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JOINT MASS SPECTROMETRY CENTRE

SAARUS

Evaluation of aerosol emissions from a marine diesel engine using a wet sulfur scrubber and filtration system for exhaust gas abatement

(Project SAARUS: Optimization of scrubber technology for reduction of environmentally harmful ship emissions)

25th ETH Conference on Combustion Generated Nanoparticles

21.06.2022

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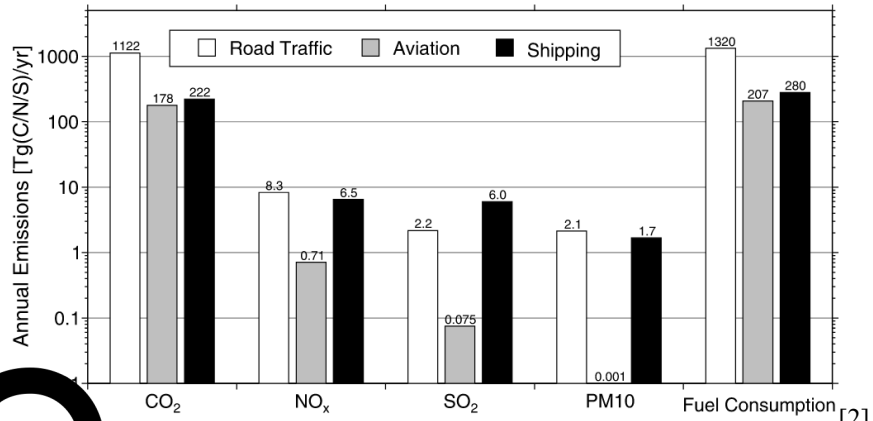
Agenda & Background

- **Background**
- **Experimental setup**
- **Results**
- **Summary & Outlook**

[1]



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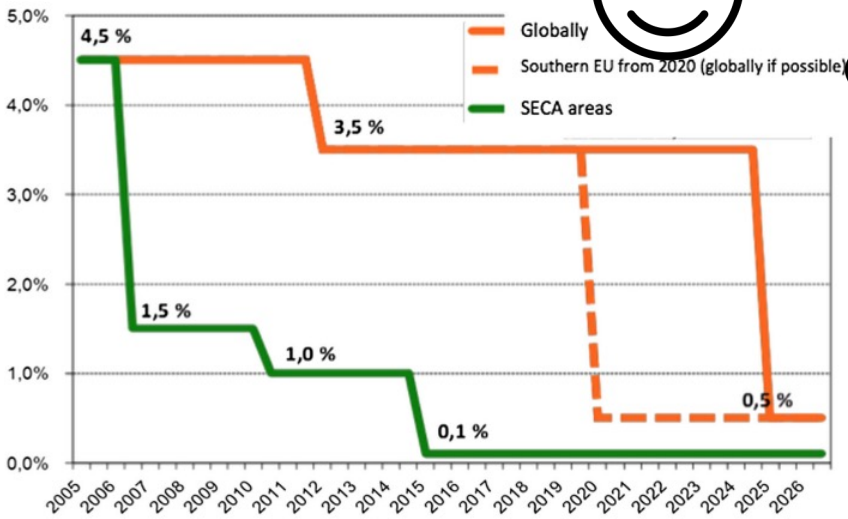

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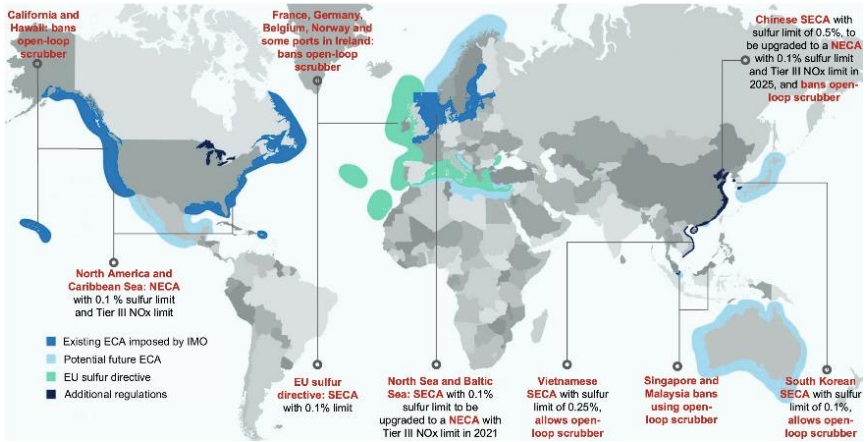


