Novel electrical charging condensing heat exchanger for particle emission reduction and efficient heat recovery in small boilers

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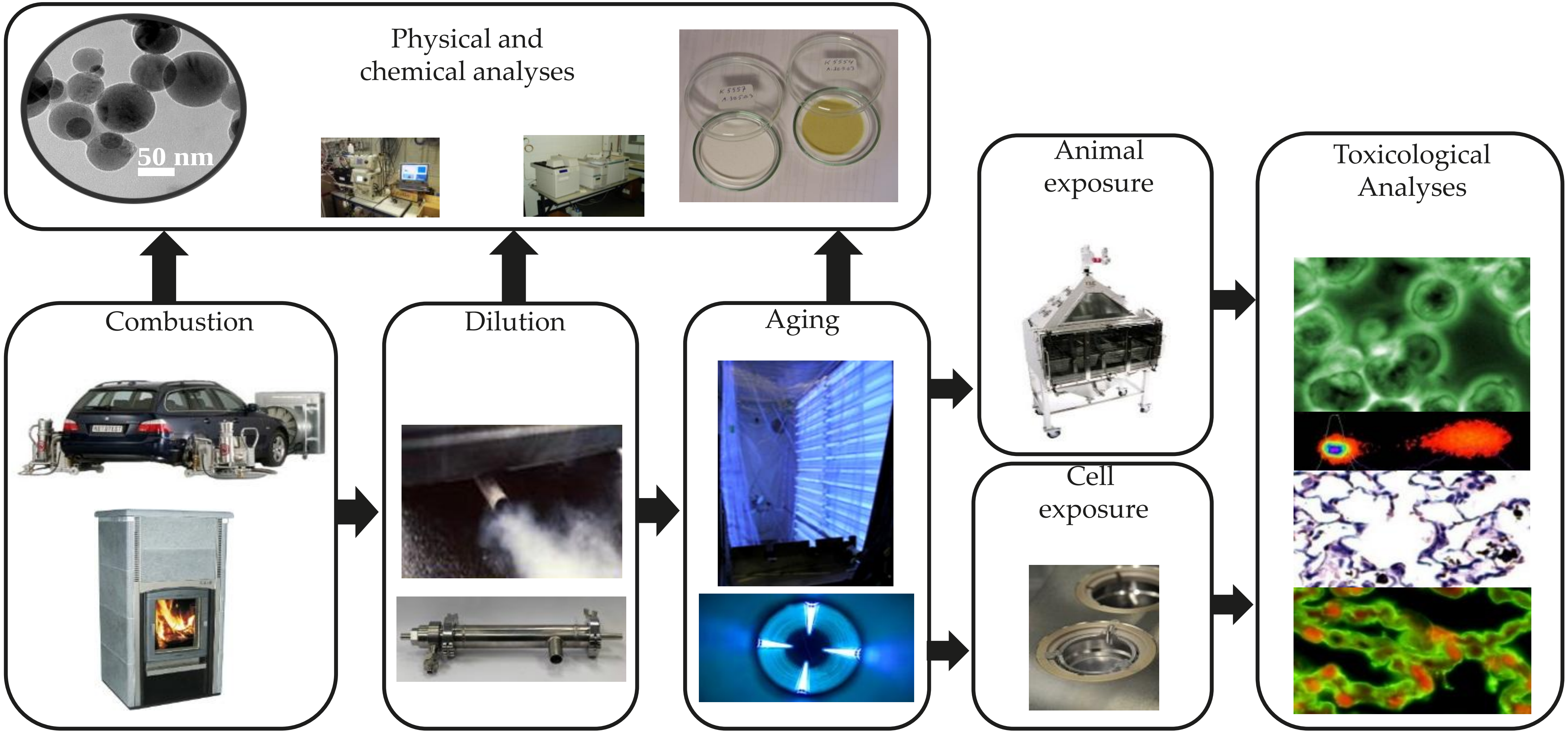
UNIVERSITY OF EASTERN FINLAND

ILMARI - Aerosol physics, chemistry and toxicology research unit

ILMARI research infrastructure offers versatile possibilities for studies on characteristics of emissions and aerosol particles, their atmospheric effects and toxicological properties.



Schema of the ILMARI Research Unit

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- **Background**

There is an obvious need to develop cost-efficient particle emission reduction technologies for small biofuel-fired boilers

