Deutsches Biomasseforschungszentrum
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Influence of electrostatic precipitators at small-scale biomass combustion systems on particle number emissions and particle size distributions

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Research Setting

- Results out of two research projects at DBFZ with the aim of emission characterization from small-scale biomass combustion systems
- Gravimetric measurements according to VDI 2066 and particle number measurements with three different types of devices (MPSS, NPET, ELPI®+).
- Before and after the three different precipitators in combination with a wood log stove, a pellet stove and a multi-fuel boiler
- Accompanied by studies on quality assurance and calibration analyses of the measuring devices with aerosol generators and comparison measurements in combustion flue gas

- WePart – Untersuchung der Wirkung bestehender primärer und sekundärer Emissionsminderungstechniken an Feuerungsanlagen zur Partikelzahlminderung abhängig von Brennstoff und Feuerungstechnik (2022-2025)
- LangEFeld – Langzeitmonitoring und Funktionalität von Staubabscheidern für Einzelraumfeuerungen im Feld (2022-2025)

Research Setting

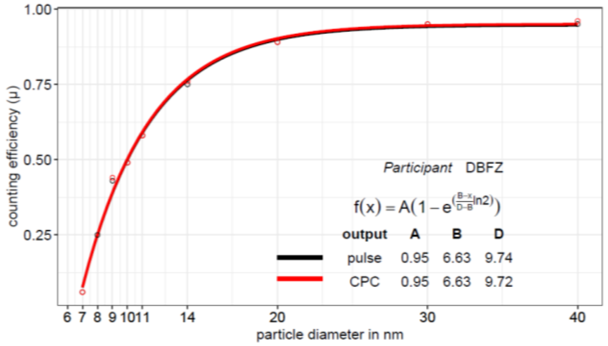
Device name	Measuring principle	Particle size range
MPSS (TROPOS, TSI)	Bipolar neutralization, classification according to electrical mobility, detection with condensation particle counter (DMA/CPC)	8.7 - 835 nm
HC-NPET/NPET (TSI)	Detection with condensation particle counter (CPC), no size classification	23 nm - 1 µm
ELPI®+ (Dekati)	Size classification in cascade impactor after particle charging, electrical detection	6 nm - 10 µm

SMPS = MPSS (Mobility Particle Size Spectrometer)
→ Official term according to CEN directive for atmospheric measurements and ACTRIS (Aerosols, Clouds, and Trace gases Research InfraStructure)

- CPC – Measurement of electrical mobility diameter
- ELPI – Measurement of aerodynamic diameter
- Dilution with eDiluter from Dekati/Envilyse

Comparison and calibration measurements

- Efficiency and evaluation procedure has major impact on results
  - MPSS → Plateau counting efficiency 95 %, below 20 nm drop in efficiency and greater measurement deviation
  - HC-NPET/NPET after maintenance counting efficiency at 69 % (HC-NPET) and 90 % (NPET)
  - Particle density important factor for evaluation of ELPI results → According to Leskinen et al. (2014)[1] particle size for wood combustion in the relevant size range at about 0.2-0.5 g/cm³



➢ Regular comparison and calibration measurements before and after test series are essential

Comparison and calibration measurements

- Results of comparison measurements in combustion flue gas standardized to 13 vol.-% O_2
- Value output of ELPI twice as high as for MPSS → correction with density of 0.5 g/cm³
- NPET/HCNPET lowest measurement vales
- ➢ Deviation for two measuring devices of one type 20 %
- NPET shows 3-10 % lower values as MPSS → particle numbers in the range 6-23 nm (differences of the devices in the detection > 835 nm not signficant)

Measurement results without correction

Batch-No.	HC-NPET	NPET	ELPI_1	ELPI_2	MPSS_1	MPSS_2
1	1.81E+07	2.06E+07	6.22E+07	6.96E+07	2.57E+07	2.21E+07
2	1.97E+07	2.04E+07	4.93E+07	4.93E+07	2.76E+07	2.40E+07
3	1.39E+07	1.42E+07	3.53E+07	4.09E+07	2.19E+07	1.93E+07
4	1.36E+07	1.35E+07	4.32E+07	5.03E+07	2.07E+07	1.79E+07
5	1.10E+07	1.17E+07	2.72E+07	3.06E+07	2.01E+07	1.73E+07