[4]

[1] https://www.klapton.com/publications/new-imo-sulphur-emission-regulation-just-around-the-corner/ [2] Erying et al. *Journal of Geophysical research* V110 D17305 (2005)
[3] Berggvist et al. *Eur. Transp. Res. Rev*. 7:10 (2015) [4] Zhao et al. *Transport Research Part D* V90 102641 (2021)

ECA: Emission Control Area

Background

❖ **Scrubber as abatement system for ship emission**

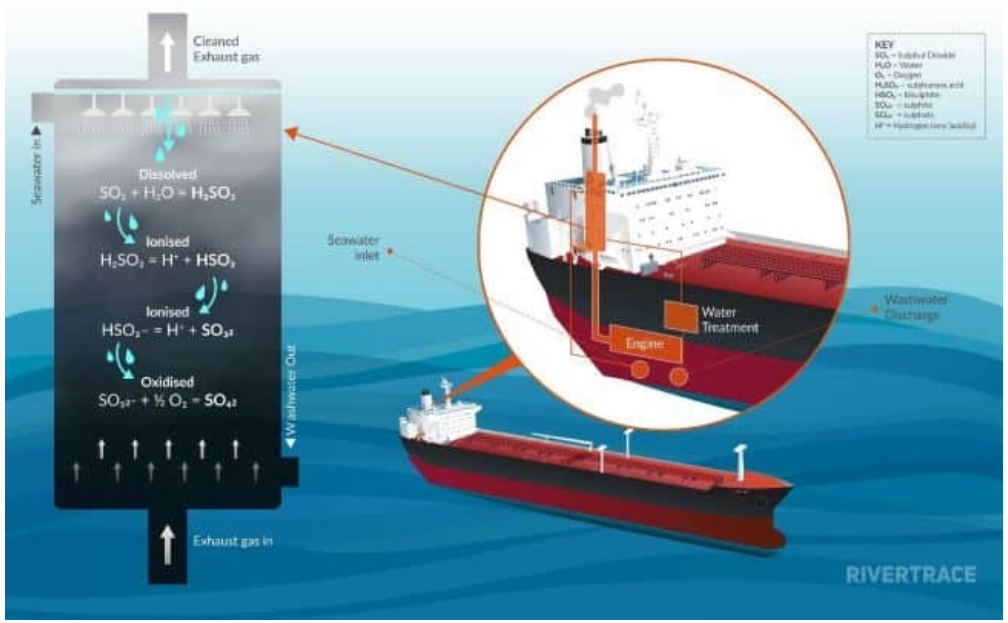
- SO_2 reduction

  SO_2 (g) + H_2O ⇌ H_2SO_3

  H_2SO_3 ⇌ H^+ + HSO_3^-

  HSO_3- ⇌ H^+ + SO_3^{2-}

  $2SO_3^{2-}$ + O2 ⇌ $2SO_4^{2-}$



[5]

- Possible reduction of particulate matter (PM) by Scrubber
  - Size of PM
  - Type of fuel and scrubber
  - Salinity of wash water
  - Sampling methods