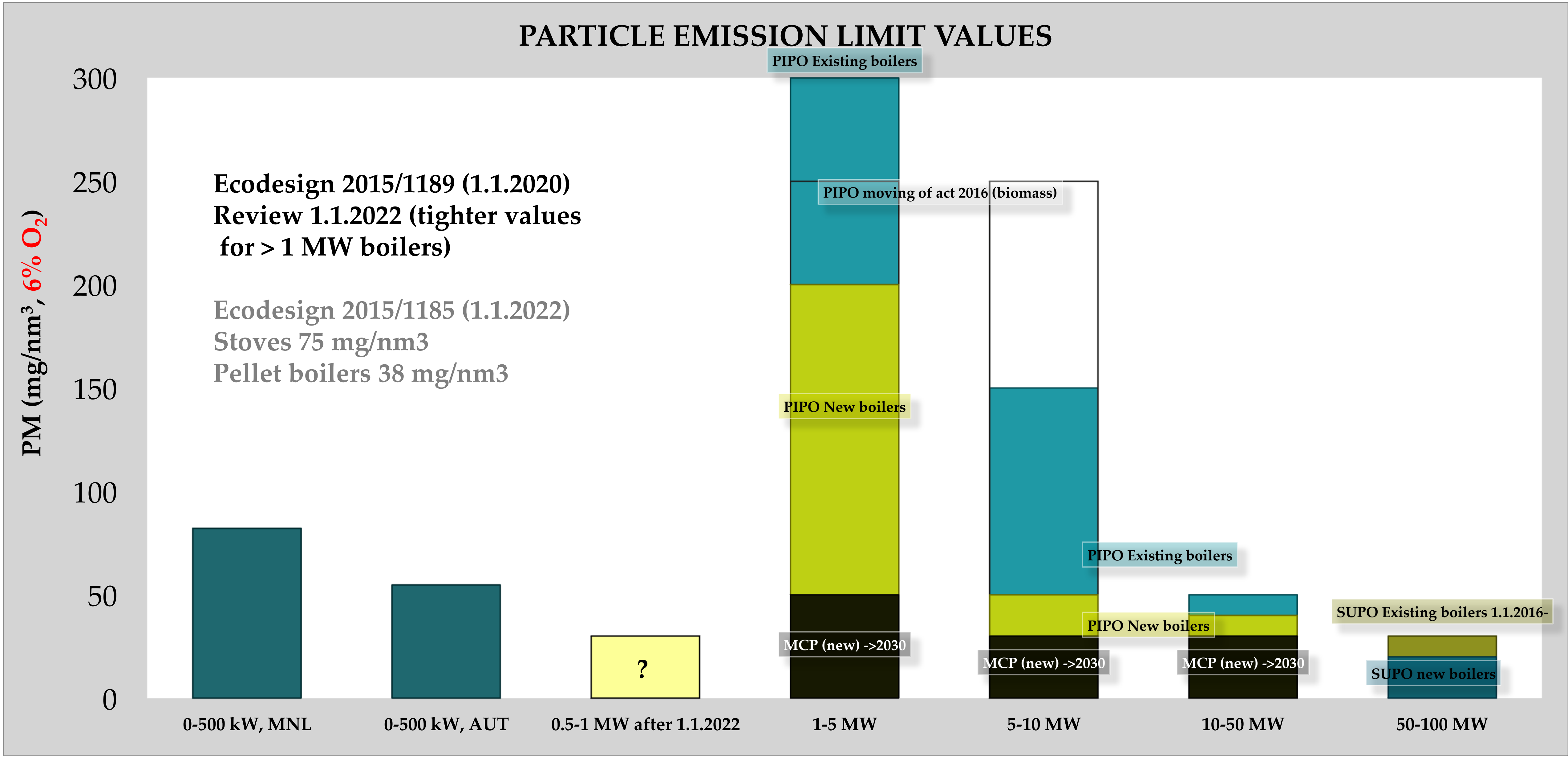
– to reduce adverse health and environmental effects of fine particulate matter and

– to comply the small boilers with the forthcoming EU emission regulation (e.g. Ecodesign directive)

In this collaborative work of UEF&TUT, we demonstrate a novel system for reduction of particle emissions which is based on

– high-temperature electrical charging of particles and

– subsequent collection of particles in a condensing heat exchanger



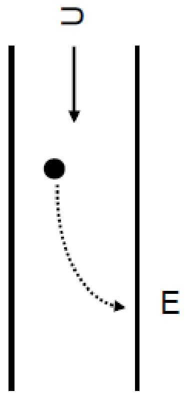
PARTICLE EMISSION LIMIT VALUES
PM (mg/nm3, 6% O2)
300
250
200
150
100
50
0
Ecodesign 2015/1189 (1.1.2020)
Review 1.1.2022 (tighter values
for > 1 MW boilers)
Ecodesign 2015/1185 (1.1.2022)
Stoves 75 mg/nm3
Pellet boilers 38 mg/nm3
PIPO Existing boilers
PIPO moving of act 2016 (biomass)
PIPO New boilers
MCP (new) ->2030
PIPO Existing boilers
PIPO New boilers
MCP (new) ->2030
MCP (new) ->2030
SUPO Existing boilers 1.1.2016-
SUPO new boilers
?
0-500 kW, MNL
0-500 kW, AUT
0.5-1 MW after 1.1.2022
1-5 MW
5-10 MW
10-50 MW
50-100 MW

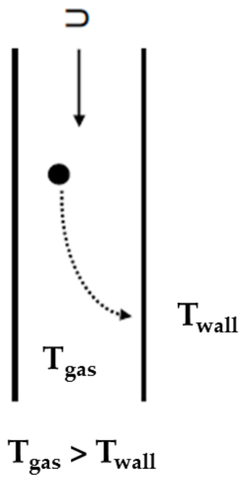
Earlier R&D at UEF on flue gas scrubbers:

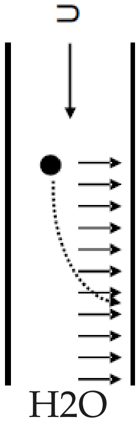
1. Development of condensing heat exchanger / scrubber optimized for fine particle reduction in small biomass-fired boilers:
   - ERA-NET project Future Low Emission Biomass combustion systems (FutureBioTec), 2009-2012
   - Particle reduction of approx 50 % was achieved by optimizing thermophoresis and diffusiophoresis
   - Water spray-based cleaning system was developed for flushing the heat exchanger during operation (e.g. 5 min cycle every 2 hours)
   - Aerosol simulation model was developed for assisting the design of heat exchangers / scrubbers
2. Demonstrating the utilization of condensing scrubber for particle and SO_2 removal from marine engine exhaust
   - EU FP7 Hercules-B project
   - The pilot-scale method (partial exhaust gas flow) was demonstrated at 1640 kW Wärtsilä marine engine
   - The system removed 40-50 % of PM and 60% of SO_2 (via NaOH additives)
3. High-temperature charging of particles upstream of heat exchanger
   - Tested so far in a 40 kW grate combustion reactor fired with wood chips
   - Enhanced the PM collection up to 80%
   - Further optimization on-going within the Pyreus-project (ERDF-funding)

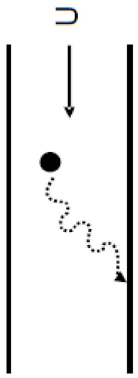
Electrical condensing heat exchanger / scrubber (eCHX)

