana Garcia, Laura Herraiz-Palomino, Charithea Charalambous, Mijndert van der Spek, Heriot-Watt University
Hallvard F. Svendsen, **Maxime Francois**, Hanna K. Knuutila, NTNU Kjemisk Prosessteknologi
Peter van Os, Juliana Garcia Moretz-Sohn Monteiro, Roberta Veronezi Figueiredo, Eirini Skylogianni, TNO

TCCS 12 The 12th Trondheim Conference on CO_2 Capture, Transport and Storage, 19. – 21. June 2023

TCCS 12

SCOPE – Sustainable OPEration of post-combustion Capture plants

Follow the continuous path of the treated gas from source to recipient and ensure a sustainable and environmentally safe operation of the amine-based capture plant



Demonstration of emission management technologies at capture pilot plants

- **Validated models** to **predict volatile** and **aerosol-based emissions**
- **Reliable process** and **operational data, sample analysis, operational** and **maintenance costs** from tests at **6 industrial sites** for the assessment of the **performance of emission mitigation technologies**
- Dependence of emissions on **solvents, solvent aging, flue gas properties, plant operation,** and **capture rate**

Hengelo

Waste-to Energy
500 kg CO_2/h

Niederaussem

Lignite
300 kg CO_2/h

Tiller CO_2 Lab

Biomass, propane
30-40 kg CO_2/h

Alkmaar

Waste-to Energy
540 kg CO_2/h

Vindyachal

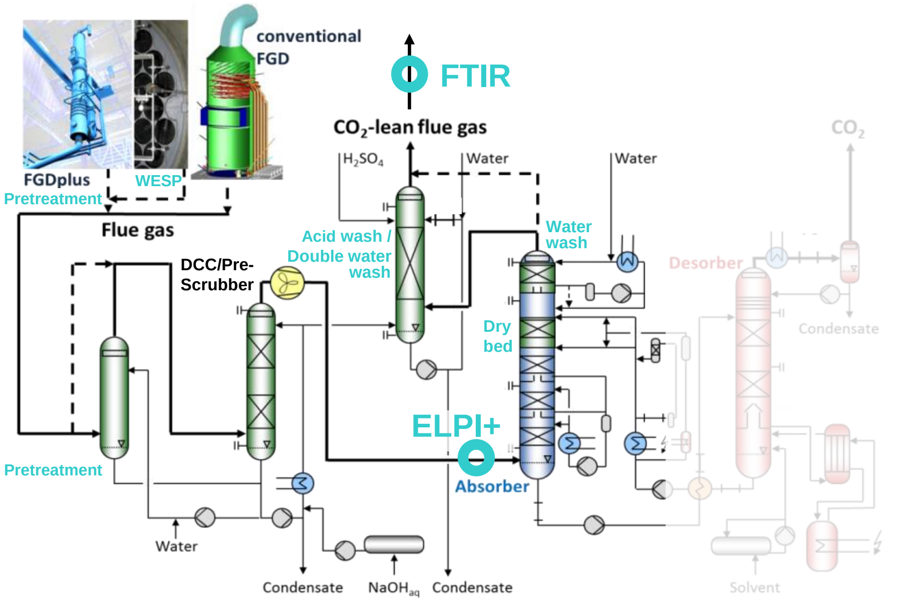
Hard coal
830 kg CO_2/h

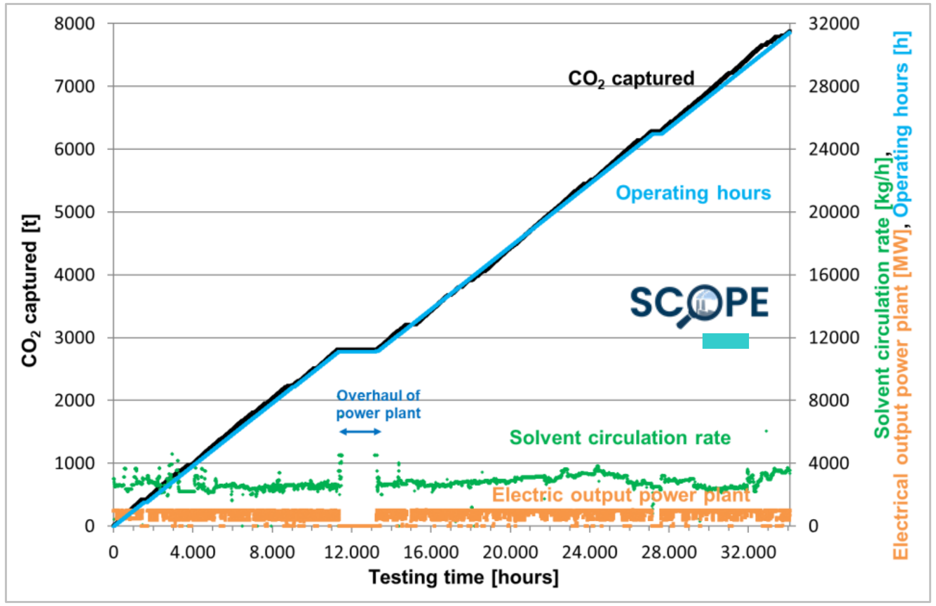
Tuticorin

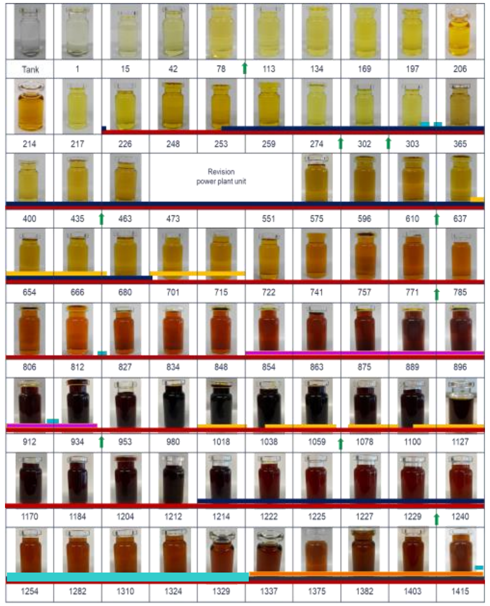
Chemicals
7,500 kg CO_2/h

Test of emission mitigation technologies for CESAR1 at Niederaussem

- Flue gas source: 1,000 MW **lignite**-fired power plant
- Operation mode: **24/7**, 300 kg_{CO2}/h@90% capture rate, 120-130°C/1.75-2.4 bar(a)
- Solvent: **aged CESAR1**, aqueous blend of 3.0 M AMP and 1.5 M PZ
- Test of more than **20 configurations of emission mitigation technologies** for **aerosol-based** and **volatile emissions** (water wash, double water wash, acid wash, dry bed (OASE aerozone®), pretreatment, WESP)
- Start of measuring campaign: **after 29,800 testing hours** (1,242 days) **without inventory exchange**



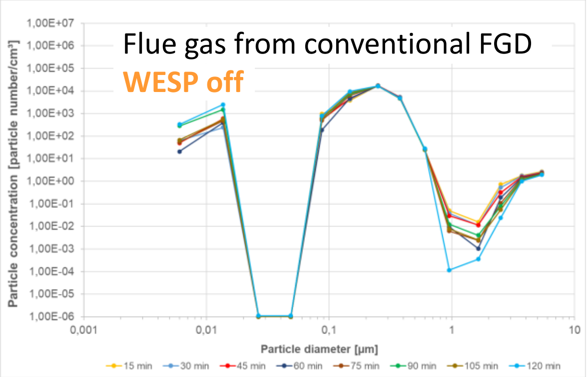




Generation of aerosol nuclei by the WESP upstream the CO_2 absorber

29 Repeat measurements for the benchmark for emission mitigation: Water wash

- Operating voltage of the **WESP** (wet electrostatic precipitator) **~35 kV**
- Investigation of aerosol-based emissions by **ELPI+** (14 size classes, diameter 6-5,400 nm), **FTIR** (uncertainty ± 3 % relative)
- As expected, the **WESP** causes **increase of the particle number concentration from ~10^4 to ~10^6 particles per cm³** by the **formation of small particles <0.1 µm** and **increase of the amine emissions >25%**