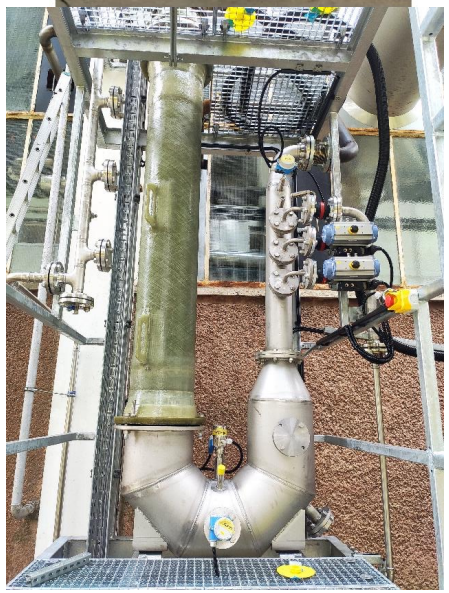
❖ **Objectives:**

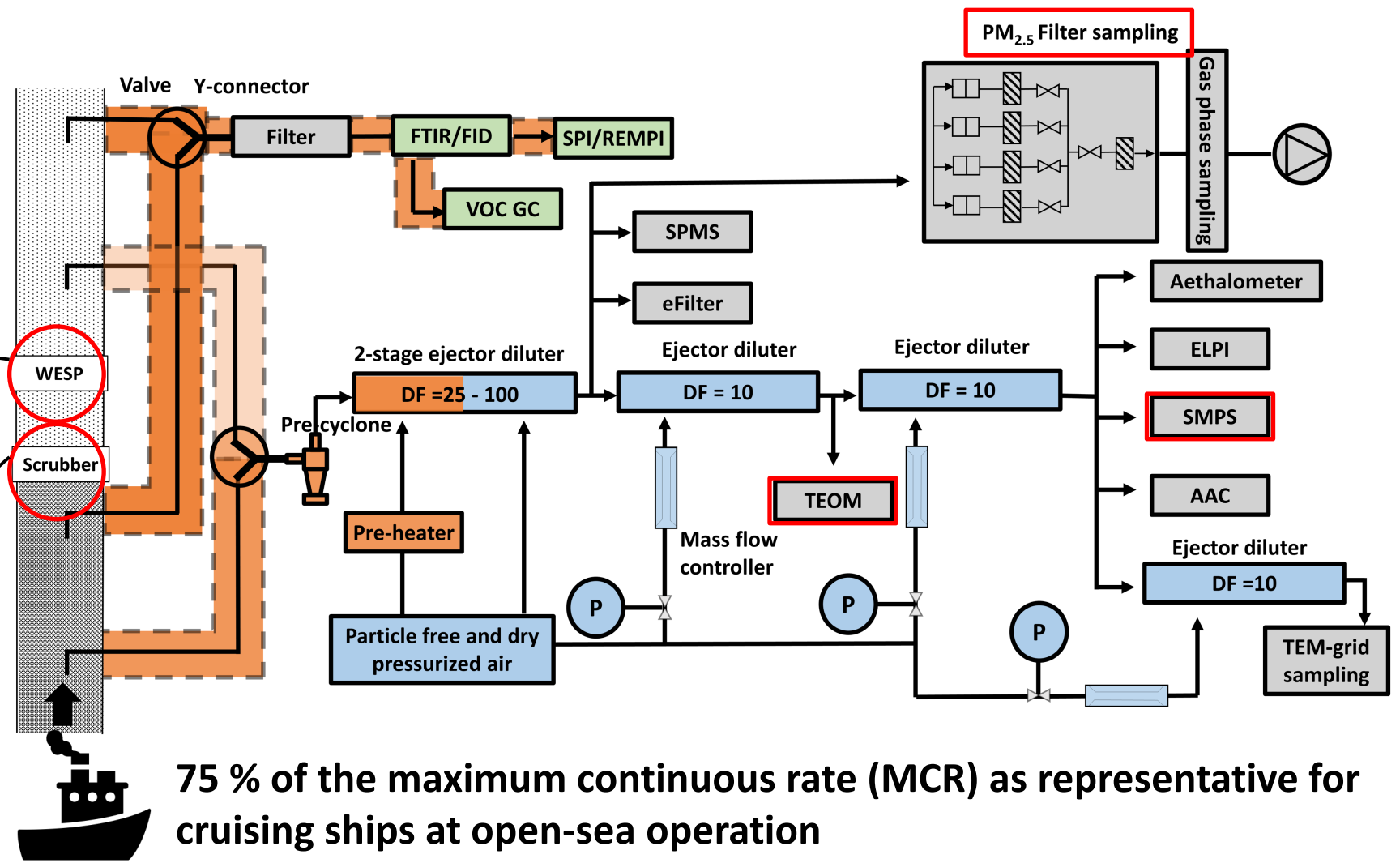
- **Investigation of ship emission from different fuel types (marine gas oil (MGO), heavy fuel oils (HFOs))**
- **Reduction of fine particulate matter ($PM_{2.5}$) regarding number and mass concentration by a wet scrubber**
- **Investigation for further optimization to reduce ship emission**

[5] https://vpoglobal.com/2020/01/16/rivertrace-smart-esm-granted-dnv-gl-statement-of-compliance/

