## Influence of gas distribution, field velocity and power supply technique for small scale industrial ESP's

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## 1 Abstract

In this work the influence of gas distribution and field velocity on the electrostatic precipitator (ESP) separation efficiency when using either a conventional T/R-set or a High-Frequency power supply was investigated. The tests where focused on small scale industrial ESP's for biomass combustion systems in the range of 300 kW to 2 MW thermal power.

A small scale industrial ESP which could be equipped with different perforated screen combinations in the inlet section was used to investigate the influence of two different power supply techniques on the separation efficiency when using different gas distribution systems and altering gas velocity within the electrical field of an ESP.

## 2 Introduction

Much work was done on the gas flow regime within electrostatic precipitators the last years; a good overview is given in [1]. Newer papers including CFD simulations can be found in [2]. Basically, for good precipitation results the primary crude gas flow should be distributed as homogenous as possible within the electrode system of the ESP according to standards like IGCI EP-7 [3] or VDI 3678 [4]. For some applications good results were obtained with skewed gas flow due to inhomogeneous dust concentrations across the inlet section of the ESP [5].

Anyway, crude gas flow has to be distributed via guiding- or baffle plates or perforated screens in the inlet section of the ESP. When using perforated screens the distribution behavior can be influenced via altering screen porosity.

The crude gas flow (primary flow) inside the electric field gets furthermore influenced by a secondary flow referred to as electric wind. Thus actual flow regime within an industrial ESP is a combination of primary and secondary gas flow which is called electrohydrodynamic (EHD) flow. Secondary flow depends on current strength which may change when using different power supplies.

For smaller ESP's also bypass flows in the top and bottom region of the electric field may play a significant role. Summing up, to investigate the gas flow regime within a small industrial ESP the following tests should be performed:

- Altering primary gas flow velocity
- Altering primary gas flow distribution by modifying gas flow distribution devices
- Sealing top and bottom zones and ash hopper of the ESP
- Using different power supplies to power the ESP

## 3 Motivation

#### 3.1 Influence of gas distribution

When designing ESPs for industrial applications e. g. power plant or cement industry application, nowadays Computational Fluid Dynamic (CFD) simulation is used as a state-ofthe-art tool to optimize gas flow distribution upstream and within the ESP. Simulation of total particle precipitation process with high accuracy, including primary and secondary flow, particle migration behaviour within the electric field, precipitation of particles at the collecting electrode and reentrainment phenomena seems to be too complex even for smaller industrial ESP's.

Hence, in this work only the primary gas flow within the ESP was simulated via CFD, separation efficiency was determined by means of a laboratory setup and measurements. Most of the previous work to investigate the influence of gas distribution on separation efficiency was done with regards to large ESP's.

The influence of the top zone between ESP roof and discharge electrodes (DE), the bottom zone between collecting electrodes (CE) and DE, respectively, were not taken into consideration. Some results of the influence of gas distribution for small ESP's were already presented in [6] whereas the influence of top and bottom zone could only be assumed. In this work also those top and bottom zone effects, noticeably for smaller ESP applications, will be discussed.

#### 3.2 Influence of power supply

Using High Frequency (HF) power supplies instead of conventional T/R sets leads to higher voltage and current values for same gas conditions and electrode arrangements as investigated in previous works [7] [8]. Thus the ratio of primary to secondary flow within the ESP is modified when changing the power supply.

#### 3.3 Aim of this work

The aim of this work now was to investigate the influence of

- perforated screen combinations with different porosities (β1 – β5) on primary gas velocity distribution
- those different perforated screen combinations on ESP separation efficiency
- average primary gas velocity on ESP separation efficiency
- influence of top and bottom zones on ESP separation efficiency
- the influence of different power supply techniques on ESP separation efficiency for the above mentioned parameter variations

## 4 Experimental setup

A small industrial ESP was set up at a laboratory as shown in Fig. 4-1. Air was circulated via a fan across a heating system to maintain gas temperature and furthermore through a highspeed nozzle where biomass ash was redispersed. The gas then entered the ESP which was powered either with a conventional T/R set or a High-Frequency power supply, also referred to as Switch Mode Power Supply (SMPS). A High-Voltage splitter switch was used to change the ESP power supply within seconds.

Downstream the ESP a fabric filter was installed as a back-up filter to collect remaining particles after the ESP. For all tests 150 m<sup>3</sup>/h of circulated gas was substituted with fresh air which was heated up and sucked through a vaporizer to maintain constant gas humidity.

All process parameters except volume flow were kept constant for all tests as shown in Tab. 4-1. The specifications of the different power supplies can be found in Tab. 4-2.

Both power supplies were operated in automatic mode; the control parameters were set to sparking rates of about 4 sparks/minute.