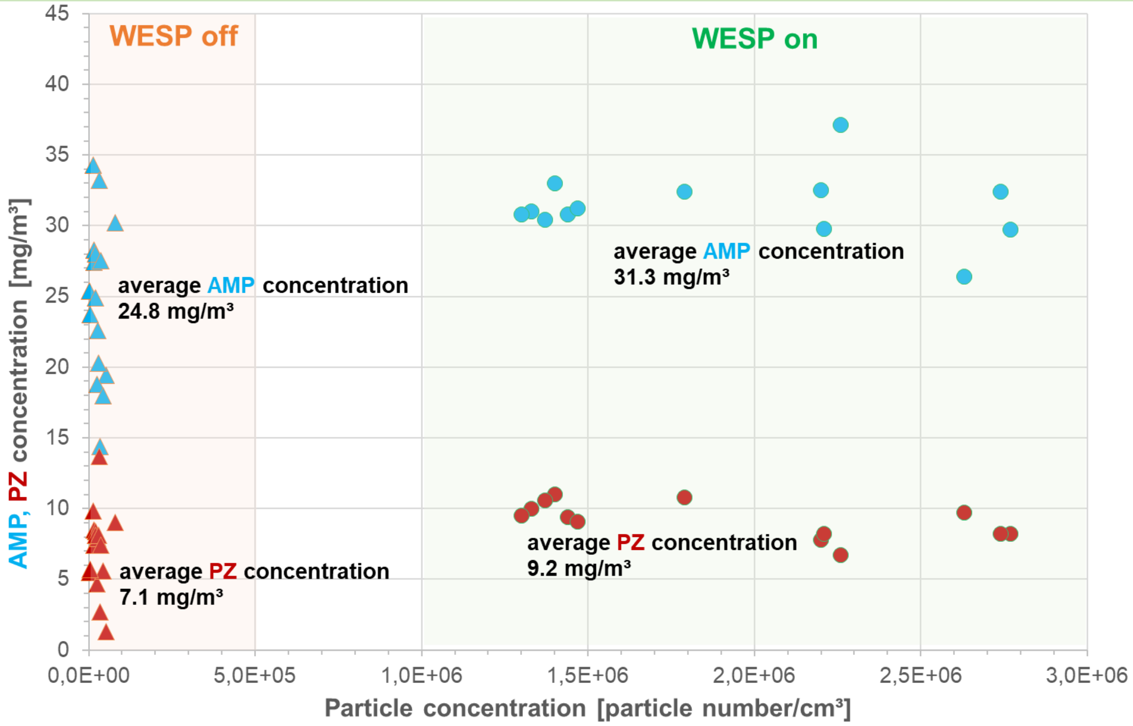


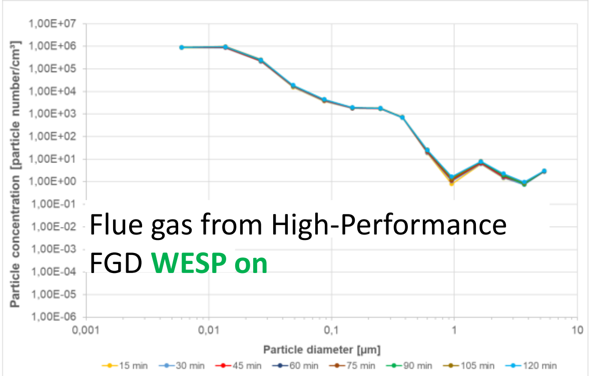
WESP off

average (157 hours, 16 tests) of particle concentration

2.8 x 10^4

particle number/cm³





WESP on

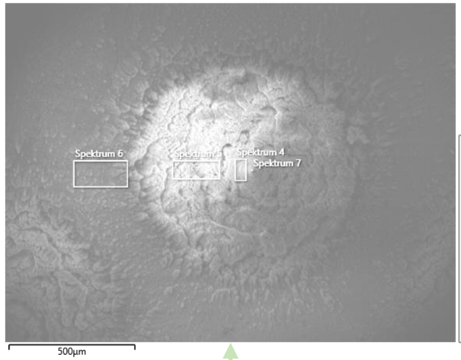
average (101 hours, 13 tests) of particle concentration

1.9 x 10^6

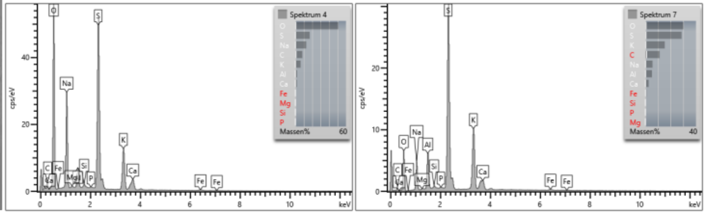
particle number/cm³

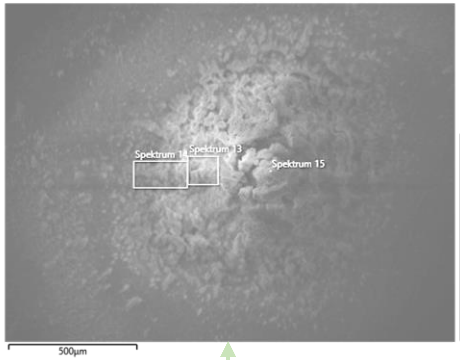
Generation of aerosol nuclei by the WESP and their investigation

