Direct measurement of ESP charging efficiency with Electrical Low Pressure Impactor +

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1 Summary / Abstract:

Electrostatic precipitator particle removal efficiency is governed by the level of charge that the particles gain in the ESP. The ELPI+™ measures real-time (10 Hz) particle size distribution and concentration in the size range from 6nm to 10 µm. As a unique feature of the instrument ELPI+™ can also measure the size resolved number of charges per particle. In this work we will present ESP charging efficiency measurement data along with discussion on factors that affect the performance of ESPs.

2 Introduction

Electrostatic precipitators are used to remove particulate matter from flue gases. The operation principle of an ESP is based on charging particles in flue gas as effectively as possible and collection of said particles with an electric field. The performance of an ESP is therefore dependent on more complex factors than the performance of a mechanical filtration system. ESP performance is affected by e.g. particle composition, flue gas temperature and flue gas humidity. All of these parameters have an effect on the charging efficiency of the ESP. Due to the complex nature of the effects, it is critically important to be able to directly measure the ESP charging efficiency when optimizing and improving ESP performance.

Detailed measurement of emissions from a combustion source generally requires the flue gas to be conditioned before measurement. Conditioning typically includes reduction of particle concentration, temperature and humidity in a controlled way. A common method in conditioning is to apply two-stage dilution with heated first stage. This eliminates condensation and drops temperature in a controlled way to avoid particle losses and transformation. After conditioning, the sample is led to the measurement instrument.

The Electrical Low Pressure Impactor+, ELPI+™, measures particle number and mass concentration and size distribution in real-time. The measurement range (6nm-10µm) of the ELPI+™ instrument covers ultrafine, fine and coarse modes with 14 logarithmically evenly spaced size fractions. As a special feature of the operation principle, ELPI+™ can measure the charge of particles, thus enabling direct charge studies.

In this work we present new studies on ESP charging efficiency and compare them to previously published data. In addition, we compare the emissions and particle characteristics of emitted particles from a coal-firing and from an oil-firing power plant. Studies of ESP charging efficiency and particle removal efficiency are crucial for high-level optimization of power plant processes.

Measurement location

Measurements were carried out at a large-scale coal-firing power plant and at a medium-scale oil-firing plant in Helsinki, Finland. The coal-firing power plant is equipped with an electrostatic precipitator, scrubber for sulphur removal and a baghouse filter. PM measurements at the coal-firing power plant were carried out at after the electrostatic precipitator. Measurements at the oil-firing power plant were carried out directly after the combustion process and before any particle removal processes. In addition to normal PM measurements, studies were also carried out at the coal firing-plant to determine the charging efficiency of the ESP.

Methods

Conditioning of the extracted flue gas was carried out with Fine Particle Sampler, FPS-4000, which allows conditioning with different dilution ratios and temperatures. FPS-4000 employs two-stage dilution, where the first stage dilution is carried out with a perforated tube diluter which allows both cooled and heated dilution. Second dilution stage is an ejector diluter that dilutes the sample at ambient temperature and also operates as the pump of the dilution system. The temperatures, pressures and dilution ratios of both dilution stages are continuously monitored and recorded. The operation principle of the FPS-4000 is shown in Figure 2-1.

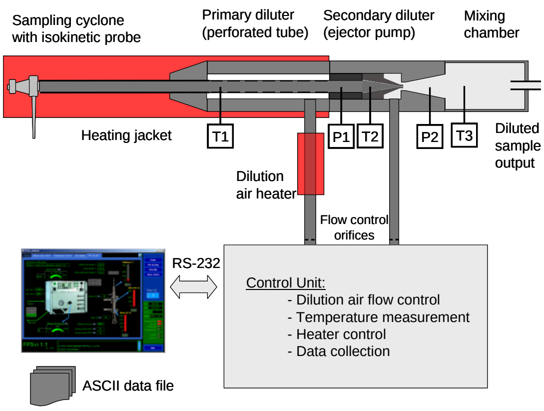

Figure 2-1. FPS-4000 operation principle

FPS-4000 allows multiple measurement instruments to be connected at once including real-time measurements and gravimetric collection. All relevant parameters are stored and are available for data evaluation after the measurements.

ELPI+™ operation principle is based on particle charging, size fractionation with an impactor and measurement of current by individual electrometers [1]. This method allows for a simultaneous real-time measurement of a wide size range from 6nm to 10µm. ELPI+™ operation principle is shown in Figure 2-2.