- The method combines effective particle separation and heat energy recovery (if needed)
- High particle separation efficiency by combining four phenomena:
  - Electrophoretic deposition due to charging of particles
  - Thermophoretic deposition based on high thermal gradient
  - Diffusiophoretic deposition due to water condensation
  - Brownian diffusion (only very small particles affected)









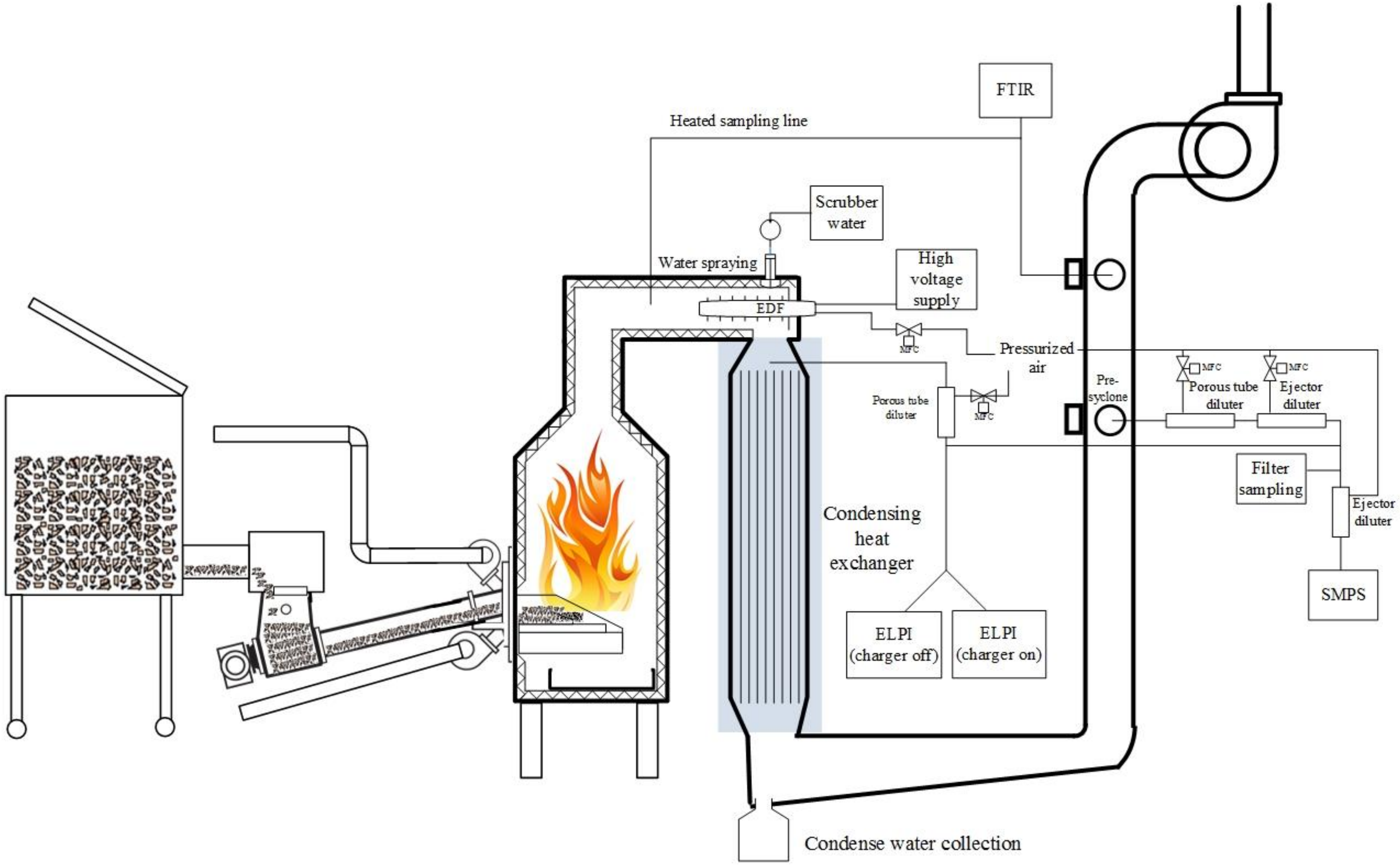
- Condense water film prevents fouling of the heat exchanger
- Additional water spraying system upstream of heat exchanger for moisturing the flue gas
- The spraying system enables various additives (e.g. NaOH) for SO_2 and other gases like VOC removal

Assembly of the electrical charging system upstream of the condensing heat exchanger

There is a dramatic decrease in problems associated with keeping the corona electrode clean, as it operates in clean gas flow.
Changes in the aerosol concentration of the gas flow do not affect the corona's operation. An ESP applying a sonic jet-type charger is a two-stage device; hence, the collection section can also be optimized freely without influencing the charging process.

The principles of the shielded corona charger (SCC) are presented in Laitinen A., Keskinen J. J Electrostat 2016; 83, 1-6 2016; 83, 1-6

- **Laboratory pilot-experiments at 40 kW grate reactor fueled with wood chips**



Experimental

Moving grate combustion reactor was operated at 9 kW_{th}, with wood chips (30% moisture content)

A pilot condensing heat exchanger (CHX) optimized for thermophoretic and diffusiophoretic deposition of fine particles (Grigonyte et al., 2014), was connected to the reactor.

A shielded corona charger was utilized for electrical charging of particles.

