Testing and characterization of a shielded corona electrode charger with Electrical Low Pressure Impactor+

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Abstract

This study will present laboratory and field testing results of a shielded corona electrode (SCC) for the purpose of particulate removal from small and medium scale combustion boilers. The SCC charging efficiency is shown to agree with theory in laboratory conditions. In field conditions the SCC achieved a high particulate removal efficiency (85%) for a pellet boiler. This study suggests that SCC is a potential low cost solution to meet future emission limits for small and medium scale boilers.

Methods

Shielded Corona Electrode (Fig. 1) was designed to overcome these difficulties [2].

Aggressive chemical components in the flue gas can cause corrosion in the discharge electrodes decreasing their life time. Part of the particle matter in the flue gas accumulate to the discharge electrode surfaces and needs to be cleaned regularly to ensure proper operation.

Introduction

Upcoming emission regulation of small-scale combustion sources will require the application of secondary flue gas cleaning devices. This need is pronounced in the case of older type boilers and in locations where high quality fuel is unavailable or uneconomical to use.

Electrostatic precipitators (ESPs) are widely used in industrial scale particle removal and there are now several devices available also for small scale energy production [1]. For domestic use the particle removal device must operate as maintenance free as possible. The device cost must also be considerably low so the need of additional components, like rapping systems, is a disadvantage.

When the discharge electrode is located directly in the flue gas flow, the chemical composition, temperature and particle load of the flue gas can have negative effect on the corona operation. Increase in flue gas temperature and decrease in pressure both lead to narrower range of suitable corona voltages. Corona chargers operating at atmospheric pressure levels need to be modified at temperatures above 500°C.

Figure 1. A concept drawing of the Shielded Corona Charger. The corona electrode and the HV rail and insulators are protected by the outer shell and sheath air.

The main difference to normal corona electrodes is that in the SCC corona electrode is not in contact with the flue gas. Corona discharge and ion formation takes place in a shield gas flow. Temperature, pressure and chemical composition of the sheath flow can be adjusted for optimal corona operation. The sheath flow also protects the corona electrode from dust build up (Fig. 2)
Figure 2. The sheath air prevents dust build up to the corona electrode.

Like with normal corona electrodes the discharge is formed between the corona needle and the grounded collection plate. This allows easy installation to both small and large scale applications as well as retrofitting to an existing ESP systems. As the SCC systems uses boilers’ existing surfaces to collect particles the cost of retrofitting is relatively low and can be made in several different types of boilers. SCC’s with several corona tips (Fig. 3) can be used to replace normal unshielded electrodes in existing small and medium scale ESP configurations. SCC electrodes using ceramic outer shell can be made up to 2.5 meters long.

Figure 3. SCC electrode with ceramic outer shell and several corona tips.

As the sheath air protects the corona electrode from the flue gas it can be operated also during boiler start up/shut down and it needs cleaning only few times during heating seasons.

SCC electrodes can also be used in many other applications where there is need to protect the corona electrode from flue gas or to condition the gas composition/temperature at the corona onset region.

Electrical Low Pressure Impactor+ (ELPI®+, Dekati Ltd.) [3][4], was used to characterize the operation of the SCC. + allows direct real-time measurement of both charging efficiency and precipitation efficiency of any ESP in a particle size range from 6nm to 10 µm. ELPI®+™ operation principle is shown in Fig. 4.

Figure 4. ELPI®+™ operation principle

ELPI®+ operation is based on a corona charger, a cascade impactor and sensitive electrometers. A vacuum pump is used to pull a sample of 10 lpm through the charger and the cascade impactor.

Figure 5. ELPI®+ charger

The charger (Fig.5) consists of a tungsten wire at high voltage which produces positive ions at a current regulated to 1 µA. The charging region is followed by a trap field at 20 volts to remove ions which have not diffused onto a particle surface. The positively charged particles then enter into a cascade impactor which size classifies the particles by their aerodynamic size.
A cascade impactor (Fig. 6) is a series of impactor stages which use a jet plate to increase the speed of the gas flow. The gas jet is directed towards a collection plate which forces the gas to make a sharp turn. The particles with sufficient inertia cannot follow the gas flow, impact and get collected on the collection plate. A cascade impactor uses multiple impactor stages with increased jet speed at each step to collect smaller and smaller particles at each stage. Each impactor stage is electrically insulated from one another allowing a measurement of current from each stage with sensitive electrometers.

The charging efficiency and impactor collection curves have been determined through experimental studies using monodisperse particles [3][4]. Therefore the measured electrometer current can be calculated into particle number and particle mass.

In addition to the number and mass measurement, the charge level carried by particles prior to the instrument can be measured by switching the charger off. If the charger is off, then the electrometers at each impactor stage will register the current resulting from the charges on collected particles. This data can be then combined with the data from measurement with charger on, which gives in particle number and mass concentration. This allows calculation of charge/number and charge/mass for the entire instrument measurement size range. ELPI®+™ instrument performs this measurement automatically through switching the charger on/off and subsequently calculating size resolved charge/number and charge/mass values.

**Laboratory tests**

The SCC electrodes were tested with both laboratory generated aerosol as well as with flue gas from a pellet boiler. In the laboratory tests (Fig. 7) the goal was to find out how residence time affects the particle charge state.