- **Macroscopic amounts of aerosol nuclei could be sampled** at the inlet of the CO_2 absorber
- Analysis of samples by **SEM/EDX**
- The **solid material** consists mainly of **Na, S, and O** ($Na_xS_yO_x$, most likely **Na_2SO_4**)
- **Results confirm former analysis** data of single particles

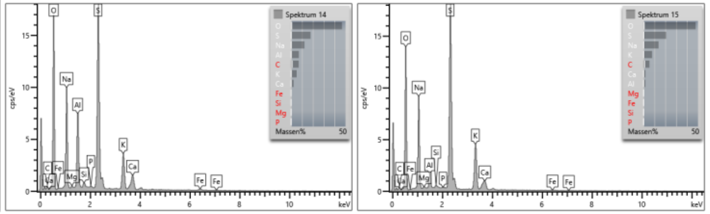


4 days particle collection
SEM/EDX collector plate 6 (0.147 µm)





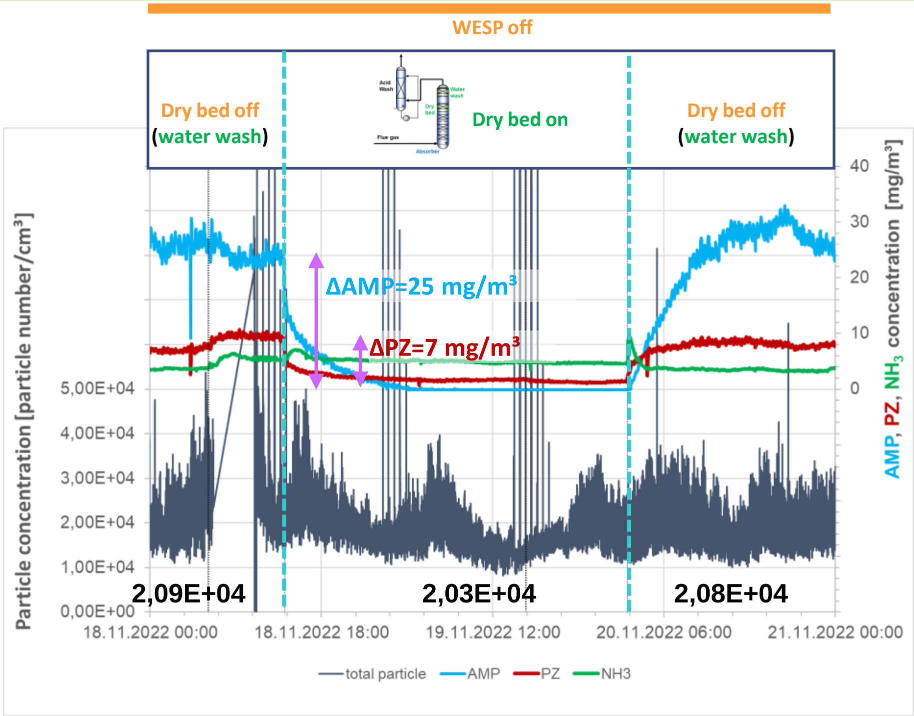
4 days particle collection
SEM/EDX collector plate 7 (0.249 µm)