Measurement results with correction of device Plateau efficiency and particle density (ELPI), Efficiency loss below 20 nm and diffusion losses in sampling lines not corrected

Batch-No.	HC-NPET	NPET	ELPI_1	ELPI_2	MPSS_1	MPSS_2
1	2.62E+07	2.28E+07	3.11E+07	3.48E+07	2.68E+07	2.35E+07
2	2.86E+07	2.26E+07	2.46E+07	2.47E+07	2.88E+07	2.55E+07
3	2.02E+07	1.58E+07	1.77E+07	2.05E+07	2.28E+07	2.05E+07
4	1.97E+07	1.50E+07	2.16E+07	2.52E+07	2.15E+07	1.90E+07
5	1.60E+07	1.30E+07	1.36E+07	1.53E+07	2.09E+07	1.84E+07

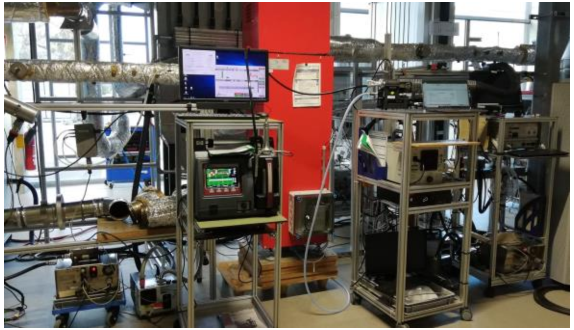
Emission reduction by precipitators

Wood log stove

© DBFZ

© Exodraft

Multifuel boiler



© DBFZ

Pellet boiler

© DBFZ

Emission reduction by precipitators

Wood log stove

- StoveWamsler and Exodraft precipitator
- Beech wood as fuel
- Experiment setting based on DIN SPEC 33999
- Parallel gravimetric measurement and with all particle number measurement devices

Multifuel boiler

- Ökotherm CO UA-E AP 10 with field precipitator type 1
- Fuel wood chips
- Parallel gravimetric measurement
- Alternating measurement by particle number measurement devices before and after the precpitator

Pellet boiler

- ETA Heiztechnik GmbH (type: PelletsUnit 15 kW) with precipitator by Oeko-Solve AG (type: OS-CTRL)
- Wood pellets as fuel
- Parallel gravimetric measurement
- Alternating measurement by particle number measurement devices before and after the precpitator

Particle number reduction by precipitators

- Dummy/Blind seperation efficiency
    - Minor gravimetric PM reduction by precipitator switched off (boilers) or dummy precipitator section (wood log stove) → wood log stove by 2 %, multifuel boiler by 10 % and pellet stove by 0 % (dependent on design of precipitator)
    - Significant particle number reduction for wood log stove by 30-62 %, multifuel boiler by 48-56 % and pellet stove by 61-66 %

Particle number reduction by precipitators

- Electrostatic seperation efficiency – Wood log stove
  - Data corrected with blind efficiency of 2 % for grav. values and 30 % for particle number and standardized to STP and 13 vol.-% O_2
  - Raw particle number concentrations and separation efficiency

Combustion	Temperature	HC-NPET	ELPI	MPSS	Grav.	ΔNPET	ΔELPI	ΔMPSS	Grav.
			#		mg/m³			%	
Good	Low	1.4E+07	4.8E+07	2.2E+07	42	**47**	**48**	**51**	**54**
Good	High	1.7E+07	6.2E+07	4.1E+07	70	**56**	**56**	**51**	**53**
Poor	Low	2.4E+07	1.1E+08	3.4E+07	233	**42**	**46**	**43**	**42**
Poor	High	5.6E+07	2.7E+08	2.5E+08	645	**44**	**43**	**38**	**56**
Poor	Low	1.8E+07	6.7E+07	2.7E+07	127	**45**	**43**	**44**	**51**