Experimental Setup

[6]





75 % of the maximum continuous rate (MCR) as representative for cruising ships at open-sea operation

WESP: Wet Electrostatic Precipitator; DF: Dilution Factor; SMPS: Scanning Mobility Particle Sizer; TEOM: Tapered Element Oscillating Microbalance

[6] Bologa et al. *IEEE Transactions on Industry Applications* 45 (6) (2009)

Change of particle mass

Total particle mass [mg/kWh]

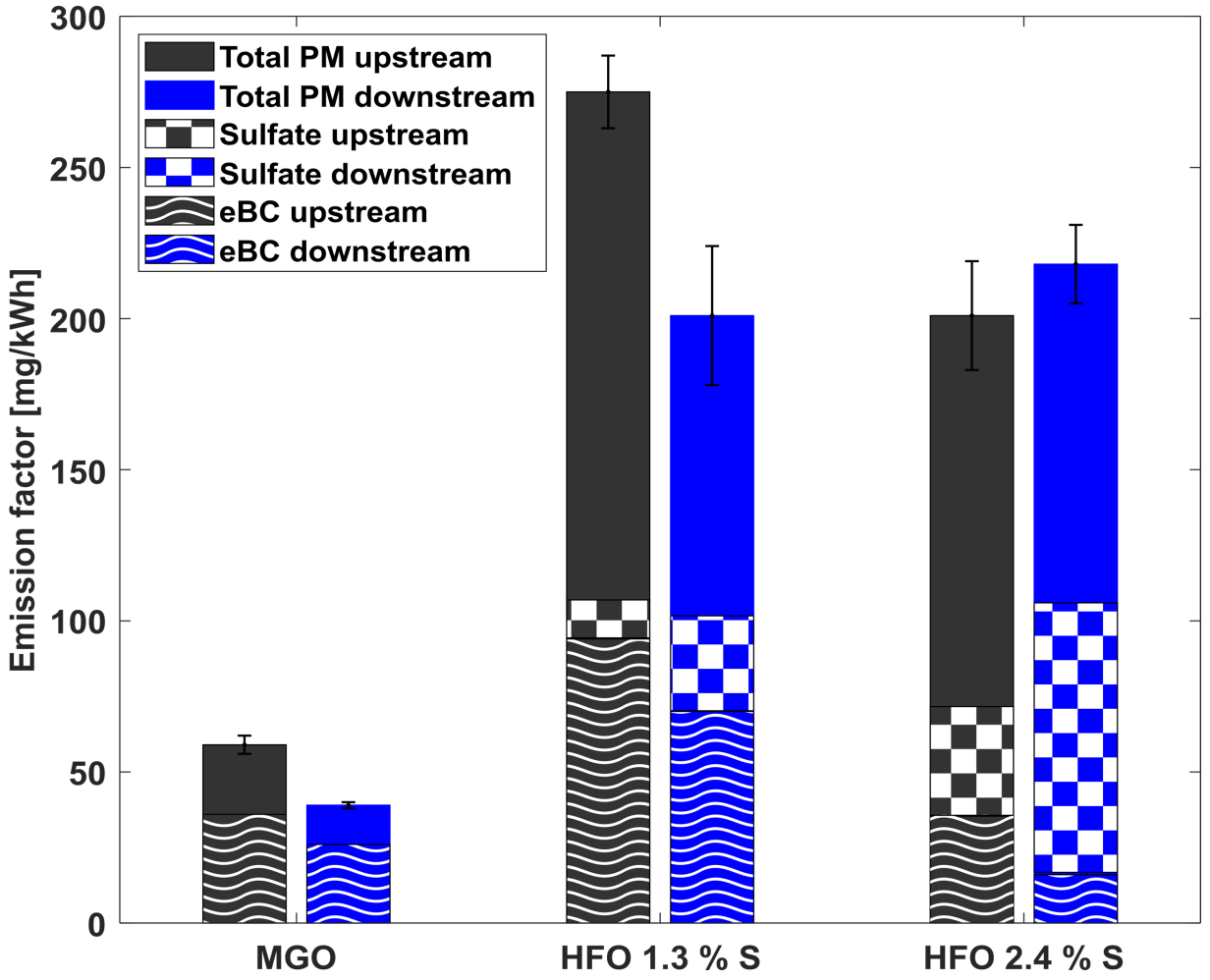
	Upstream	Downstream
MGO	60	39
HFO 1.3 % S	275	200
HFO 2.4 % S	200	218