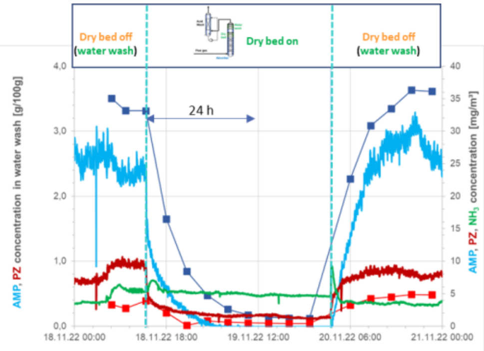


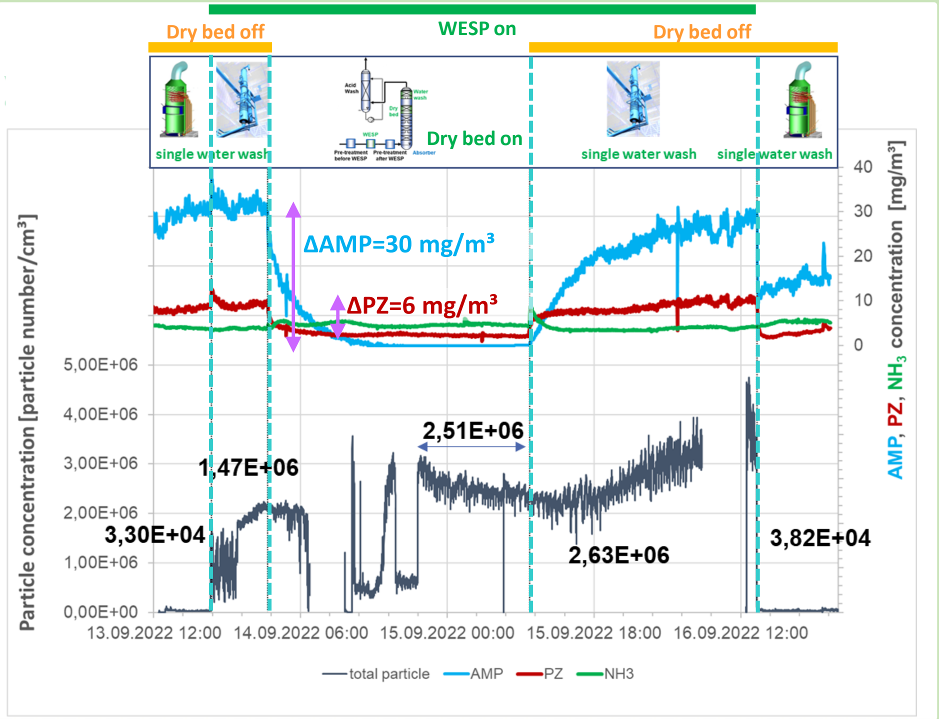
0.0265 µm | 0.0485 µm | 0.087 µm | 0.147 µm | 0.249 µm | 0.377 µm | 0.601 µm | 0.951 µm | 1.64 µm | 2.5 µm

Control of volatile and aerosol-based emissions - Example: Dry bed

- **Strong reduction of volatile and aerosol-based emissions of AMP and PZ** by the **dry bed**
- **No effect on emission of NH_3**
- Recommendation: **sufficient testing times** of **2-4 days** for individual tests to be able to evaluate the real effects after the amine concentration in the water wash has achieved **steady state**