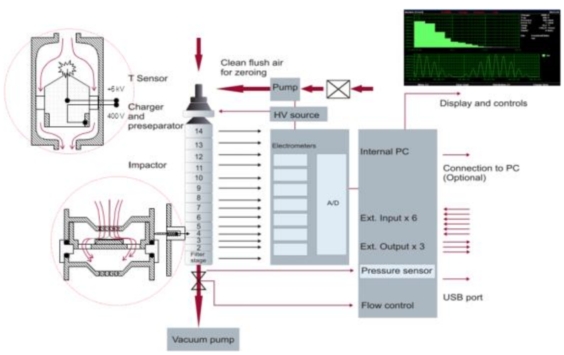

Figure 2-2. ELPI+™ operation principle

ELPI+™ is capable to measure real-time number and mass size distribution and concentration in a size range from 6nm to 10µm. Size classification with an impactor allows for subsequent size fractionated chemical analysis of the collected particles after measurement. The inherent charge level carried by particles can be measured with the instrument simply by switching the charger off. ELPI+™ instrument performs this measurement automatically through switching the charger on/off and subsequently calculating size resolved charge/number and charge/mass values. ELPI+™ was used in this study to determine total number and mass emissions, particle size distributions and ESP charging efficiency.

Results and discussion

The measurement results shown in this chapter have all been corrected for dilution ratio. All particle number results are given for the size range from 6 nanometers to 10 micrometers. All particle mass results are given for the size range from 6 nanometers to 2.5 micrometers, i.e. PM2.5.

Mass and number concentrations measured at the oil firing power plant are shown in Figure 2-3.

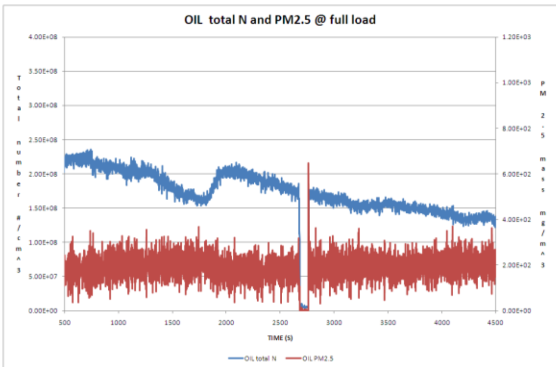

Figure 2-3. Particle number and mass concentrations from oil firing power plant

Number concentrations varied between $1*10^8$ and $2.5*10^8$ particles per cubic centimeter. PM2.5 Mass concentrations were more stable with an average roughly at 200 milligrams per cubic meter. Particle mass concentration has significant fluctuation, while the long time average of the concentration is quite stable.

Particle number concentration also has some fluctuation, but the average concentration changes more significantly over time.

Measured average particle number and mass size distributions are shown in Figure 2-4.

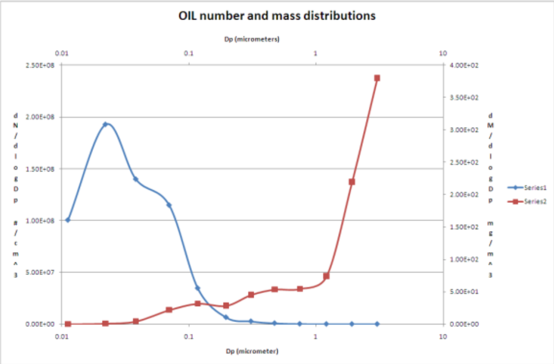

Figure 2-4. Average particle number and mass size distributions

Particle number size distribution is bimodal with peaks at 20nm and 50nm. Particle mass size distribution is tri-modal with peaks at 120nm, 500nm and a third largest peak above 2.5 micrometers. The observed particle modes suggest different mechanisms in particle formation. Largest mode consists of large ash particles, while the accumulation mode most likely is formed of both soot and ash particles. The ultrafine particles in the smallest size mode are formed from vapors through nucleation during cooling of the flue gas.

Based on the measured size distributions we can observe that the changes in the total number concentration are caused mainly by varying concentration of the particles in the mode around 20nm. The changes in the concentration of the ultrafine particles has an insignificant effect on the PM2.5 mass concentration. The fluctuation in the mass concentration is caused by the fast changes in concentration of the particles in the largest mode above 2.5 micrometers.

Particle number and mass concentrations measured from the coal firing power plant are shown in Figure 2-5.

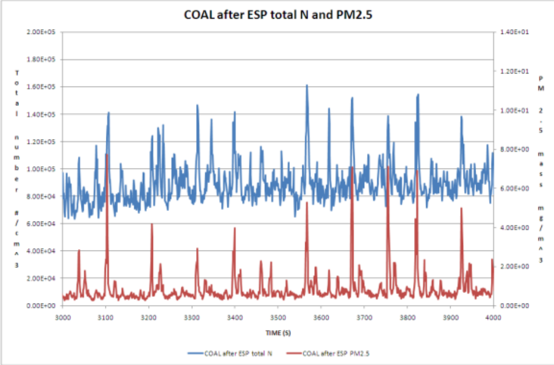

Figure 2-5. Particle number and mass concentrations from coal firing power plant

Number concentrations varied between $6*10^4$ and $1.6*10^5$ particles per cubic centimeter. PM2.5 mass concentration baseline was close to 0.5 milligrams per cubic meter with peaks up to 6 milligrams per cubic meter. Although both mass and number baseline concentrations are quite stable, we can however observe peaks in both concentrations in regular time intervals.