Sulfur as sulfate [mg/kWh]

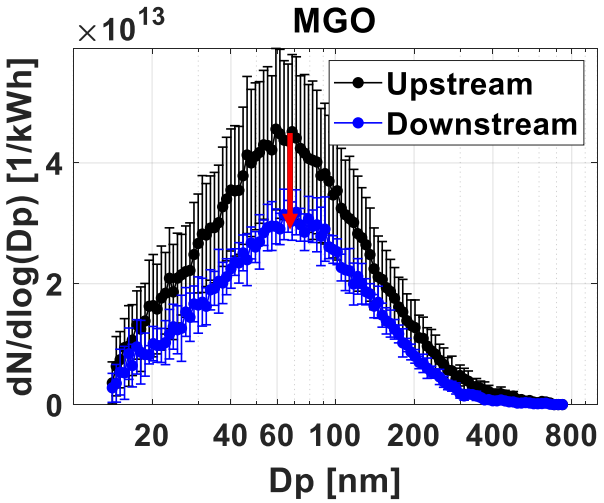
	Upstream	Downstream
MGO	0	0
HFO 1.3 % S	13	31
HFO 2.4 % S	36	89

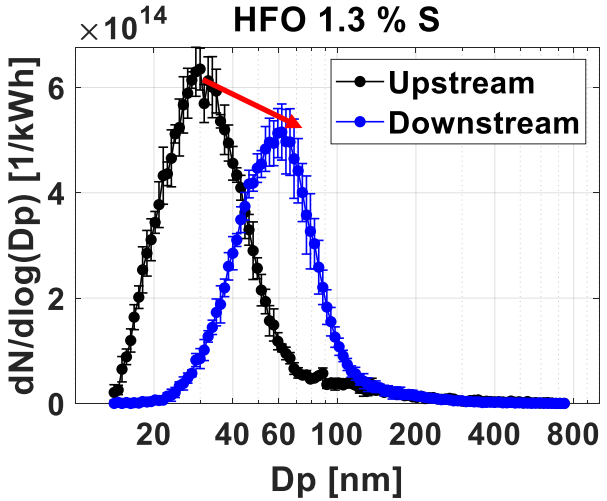
Equivalent Black Carbon [mg/kWh]

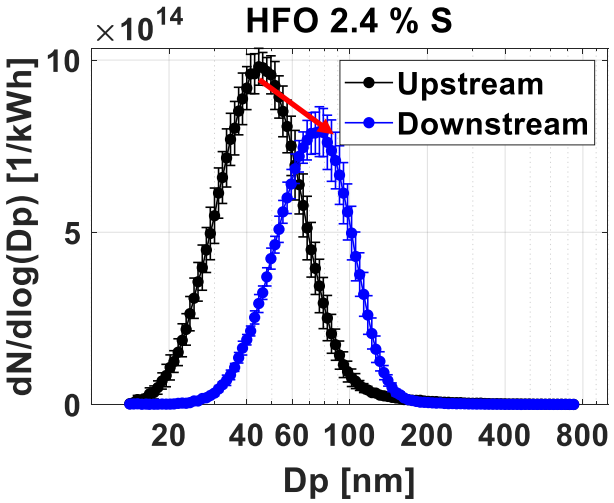
	Upstream	Downstream
MGO	36	26
HFO 1.3 % S	94	70
HFO 2.4 % S	36	16