➢ Separation efficiencies comparable for all particle number measuring devices

Particle number reduction by precipitators

- Electrostatic seperation efficiency
  - Multifuel boiler (raw concentration and efficiency corrected with blind efficiency of 10 % for grav. values and 52 % for particle number, during continuous operation)

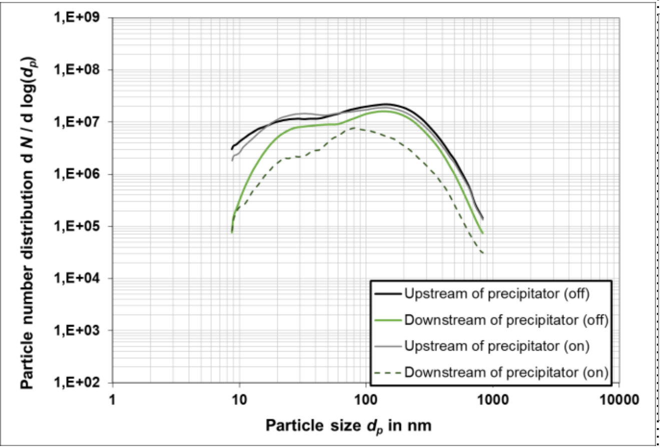
HC-NPET	ELPI	MPSS	Grav.	ΔNPET	ΔELPI	ΔMPSS	Grav.
	#		mg/m³			%	
4.7E+07	5.1E+07	4.1E+07	47	46	43	44	53

  - Pellet Boiler (raw concentration and efficiency corrected with blind efficiency of 63 % for particle number, during continuous operation)

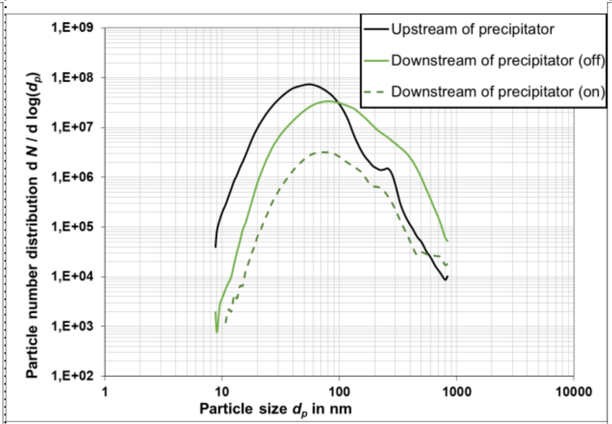
HC-NPET	ELPI	MPSS	Grav.	ΔNPET	ΔELPI	ΔMPSS	Grav.
	#		mg/m³			%	
5.2E+07	7.8E+07	6.3E+07	16	35	35	32	94