A test aerosol was generated using a combination of a pyrolysis generator (Concept ViCount Compact Generator using Concept Smoke Oil 135) and a dust feeder (using dust collected by an ESP after a large industrial biomass boiler). Measurements were done at room temperature around 21ºC. Flow rate in the duct was 0.45 m³/s or 15 m/s. The acquired aerosol charge state was measured using 1, 2 and 4 negative corona SCCs. Each SCC produces similar ion concentration in the charging zone and as the aerosol flow rate is kept constant the result of adding SCC’s is equal to increasing the residence time. The aerosol was diluted using ejector diluter (Dekati™ Diluter DI-1000) to minimize losses caused by space charge effect. Aerosol concentration, size distribution and average charge distribution were measured using the ELPI®+™.

**Field test**

Commercial 20kW pellet boiler was used to test SCC in real operational environment (Fig 8). Total particle mass emission from the boiler was 69 mg/m³ indicating that the boiler was not optimized for emissions. Modern pellet boilers...
can typically achieve considerably lower mass emission values.

Domestic heating system life time is in the order of decades, resulting in a high number of boilers with antiquated technology still in the field. The goal of this study was to see if unoptimized boilers could be retrofitted with a particle removal system to reduce the emission levels. Two SCC units with one corona electrode were used. The flue gas temperature was between 120-150ºC in the charging section. Flue gas was sampled at the boiler exit. An ejector diluter was again used to lower the aerosol concentration and to cool the aerosol near room temperature. Aerosol concentration, size distribution and average charge distribution were measured using the ELPI®+

Figure 8. Measurement setup with commercial 20kW pellet boiler.

Results

In the laboratory measurements the aerosol distribution consists of two different aerosols. The pyrolysis generator produces aerosols with peak mass diameter of 0.2 µm. The aerosol from the dust feeder has peak mass diameter of 0.5 µm. The resulting distribution is shown in Fig. 9.

In Fig. 10 it is shown how the particle charge state is changed when using 1, 2 and 4 SCC chargers. In residence time this setup corresponds to approximately 1.5, 3 and 6 ms. SCCs operated at negative voltage of 26kV, near spark over voltage. Corona current was around 0.05mA each. Theoretical charge state values that are calculated using Cochet’s model (1)[5] are shown in Fig. 7.

\[
Q_p^\infty = \left(1 + \frac{2\lambda}{d_p}\right)^2 + \left(\frac{2}{1 + 2\lambda/d_p}\right)\left(\frac{\epsilon_r - 1}{\epsilon_r + 2}\right)\pi \epsilon_0 d_p^2 E
\]

\(Q_p^\infty\) particle saturation charge

\(\lambda\) mean free path of the molecules

\(d_p\) particle diameter

\(\epsilon_r\) electrical permittivity of the particle

\(\epsilon_0\) permittivity of a vacuum

\(E\) electric field strength

Equation (1) gives the saturation charge. The charge state after residence time \(t\) can be calculated using equations (2) and (3):

\[
Q_p(t) = Q_p^\infty \frac{t}{t+\tau_Q}
\]

\[
\tau_Q \approx \frac{4\epsilon_p}{j_{NE}/E}
\]

\(Q_p(t)\) particle charge at time \(t\)

\(\tau_Q\) time constant

\(j_{NE}\) current density
Figure 10. Acquired particle charge states using 1(■), 2(▲) and 4(●) SCCs (1.5ms, 3ms and 6ms residence times) and the theoretical charge values calculated using Cochet’s model (lines).

Fig. 11 shows the particle number concentrations and removal efficiency measured from the 20kW pellet boiler. Two SCC devices decrease the mass emission level ~85% from 69 mg/m³ to 10mg/m³. Particle number concentration was decreased by 80%. The achieved 10mg/m³ level is well below the present German emission regulations of 20 mg/m³.

We found out that it is important to optimize the position of the charger in the flue gas channel. In our case the correct positioning increased the removal efficiency from 60% to 85% (total mass). This optimization could be done quickly by using the ELPI®+ real-time data.

The measured particle charge values are presented in Fig.12. The SCCs operated at negative voltage of 35-40 kV, near spark over voltage. Corona current was around 0.2 mA each.

Figure 11. Particle number distribution of the pellet boiler SCC system off and on. Reduction in total particle number was 80% and in total particle mass 85%.

Figure 12. Particle charge states measured after the 20kW pellet boiler. Two SCC units were used.
Discussion

Laboratory tests showed good agreement between predicted charge levels by Cochet’s model and measured results with ELPI®+. Increasing charge state with increased residence time suggested that hypothesis on simulating longer residence time with multiple charging units is valid.

A high collection efficiency (85% for mass and 80% for number) was achieved with two SCC chargers in a 20kW pellet boiler. SCC chargers were shown to operate reliably as a retrofitted particle removal device in old pellet boiler. After retrofitting the boiler complied with new emission regulations.

The ELPI®+ instrument was shown to have value in the particle removal device development work. It’s real time measurement capability and robustness in field studies greatly reduces the needed working hours for testing of different operation parameters and device optimization.

References