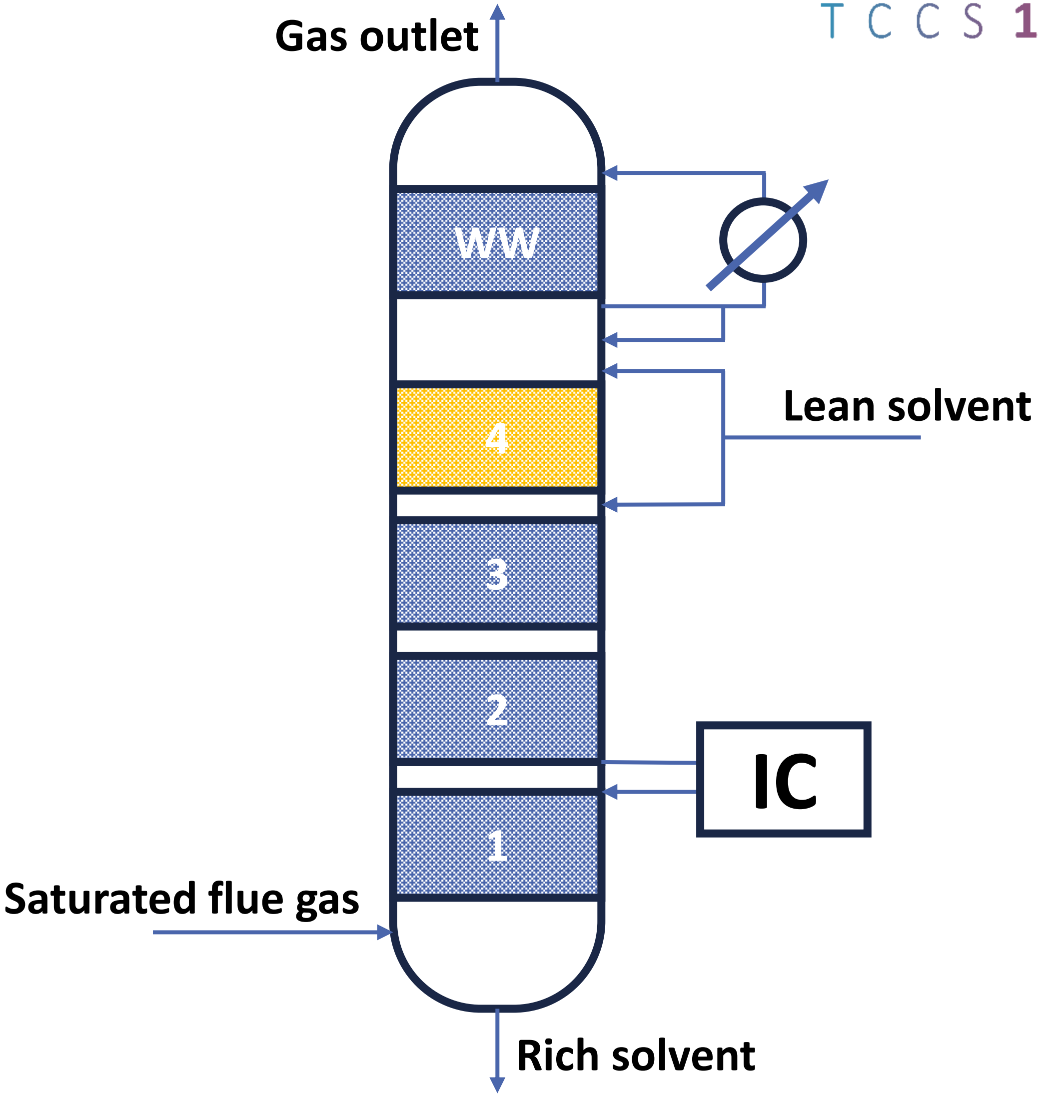




TCCS 12

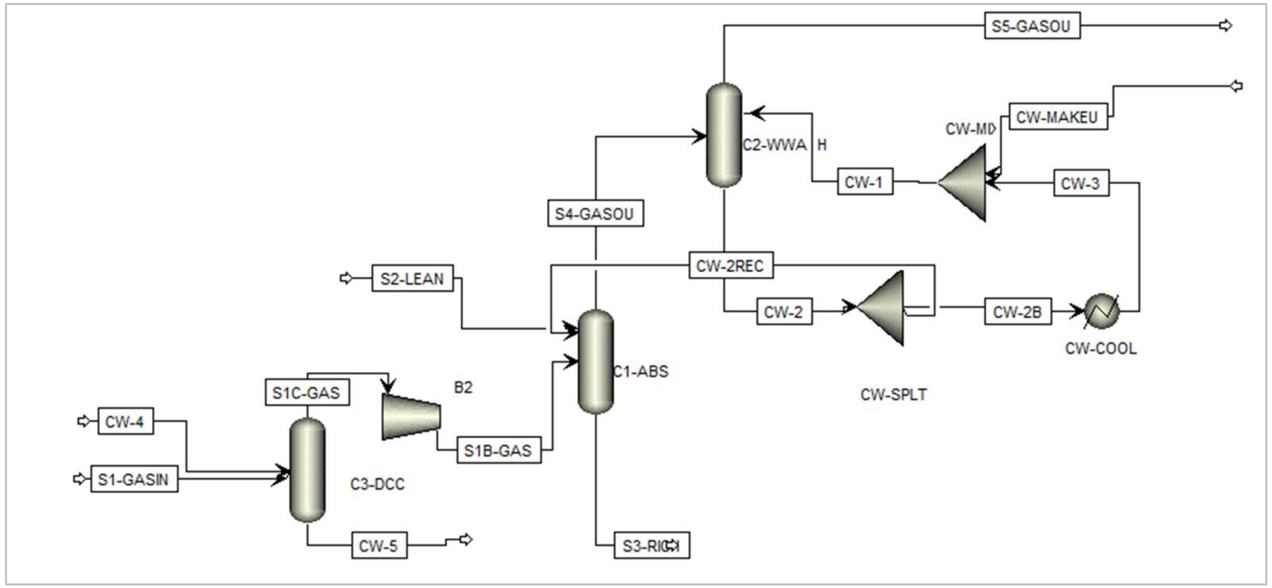
Simulation of volatile emissions for CESAR1

- **2 cases**: with and without dry-bed (conventional)
- 2 software: **ASPEN Plus and CO2SIM**
- Coal-fired power plant flue gas (15.5% CO_2) with $T_{absorber,inlet}$ ca. 40°C
- 4 packing sections: **the 4th one can serve as dry-bed** if the lean solvent is introduced below it
- 1 water-wash section; a small portion of the water is sent on the top of the 4th packing section
- **Total intercooler (IC) between the 1st and 2nd packing section**