Particle emissions were measured with several real-time instruments (SMPS, ELPI, TEOM) and by collecting filter samples

Experimental…

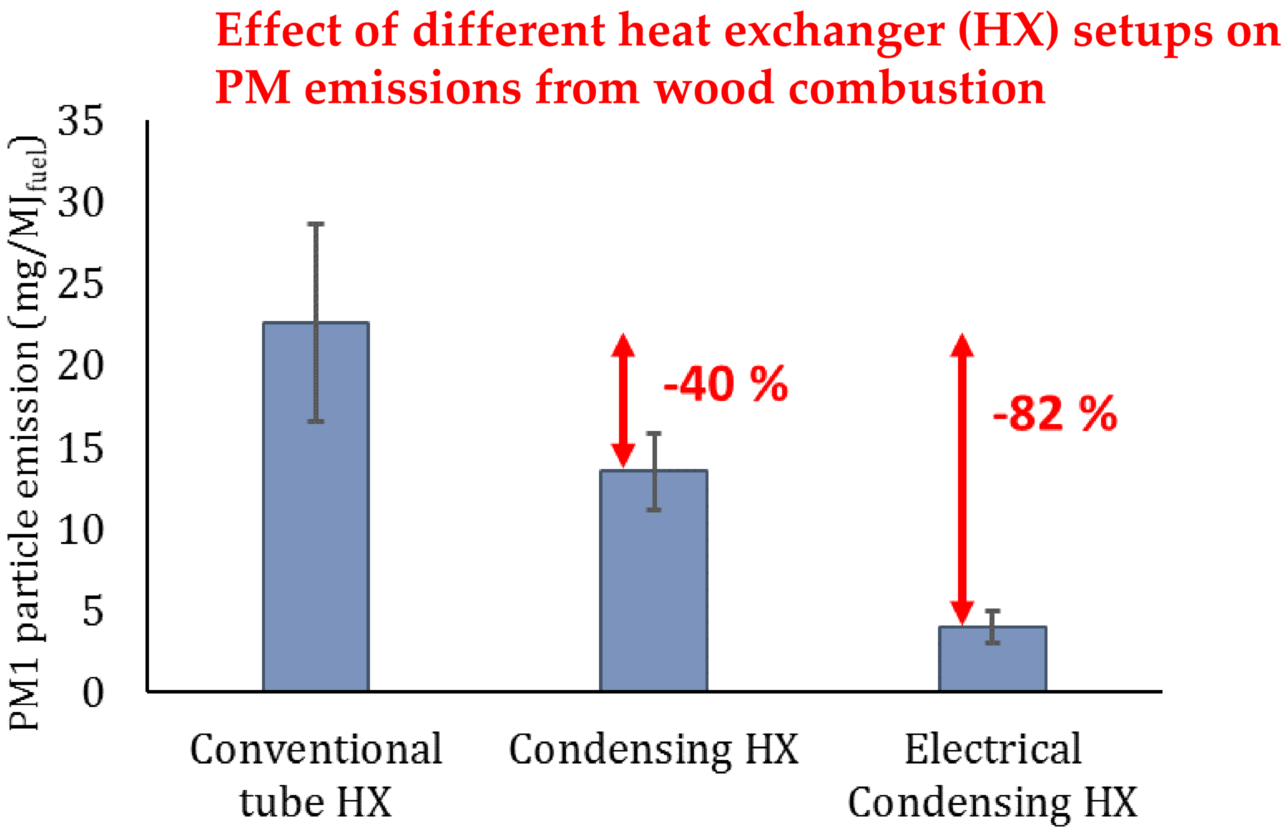
Gas-phase composition was measured with FTIR

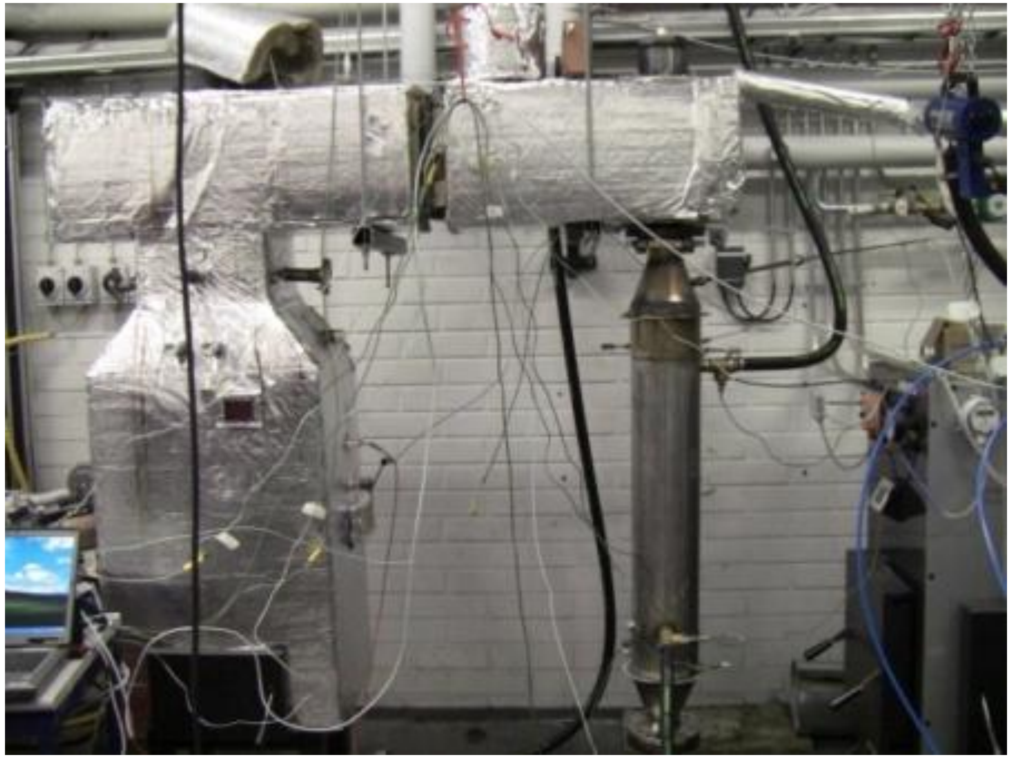
Particulate carbon fractions were analyzed with thermal-optical method (Sunset)

Condense water was collected for further analyses

Reference measurements were carried out with a conventional firetube heat exchanger.