Fig. 4-1: Simplified test setup with main components

gas temperature	100°C ±4K
water dewpoint	30°C ±1K
inlet dust concentration	600 mg/m <sup>3</sup> ±15%
volume flow	2.000, 4.000, 5.000, 6.700, 8.000 m³/h ±2%

Tab. 4-1: Experimental process parameters

	50Hz T/R-set	HF power supply
current rating	200 mA	250 mA
voltage rating	70 kV <sub>peak</sub> /50 kV <sub>ar</sub>	120 kV
switching frequency	50 Hz	>20 kHz
voltage ripple	~30%	< 3%

Tab. 4-2: Power supply specifications

Biomass ash from a 30 *MW* power plant ESP was used as test dust. The measured crude gas particle number concentration distribution is given in Fig. 4-2.



Fig. 4-2: Crude gas particle number concentration

The ESP used for the tests was a standard type with 300 *mm* spacing, typically applied at biomass combustion plants with about 1 *MW* thermal power.

Two screens at the crude gas duct (screen 1 and 2) were arranged in series to distribute the incoming crude gas across the electrode zone of the ESP. The outlet screen was not changed because of less influence for gas distribution upstream the screen [9].

The porosity  $\epsilon$  of the used perforated screens was calculated as given in Eq. 4-1.

$$\varepsilon = \frac{A_{per}}{A_{total}} = \frac{n * \frac{d^2 * \pi}{4}}{l * b}$$
Eq. 4-1  
n...... hole quantity  
d...... hole diameter  
l...... perforated plate length  
b....... perforated plate width

To affect the gas velocity distribution within the ESP different perforated screen combinations

were used at the inlet duct but were not optimized for this particular case. The combinations are given in Tab. 4-3.

	Lochblech 1	Lochblech 2
β1	Ø36/0.4	Ø36/0.3
β2	Ø41/0.5	Ø41/0.44
β3	Ø41/0.5	Ø47/0.52
β4	Ø41/0.5	none
β5	Leitbleche	Ø47/0.52

Tab. 4-3: Gas distribution setups;

hole diameter [mm] and porosity  $\epsilon$ 

In Fig. 4-3 the 3D-CFD model profile with indicated positions of the perforated screens for gas distribution is shown. Also the position of the cross-section where the velocity values for gas distribution calculations were taken from is indicated.



Fig. 4-3: Simplified test setup with main components

To determine the influence of the top- and bottom zone on separation efficiency as indicated in Fig. 4-4 sealings were applied below the collecting electrodes (CE sealing) or above and below the discharge electrodes (DE sealings).



Fig. 4-4: ESP fixtures and top- and bottom zone with sealing positions

So the influence of

- gas flow and potential whirls between ash hopper, baffle plates and precipitation zone
- gas flow (partial bypass flow) in top and bottom zone as indicated in Fig. 4-4

#### could be investigated.

Total particle concentration was determined with the laser scattered light measurement system SICK FW100 which was calibrated via gravimetrical measurements according to VDI 2066, Part 1 [10]. Particle size distribution and concentration was measured with a scattered light aerosol spectrometer Palas WELAS 2000. All concentration measurements were taken at the clean gas side of the ESP; the high voltage-off values were taken as crude gas concentrations. The CFD Simulation was performed with ANSYS Fluent 12.1 (k- $\varepsilon$  model with porous media for perforated screens) and verified with velocity measurements taken with an impeller wheel and visualized with a fognozzle.

## 5 Results and discussion

#### 5.1 Primary gas velocity distribution

The results of primary gas velocity distribution for perforated screen combinations  $\beta 1 - \beta 5$  are shown in this section.

A total uniform gas velocity distribution already at the leading edge of the electrostatic field could not be achieved with the tested perforated screen combinations. Three main tendencies of the velocity profiles at the leading edge of the field were determined:

- Smooth center/top distribution An almost uniform gas velocity distribution with no high velocity peaks and the main gas flow dominant in the center of the electrostatic field (β2, β3)
- Center/top distribution The main gas flow was in the center of the electrostatic field with high velocity peaks (β4, β5)
- Smooth bottom distribution An almost uniform gas velocity distribution with no high velocity peaks and the main gas flow dominant in the bottom region of the electrostatic field (β1)

According to the IGCI and VDI standards, the gas velocity distribution should be:

- $\begin{array}{ll} \text{IGCI EP-7 [3]} & 85\% \text{ of velocities must be} \\ \leq 1.15 \text{ times } v_{\text{average}} \text{ and} \\ 99\% \text{ of velocities must be} \\ \leq 1.40 \text{ times } v_{\text{average}} \end{array}$
- VDI 3678 [4] 75% of velocities must be  $\leq$  1.15 times v<sub>average</sub> and the relative standard deviation should be  $\leq$  25%

The cross-section for evaluating the velocities was given with 0.9 m downstream the leading edge of the first field for IGCI and before the first field for VDI 3678. Due to a total field length of ~2.5 m for the test ESP and only one field the cross-section for evaluating velocities were taken at 0.4 m downstream the leading edge as indicated in Fig. 4-3. A comparison of the CFD simulations and referred standards are shown in Fig. 5-1.