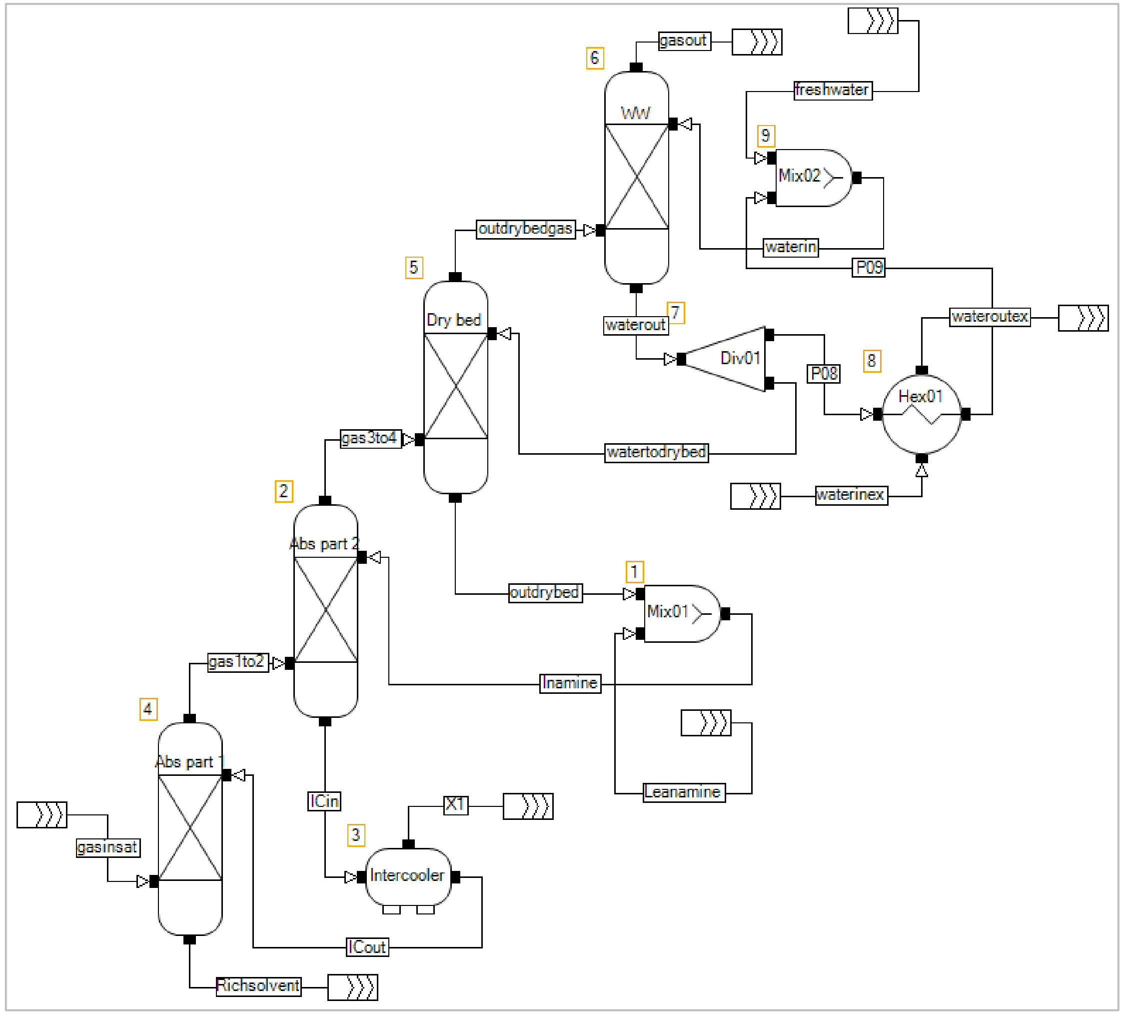


ASPEN Plus and CO2SIM simulations

Conventional case (Aspen Plus)



Dry-bed case (CO2SIM)



TCCS 12

RWE Experimental test campaign validation

AMP / PZ volatile emissions

- Conventional case

	Water at W/W outlet			Flue gas at W/W outlet					
	AMP	PZ	Total	AMP		PZ		Total	
	g/100g	g/100g	g/100g	mg/m³	ppm (mol)	mg/m³	ppm (mol)	mg/m³	ppm (mol)
RWE (*)	3.38	0.33	3.71	24.90	6.26	8.40	2.19	33.30	8.45
ASPEN Plus	2.56	0.028	2.59	30.45	9.02	0.007	2.12E-03	30.46	9.02
RWE	3.50	0.465	3.97	28.42	7.09	8.48	2.21	36.90	9.30
CO2SIM	-	-	3.52	-	-	-	-	57.10	14.5

(*) RWE experimental data with no additional emissions mitigation technologies other than a single water/wash system. Data include aerosol and volatile emissions from a test campaign in which low concentration of aerosol particles were measured

- Dry-bed case

	Water at W/W outlet			Flue gas at W/W outlet					
	AMP	PZ	Total	AMP		PZ		Total	
	g/100g	g/100g	g/100g	mg/m³	ppm (mol)	mg/m³	ppm (mol)	mg/m³	ppm (mol)
RWE (*)	0.12	0.0435	1,64E-01	ND	ND	1.273	0.33	1.273	0.33
CO2SIM	-	-	2.41E-01	-	-	-	-	2.64	0.67

TCCS 12

Simulation of aerosol-based emissions for CESAR1

Basic assumptions in the class-based aerosol model

- Experimental number counts for the various ELPI+ classes used as input
- The particles entering are saturated with Na_2SO_4
- A simplified model is developed to calculate the water partial pressure as a function of both Na_2SO_4 concentration and amine composition.
- No coalescence or break-up of particles.
- The kinetic model for CO_2 absorption into AMP/PPZ blends developed in the ALIGN project is used.