Change of particle number

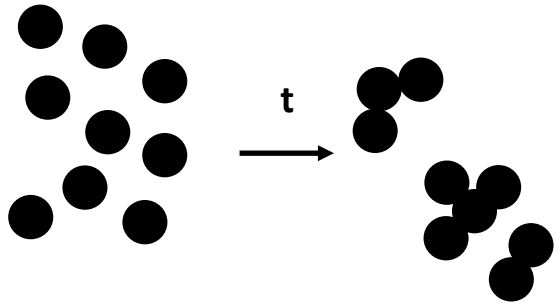


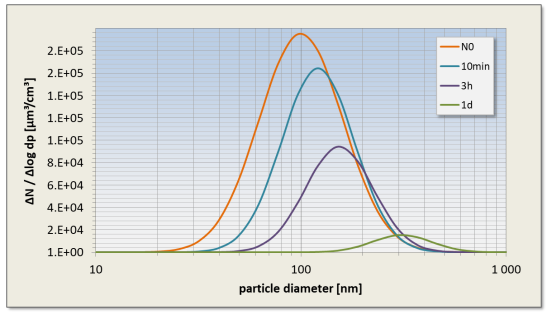




Coagulation process in the scrubber

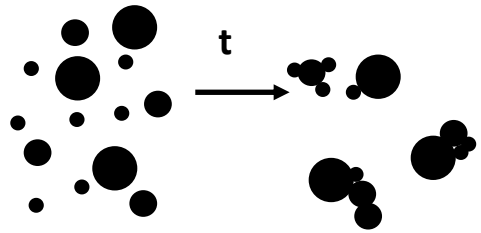
Mono-disperse coagulation





[7]

Poly-disperse coagulation



-> Further reduction of PM concerning particle number and mass needed!

[7] Karg et al. 11th Asian Aerosol Conference (2019)

Particle emission with WESP

Particle size distributions and mass emission factor with additional abatement systems

Contents lists available at ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

Novel wet electrostatic precipitator for collection of fine aerosol [8]

2170 IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 45, NO. 6, NOVEMBER/DECEMBER 2009

Collection of Fine Particles by Novel Wet Electrostatic Precipitator

Andrei Bologa, Hanns-Rudolf Paur, Markus Lehner, Helmut Seifert, Thomas Wäscher, and Klaus Woletz

882 IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 41, NO. 4, JULY/AUGUST 2005

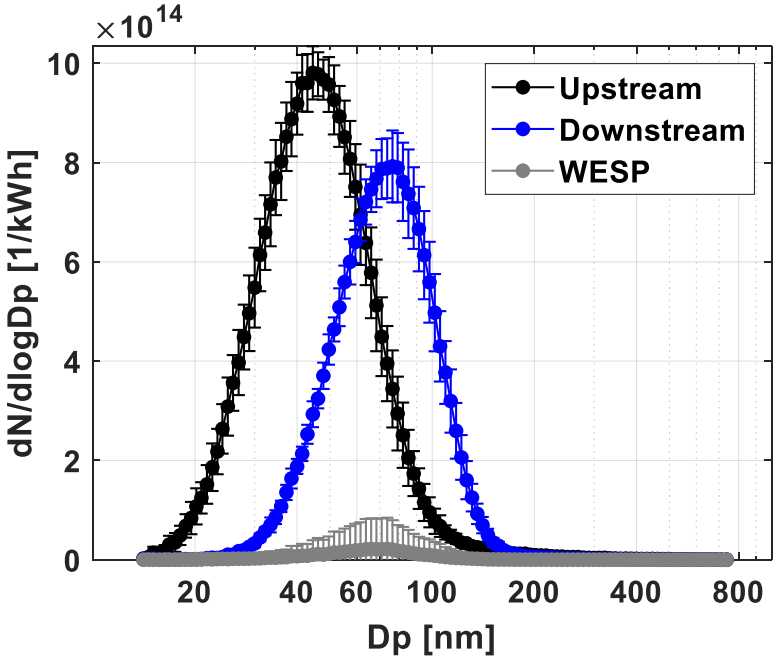
Pilot-Plant Testing of a Novel Electrostatic Collector for Submicrometer Particles [6]

Andrei M. Bologa, Hanns-Rudolf Paur, Helmut Seifert, and Thomas Wäscher

Abstract—A novel electrostatic collector CAROLA (Corona Aerosol Abscheider) for gas cleaning from submicrometer particles is described. The CAROLA concept is based on particle charging by corona discharge and subsequent particle removal in the grounded part of the collector. CAROLA collectors for fine oil mists and for fly ash were tested. The influence of the operation conditions on corona discharge was studied. It is shown that the CAROLA electrostatic collectors have high fractional removal efficiencies (>98% for particles >1 μm and 95%–98% for particles with sizes 0.3-1 μm), low operating voltages (10–20 kV), and low pressure drop (<200 Pa). The collection of charged particles without external electric field and the compact design provide a cost-effective solution for the removal of submicrometer particles from industrial off gases.