- Laboratory pilot-experiments at grate reactor fueled with wood chips





Results

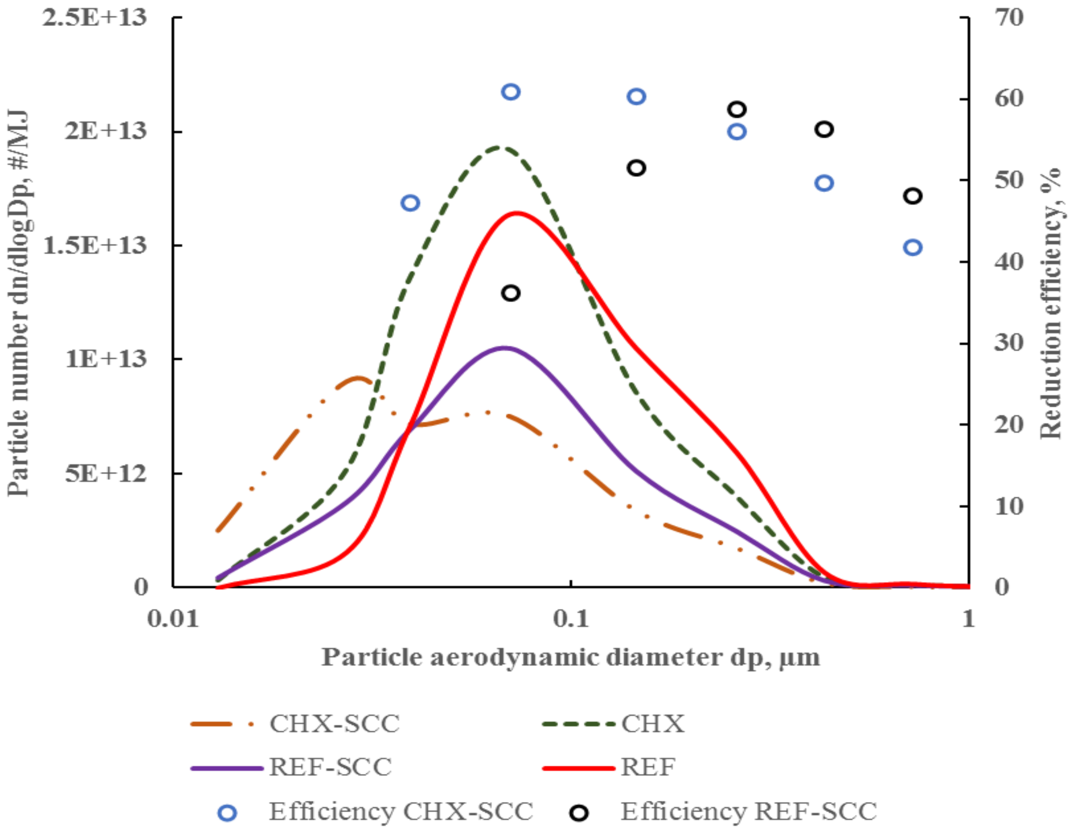
82% fine particle (PM1) reduction efficiency for the electrical charging CHX in comparison to the reference boiler.

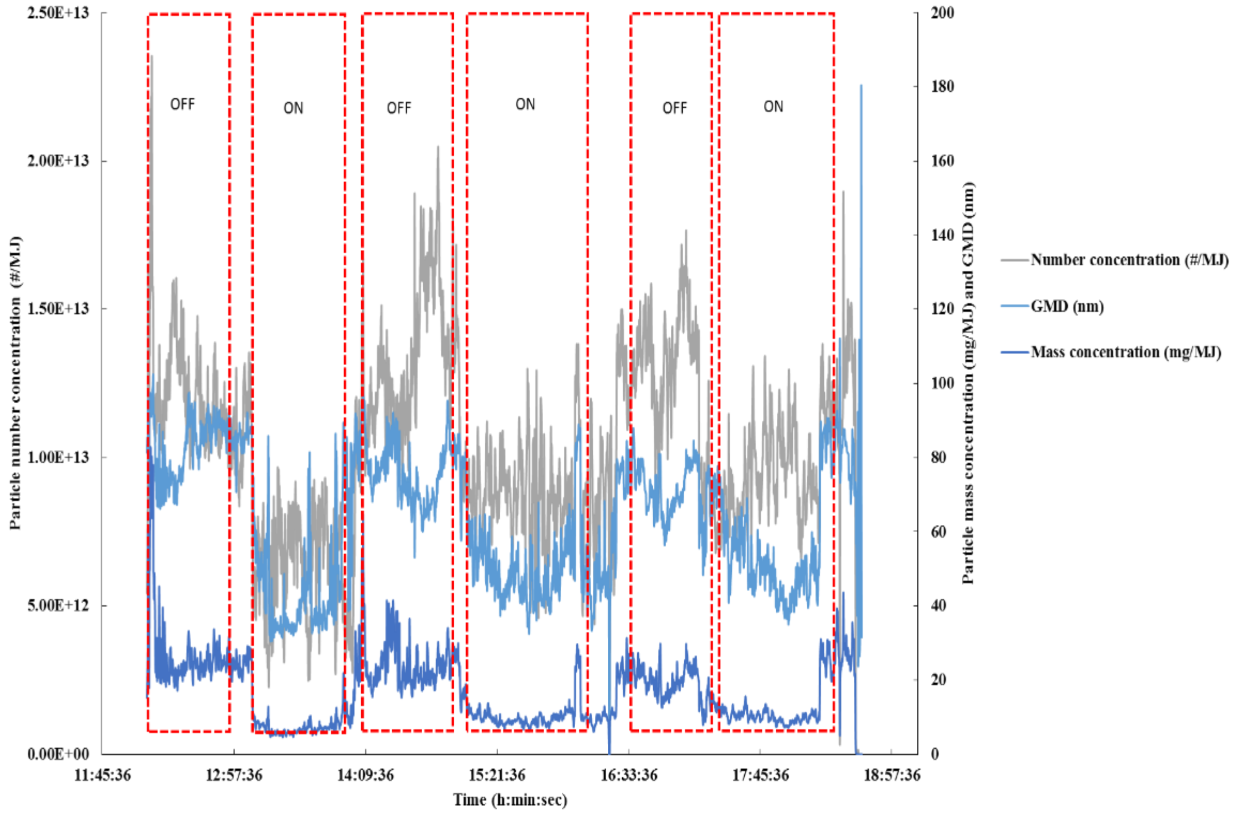
40% PM1 reduction efficiency for the CHX without electrical charging in comparison to the reference boiler.