Inlet droplet classes and counts

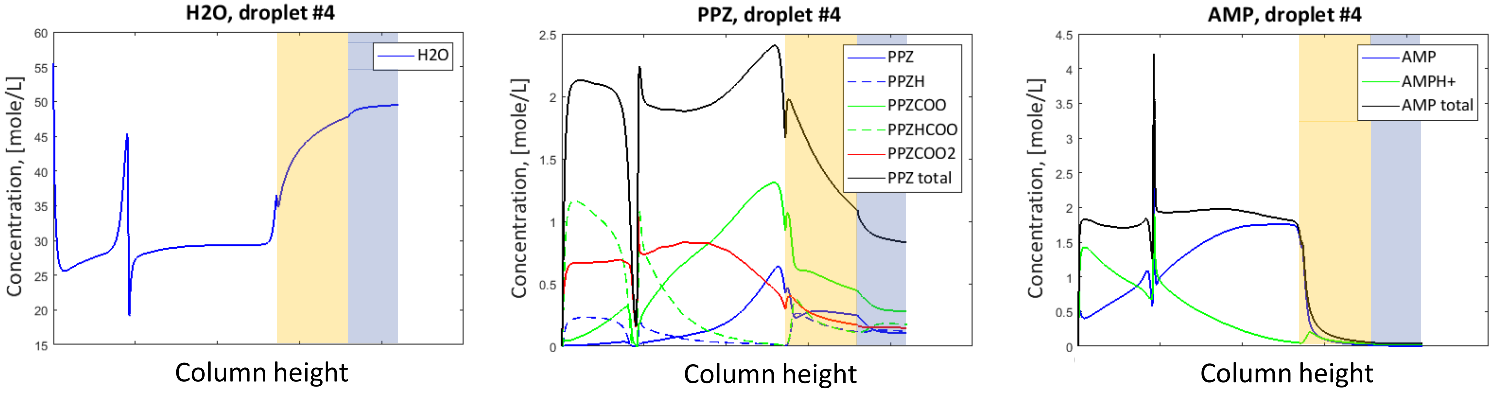
Diameter, nm	6	13.6	26.5	48.5	87	147	249	377	601	955	2500	3700	5400
No WESP, #/m^3	1e4	2.66e8	2.44e9	4.48e7	7.06e8	2.3e9	9.92e9	4.24e9	3.95e8	9.09e5	3.51e4	1.01e7	2.93e6
With WESP, #/m^3	4.65e11	7.34e11	1.69e11	2.33e10	1.03e10	1.86e9	1.22e9	4.3e8	2.07e8	4.34e7	3.42e7	5.68e6	4.2e6

Classes 1 and 2 are merged into class 3, and classes 10-13 are disregarded

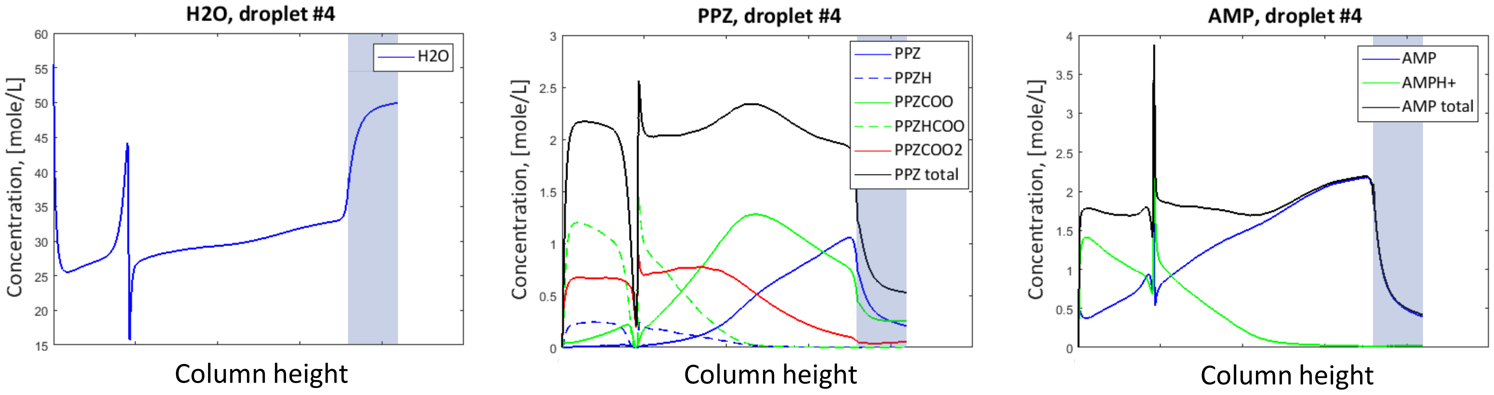
Simulation of aerosol-based emissions for CESAR1

Typical concentration profiles for AMP and PPZ. Droplet initial diameter 87 nm

- Intercooling causes rapid changes in AMP and PPZ concentrations because of water condensation and evaporation
- Dry bed has a strong effect on the droplet AMP concentration but not on the PPZ concentration
- Results without WESP are very similar