Index Terms—Corona discharge, electrostatic precipitator, submicrometer particles.

In this paper, the results of the development of a new cost-effective flue gas cleaning technology for submicrometer particles are presented. The scope is to minimize the investment and operation cost of the electrostatic collector and to simplify the construction of the collector. For this purpose a novel electrostatic collector for submicrometer particles (CAROLA collector) is developed. In the CAROLA, fine particles are charged by the corona discharge and then removed in the grounded part of a field-free collector. The results of the pilot-plant tests of the CAROLA electrostatic collector are discussed. The influence of the operation conditions on the corona discharge is investigated. The particle number concentration and the mass collection efficiency of the pilot unit are determined. [9]

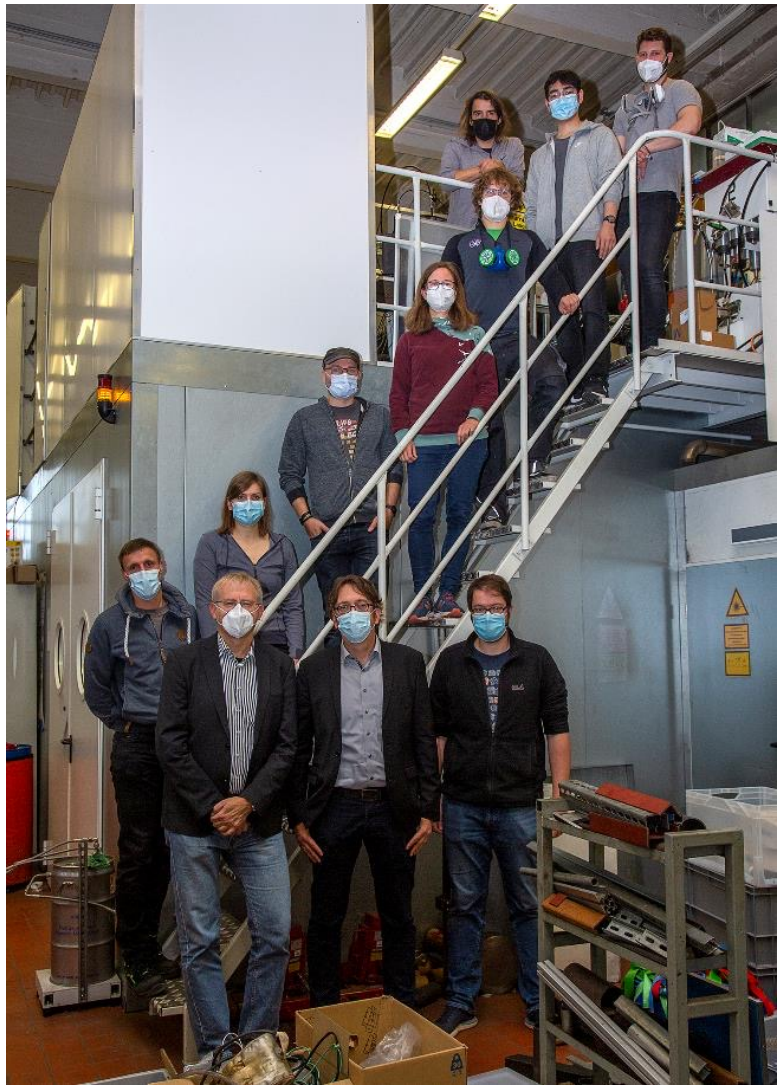


[mg/kWh]	Upstream	Downstream	WESP
HFO 2.4 % S	200	218	< 2

- ❖ **Combining with a wet electrostatic precipitator (WESP)**
- **Reduction of particle number > 98 %**
- **Reduction of particle mass > 99 %**

[8] Bologa et al. *Journal of Electrostatics* 67 150-153 (2009)
[9] Bologa et al. *IEEE Transactions on Industry Applications* 41(4) (2005)

Summary and Outlook



- **Coagulation as one of the main interparticle mechanism in the scrubber**
- **Needs for further reduction of particle number and mass concentration after scrubber**
- **Accomplishment of significant reduction of particle emission by combining the scrubber with WESP**
- **Application of scrubber as pre-conditioner for WESP**
- **Possible application of reduced operation of WESP even for low-sulfur containing fuels at port/berth**

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