60% of the flue gas water vapour condensed in CHX, resulting in an overall thermal efficiency of 105%.

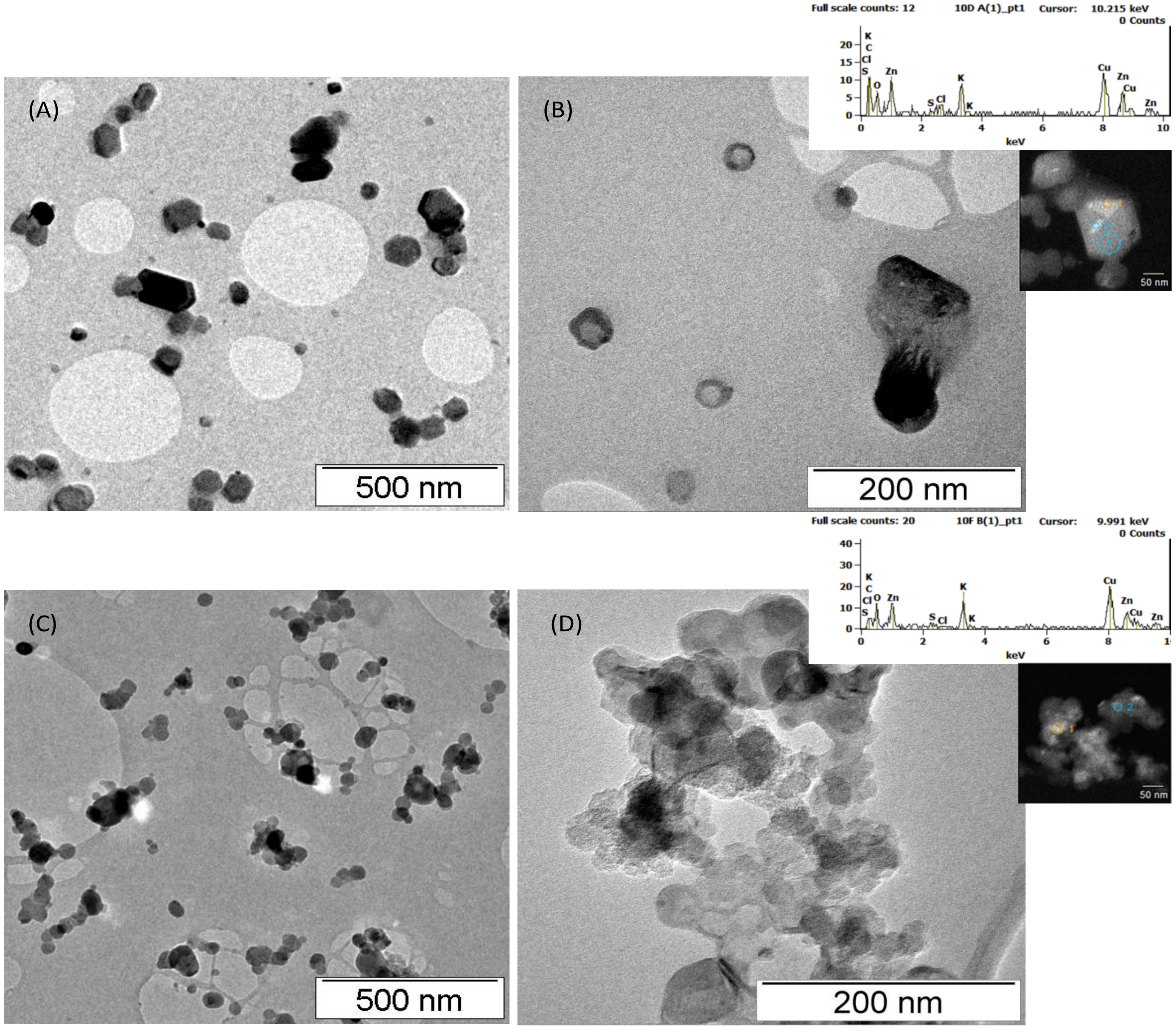
Condense water contained similar ash compounds as the fly ash