Change of the particle size distribution

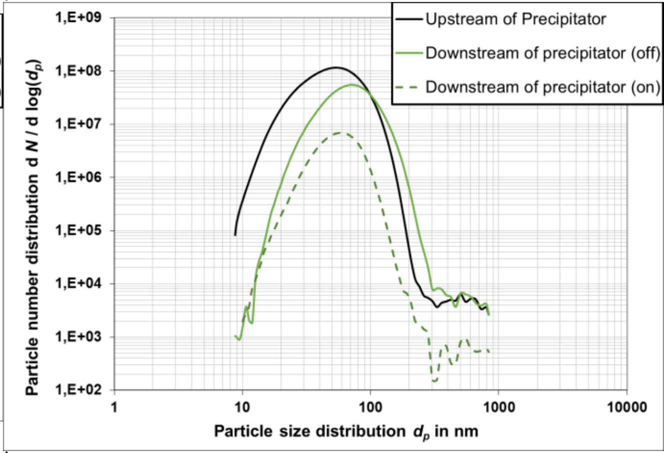
Wood log stove



Multifuel boiler



Pellet boiler



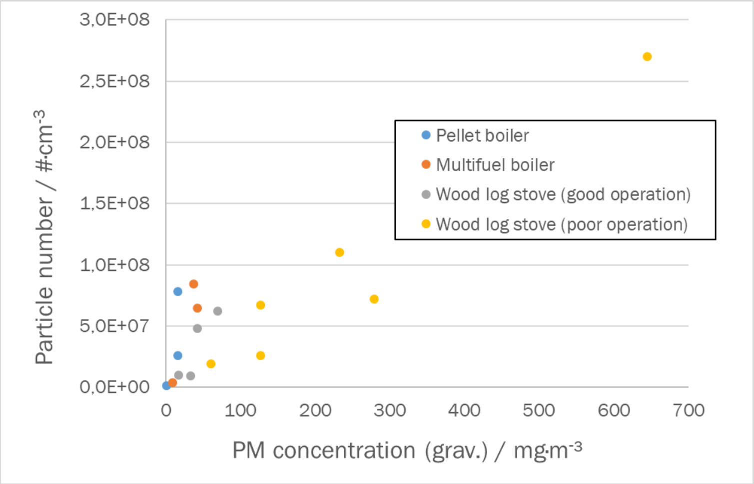
- Data of MPSS devices

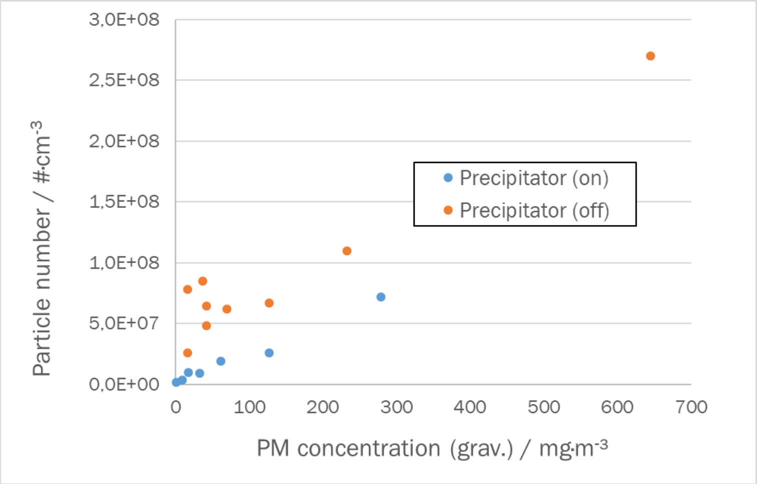
Change of the particle size distribution

- Change of particle size distribution
    - Shift in particle size distribution during flow through the electrostatic precipitator (without electrostatic charging) - particles smaller than 100 nm decrease; particles larger than 100 nm increase in size → agglomeration, coagulation
    - Particles < 100 nm are reduced by approx. 1-2 orders of magnitude by electrostatic precipitators
    - Partially increase of particles > 600 nm by electrostatic (visible by ELPI measurements) → promotion of agglomeration or also particle discharge possible

Particle number concentration vs. gravimetric measurement

- General trend - increase of grav. concentration also increase of particle number
- Partly large differences of the change





- Differences in particle size and type during good an poor combustion → more data and analysis with conclusions on particle composition and size distribution required

Conclusion / Further investigations

- Significant reduction of ultrafine particles observed via electrostatic precipitators
- Reduction of particles passing the precipitators not solely due to electrostatic separation, but also agglomeration, coagulation (condensation effects also possible)
- Influences on the results
  - Precipitator design and size
  - Particle concentration and flue gas composition
- Framework conditions (measurement setup, evaluation procedure) crucial for results → comprehensible results for separation efficiency for different used measurement devices
- Determination of defined particle number concentration for evaluation of combustion quality is more challenging → evaluation solely based on particle number difficult (combination with grav. measurement necessary)
- Further investigations – Comparison of results with data from already available mobile devices for particle number measurement

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