The screen combinations  $\beta 1$  and  $\beta 2$  achieved the most even velocity distributions whereas no distribution profile could meet the standard requirements. For combinations  $\beta 3 - \beta 5$  a rather worse velocity distribution was found.



Fig. 5-1: ESP fixtures and top- and bottom zone with sealing positions

# 5.2 Influence of perforated screen combinations on separation efficiency

The fractional separation efficiencies for the 5 different primary gas velocity distributions when altering perforated screen combinations are shown in Fig. 5-2 as average of T/R-set and HF-power supply measurements.



Fig. 5-2: Average fractional separations efficiencies for perforated screen combinations  $\beta$ 1 -  $\beta$ 5, v=1 *m/s* 

The efficiencies for  $\beta$  5 and  $\beta$  3 are close together at high level whereas efficiency for  $\beta$  1 and  $\beta$  4 are the lowest; efficiency for  $\beta$  2 is in the middle.

These results do not match when only standard deviation of the primary gas velocity distribution is used as a parameter to assess ESP efficiency because  $\beta 1$  and  $\beta 2$  should have had the best ESP performance.

#### 5.3 Influence of top and bottom zones on separation efficiency

In Fig. 5-3 the average fractional separation efficiencies for normal operation without any sealing, when CE was sealed and top and bottom zone was sealed (DE sealing) can be found.



Fig. 5-3: Average fractional separations efficiencies for normal operation, CE and DE sealing,  $\beta 2$ , fixed voltages

The gas flow and potential whirls between ash hopper, baffle plates and precipitation zone do not have major influence on precipitation efficiency since both efficiency curves are in the same range. A noticeably influence of top and bottom zone was found as shown in Fig. 5-3 as efficiency did increase when the zones were sealed.

#### 5.4 Influence of primary gas velocity on separation efficiency

Fig. 5-4 shows the average fractional separation efficiencies for average gas velocities from 0.3 - 1.2 m/s.



Fig. 5-4: Average fractional separations efficiencies for 0.3 - 1.2 m/s,  $\beta 2$ 

The separation efficiency for particles >5  $\mu m$  slightly decrease with higher average gas velocities whereas separation efficiency for

smaller particles, especially in the range of  $0.3 - 1 \ \mu m$  do decrease dramatically.

The average total separation efficiency of both power supplies for different gas velocities is give in Fig. 5-5.



Fig. 5-5: Average total separations efficiencies for β1 - β5 and 0.3 – 1.2 m/s

For all perforated screen combinations with velocity decreasing total separation efficiencies were found.  $\beta$ 1 and  $\beta$ 2 again showed the lowest separation efficiencies whereas for all other combinations almost similar efficiencies were investigated.

#### 5.5 Influence of different power supply techniques on separation efficiency

The separation efficiencies for 3 different particle sizes dependent on average gas velocity for the two different power supplies is given in Fig. 5-6.



supply,  $\beta 2$ 

Separation efficiency for both power supplies showed decreasing efficiency with increasing gas velocity. For smaller particle sizes and higher gas velocities bigger differences of the separation efficiency using the two different power supply techniques were found.

## 6 Conclusion

For smaller industrial ESP's like those similar to the one used in this work, meeting homogenous gas distribution as indicated in some standards seems only possible with excessive effort. A linear connection between gas velocity standard deviation and ESP performance could not be found.

Concluding fractional as well as total separation efficiency measurements, most important is a prevalent central gas flow with low velocity peaks. A major influence on ESP efficiency was found in partial bypass flow above and below discharge electrodes. This top and bottom zones do have increasing importance with decreasing electrode height as shown in Fig. 6-1 for constant clearings of 0.625 x spacing distance.



Fig. 6-1: Share of top and bottom zone on total ESP height for varying electric field height and 3 different spacings

In Fig. 6-1 the share of top and bottom zone for the used ESP with 300 mm spacing and 2 m field height of ~19% is indicated.

It was found that with increasing gas velocity the separation efficiency did decrease as expected. Especially for smaller particles in the size range of 0.4  $\mu m$  the efficiency drop was dramatically.

When using the HF power supply higher separation efficiencies were determined for all measurements. The greatest improvement was achieved for high velocities and small particle sizes.

### 7 Literature

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