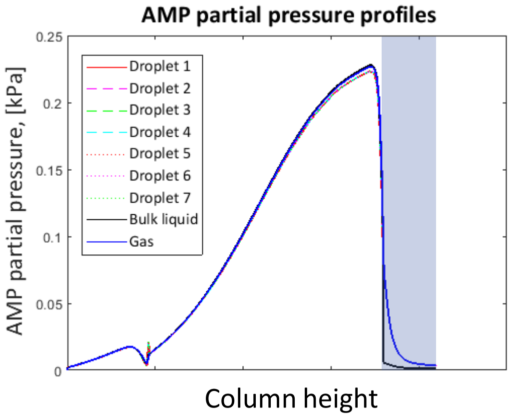
Dry bed, with WESP

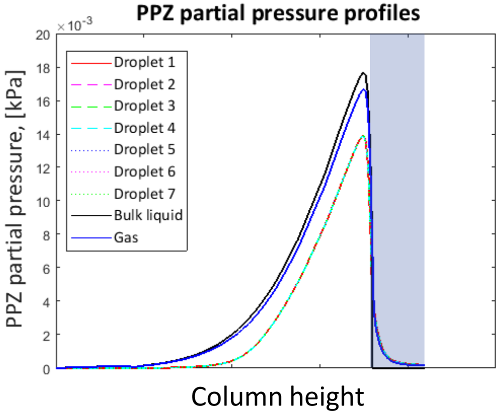


Conventional, with WESP

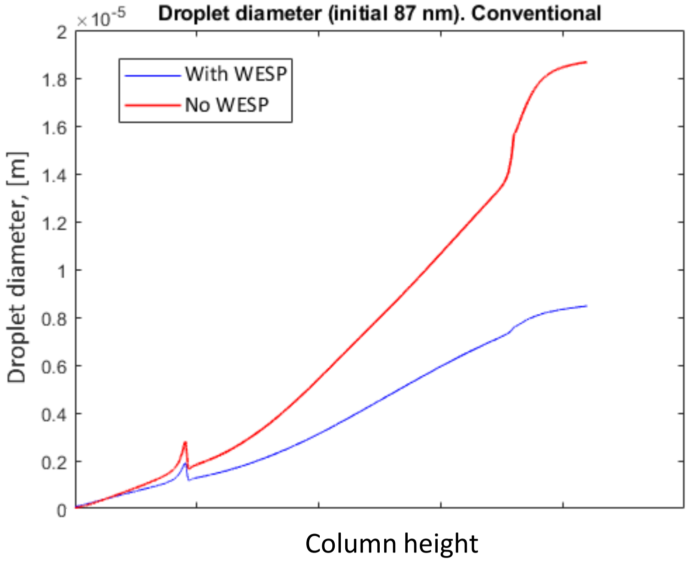
Simulation of aerosol-based emissions for CESAR1

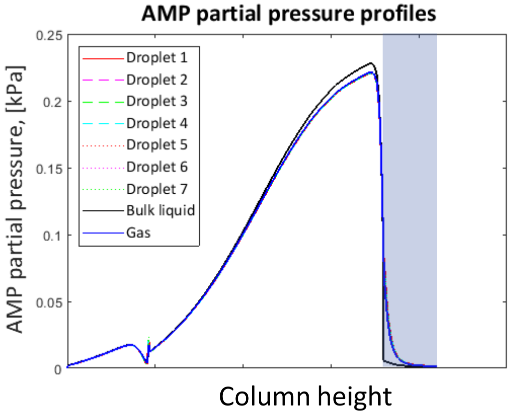
Partial pressure profiles for AMP and PPZ. Conventional case

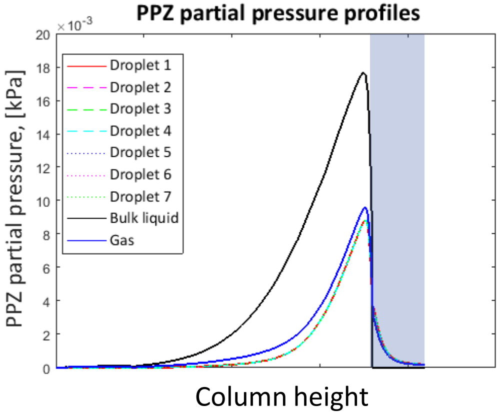




Without WESP







With WESP

Particle number concentration is 20x larger with WESP. Giving:

- Slightly more AMP gas phase depletion with WESP
- Much more PPZ gas phase depletion with WESP
- Less particle growth with WESP and smaller particles leaving the water wash
- Dry bed case shows similar trends as the conventional case

Simulation of aerosol-based emissions for CESAR1

Comparison of emissions in mg/Nm³

	Conventional no WESP		Conventional WESP		Dry bed no WESP		Dry bed WESP	
	AMP	PPZ	AMP	PPZ	AMP	PPZ	AMP	PPZ
Experimental	26-28	8-9	29-30	9-10	~0	1.5	~0	2.3
Model, aerosol	~0	~0	1	5.7	~0	~0	0.1	3.3
Model, gas phase	45.5	7.2	50.6	5.4	1.0	0.7	2.1	1.4

- Experimental emissions are total, whereas model emissions are aerosol and gas separately

Conclusions

- Need of sufficient testing time to reach steady-state (especially for the water-wash section)
- The AMP/PPZ system is complex, and it seems that small particles(<20nm) grow more than in MEA. Additionally, gas phase emissions seem over-predicted by the model
- Only initial rate kinetic data are available, making the kinetic model uncertain. However, the model does behave well.
- The reason for improved operation with a dry bed seems to be that it is not dry, but constitutes an extra wash section
- Using WESP leads to higher particle numbers, leading to more gas phase amine depletion and less particle growth
- Several emission mitigation configurations are available to control volatile and aerosol-based emissions and are holistically evaluated in SCOPE

TCCS 12

Acknowledgements

This project is funded through the ACT programme (Accelerating CCS Technologies), ACT 3 Project No 327341. Financial contributions made by the Research Council of Norway (RCN), Rijksdienst voor Ondernemend Nederland (RVO), Department for Business, Energy & Industrial Strategy UK (BEIS), Forschungszentrum Jülich GmbH, Projektträger Jülich (FZJ/PtJ) Germany, Department of Energy (DoE) USA and Department of Science and Technology (DST) India are gratefully acknowledged.

www.scope-act.org

@SCOPE_ACT

Please join the side-event to the TCCS-12 conference: The fourth SCOPE Stakeholder, Policy, Research and Industry NeTwork (SPRINT) event "How to address, interact and act on the main knowledge gaps related to emissions", Thursday, 22 June 2023, 09:00 - 15:00, free of charge, online access via registration at

www.scope-act.org/events

TCCS 12