Number and mass size distributions from baseline and from a peak concentration are shown in Figures 2-6 and 2-7, respectively.

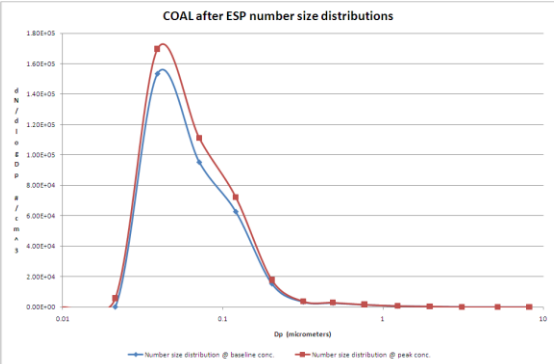

Figure 2-6. Peak and baseline number size distributions from the coal firing power plant

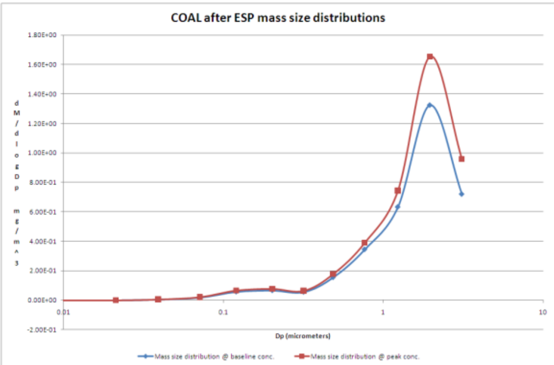

Figure 2-7. Peak and baseline mass size distributions from the coal firing power plant

Particle number size distribution is bimodal with peaks at 40nm and 100nm. Particle mass size distribution is trimodal with peaks at 150nm, 800nm and a third largest peak at 2 micrometers.

The peaks in the number and mass concentrations are caused by the cleaning process of the ESP, which causes higher penetration and re-entrainment of particles.

Results from charge per particle measurements carried out in this study are shown in Figure 2-8.

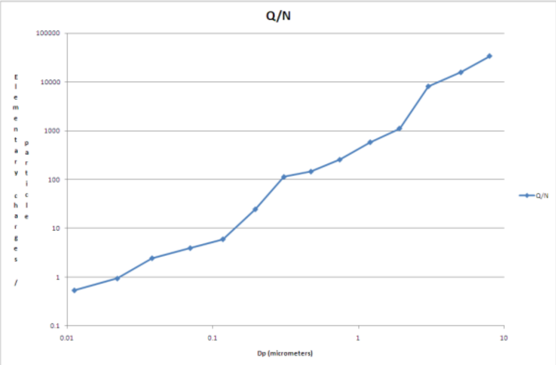

Figure 2-8. Size resolved charge per particle measurement results from coal firing plant ESP

When these results are compared with results from studies by Niemelä [2] and Moisio [3], we can observe that the trend of the results is similar, with however higher charge per number results for both ultrafine and especially coarse particles. This may be caused by either a higher charging efficiency or measurement inaccuracies due to low particle concentrations at the coarse mode. What we can see in addition are the two dips in charging efficiency at roughly 120 nanometers and a second dip around 1 micrometer. The dips in particle charging efficiency may be caused by changes in particle morphology due to different particle formation processes.

Measurement of the charging efficiency allows for direct optimization of the ESP operation parameters which can reduce both the emissions and the operating costs of the power plant.

Conclusions

ELPI+™ and FPS-4000 were successfully applied to coal- and oil-firing power plant measurement.

Although the oil-firing power plant measurements were carried out before the flue gas cleaning equipment, we can estimate that oil-firing power plant produced more ultrafine particles than the coal-firing power plant.

The PM emissions from the coal-firing power plant were low, with a baseline PM2.5 concentration at 0.5 mg per cubic meter. The peaks caused by the ESP cleaning process can be clearly identified.

Measurement of ESP charging efficiency showed high charging efficiency which correlates well with the observed low emissions. It must be noted however that the particle concentration at the coarse mode was quite low, thus causing the error margins to be larger. ESP charging efficiency measurement could be effectively used to optimize the performance of the ESP.

Measurement of ESP charging efficiency is critically important as it is the only particle measurement that is directly related to the process of charging in an ESP. While PM measurements after ESP give important information, the results are affected by other parameters outside the primary principle of the ESP.

3 Literature

[1] Keskinen, J., Pietarinen, K. and Lehtimäki, M. (1992) Electrical Low Pressure Impactor, J. Aerosol Sci. 23, 353-360

[2] Niemelä, Lamminen and Laitinen, A Novel Method for Particle Sampling and Size-Classified Electrical Charge Measurement at Power Plant Environment. ICESP XI proceedings.

[3]Moisio, M. (1999) Real time size distribution measurement of combustion aerosols. Ph.D. Thesis Tampere University of Technology publications 279, Tampere Finland.