Particle size and concentrations ELPI results



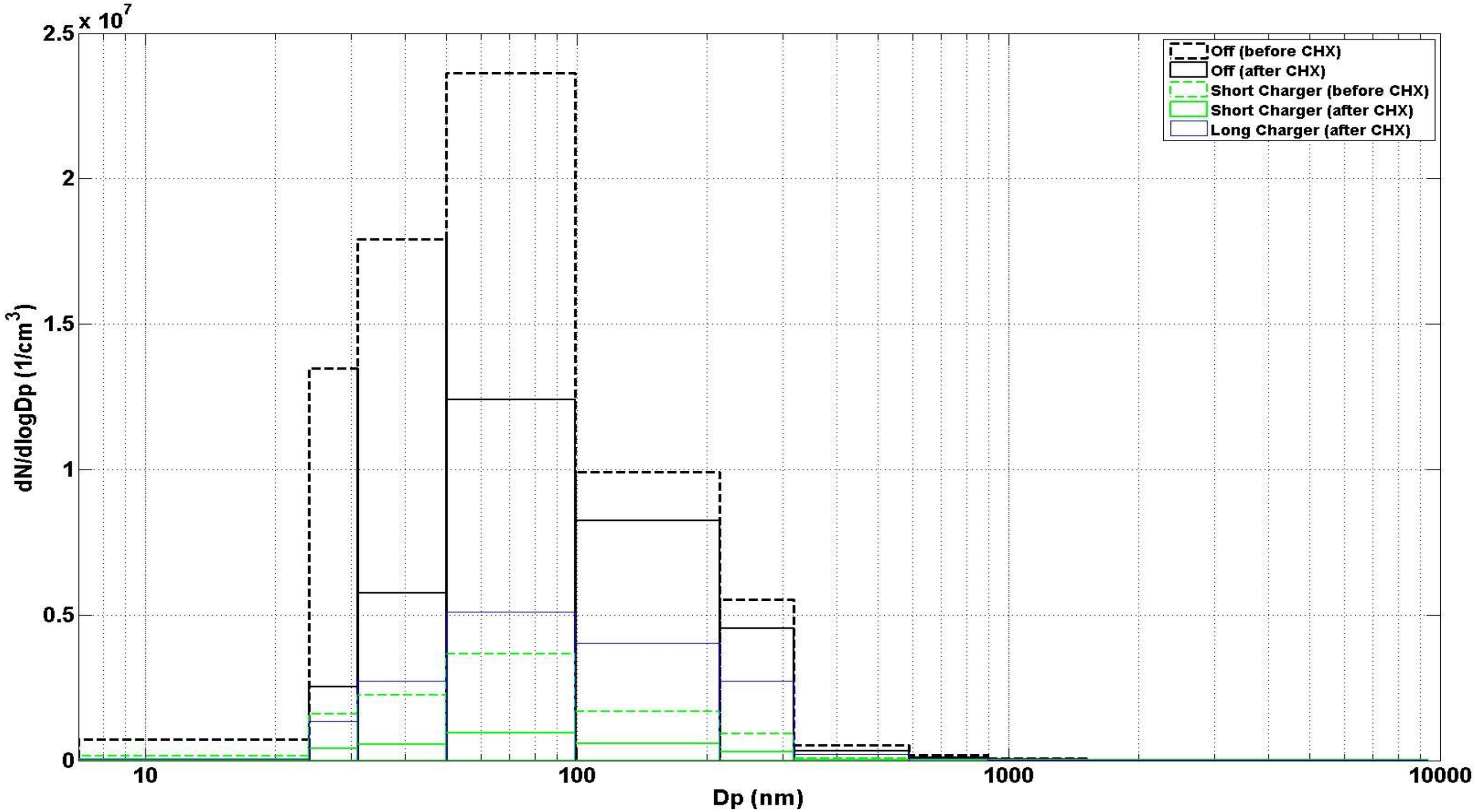


Particle morphology and composition



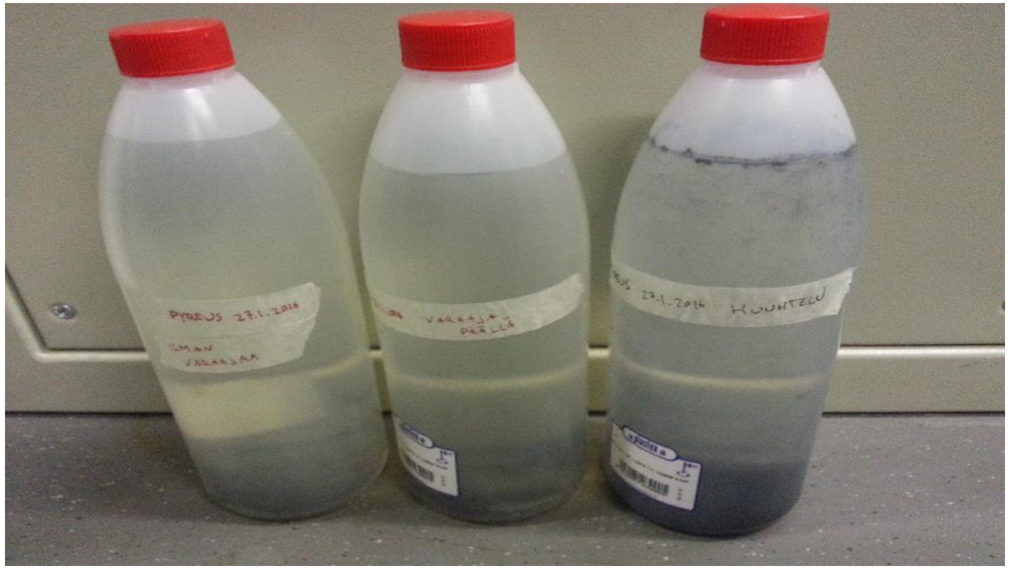
Charger comparison Short (only one needle) and Long (ELPI)

Very recent Preliminary results

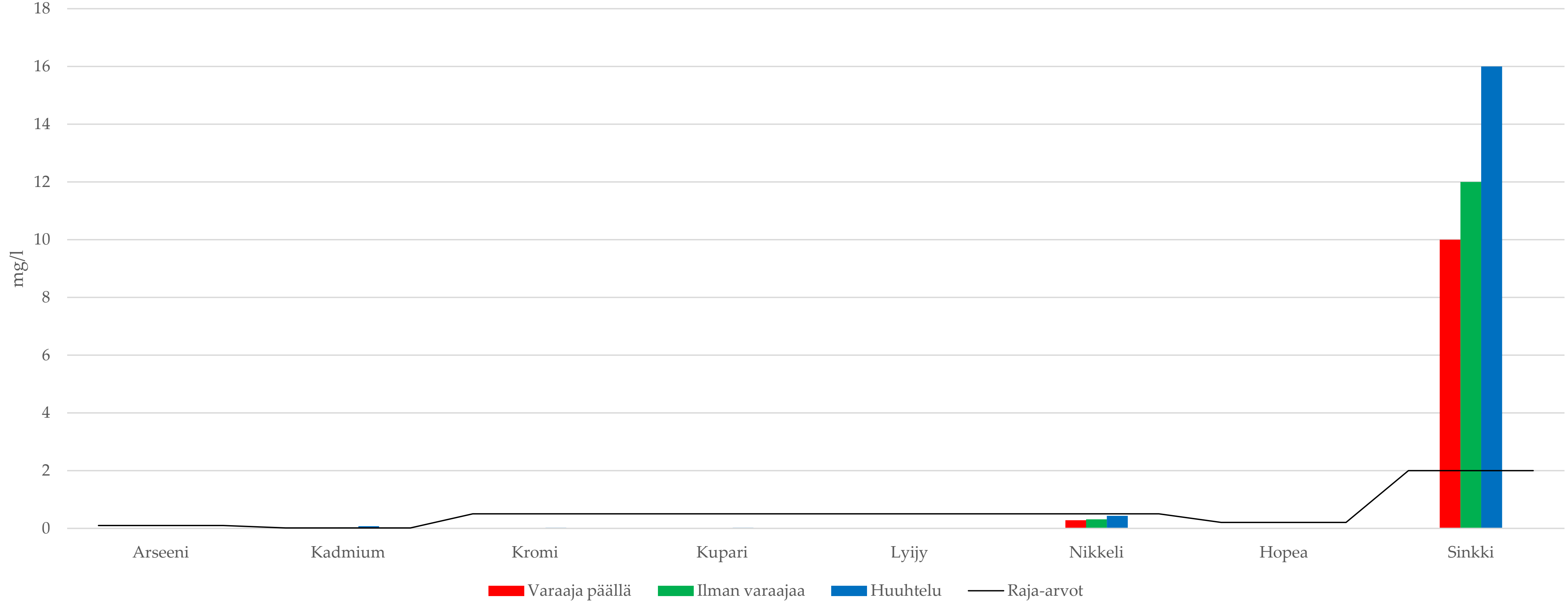


→ By optimising the charger–CHX geometry we are reaching 96% removal efficiency

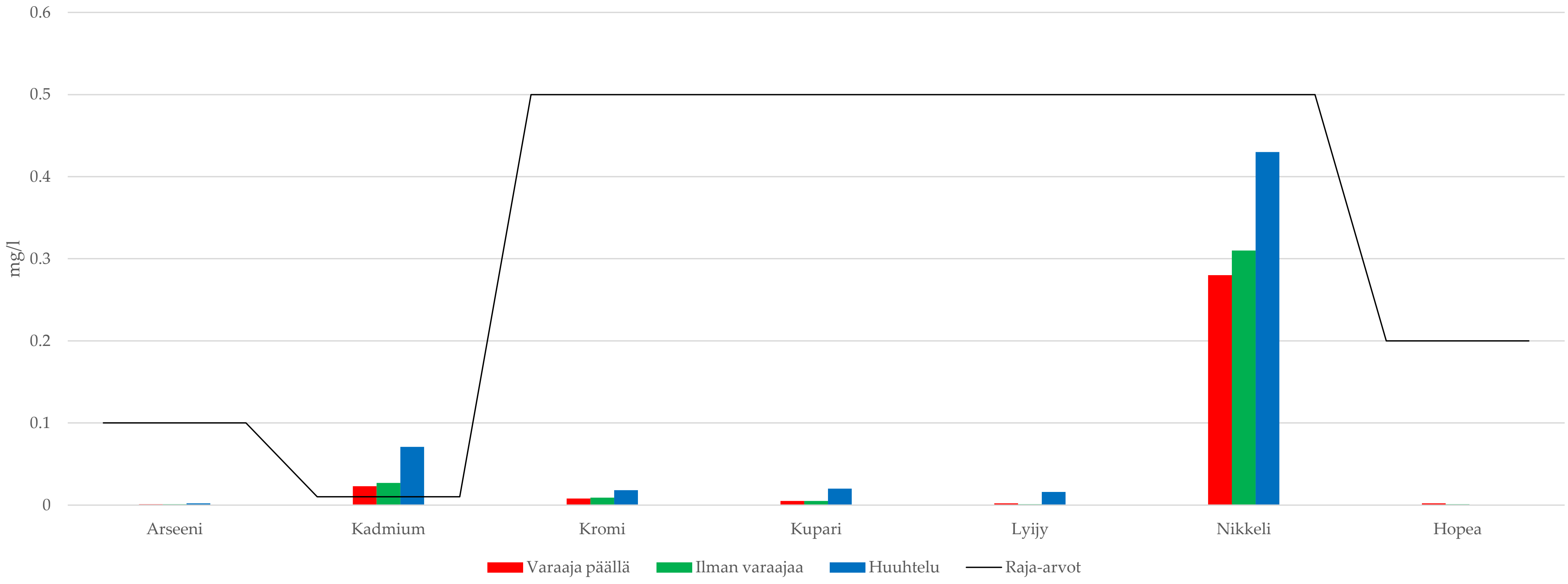
Condense water chemistry



Elemental concentrations compared with limit values



Elemental concentrations compared with limit values



Possible cadmium ja zinc removal methods

- UEF ”Lime” –treatment: 40% recovery efficiency for Cd, 80% for Zn
- ”Biocarbon”: 95% recovery efficiency for Cd

Conclusions

The electrical charging condensing heat exchanger was confirmed to have a high reduction efficiency (> 85%) for fine particles with simultaneous high thermal efficiency under conditions representing automatic biofuel boilers.

The benefits of the system are that it replaces the conventional heat exchanger and ESP in boilers, making it a compact and inexpensive solution, when compared to additional flue gas cleaning devices installed after the boiler.

Acknowledgements

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