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REDUCTION OF FINE PARTICULATE EMISSIONS FROM ESPs

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ABSTRACT

World wide the focus on the health impact of fine particles in the atmosphere is increasing and regulatory restrictions on size dependent emission are expected soon to add to the ever descending total mass limits of all countries.

The content of hazardous particles may be reduced either by means of sophisticated devices targeting the fine fraction directly or simply aim at reducing the total mass emission to "zero". The latter may be done by fabric filters or by means of high efficient ESPs and is expected to comply with the demands.

Barrier filters are characterized by having eliminated many of the non-ideal boundary conditions that maintain the ESP on higher emission levels – either due to constant contributions (re-entrainment, sneakage) or intermittent contributions (rapping loss). Many of these effects may be eliminated or minimised in ESPs e.g. by means of an efficient baffling system, electrode optimisation, etc.

This paper describes a series of case stories where dust emission is reduced to the 1-10 mg/Nm^3 range and has a low content of fine particles (PM2.5) as well. This shows that in many cases dry ESPs as well as fabric filters are valid alternatives as "best available technology" (BAT) in fine particulate removal.

PREFACE

The suppliers of modern Electrostatic Precipitators (ESPs) are facing increased requirements on a multitude of fronts. Firstly, the ever-increasing requirement to increase performance in terms of mass emissions, secondly, there is an emerging requirement to reduce the emission related to PM 2.5 (particle diameter less than 2.5 µm). This has to be done in a market where the competition is fierce and the prices are under pressure.

The European Commission ambient air quality regulations require that a daily average of particles PM10 should be less than 50 µg/m^3. This value is not to be exceeded more than 35 times per calendar year, decreasing to 7 times per calendar year in 2010. This means that the future design of dust emission control equipment must meet lower emission values than required today.

There are a number of ways to achieve low emissions of fine particles. One is to reduce the overall mass emission level, and another is to focus on reducing the emission of fine particles only. The latter can be achieved by targeting the collecting equipment improvement in this size range or by modifying the particle size before the collecting takes place.

Today many ESPs around the world operate at low emission, but in most cases there is still room for improvement – excluding the obvious and in this respect not interesting extension of the collecting area. This paper will describe a few steps down the road of improvement.

This paper will discuss the reasons why modern particulate removal equipment may have difficulties in reducing the emissions of PM2.5 illustrated via the non-ideal effects in an ESP. Then some recent specific improvements in the field of fine particle removal will be described and, finally, some relevant case stories will be presented.

REMEDIES FOR FINE PARTICULATE REMOVAL

The fractional efficiency of an ESP depends on the particle size and has a local minimum around 0.5 µm [White 1963]. For most industrial applications the major part of the dust on mass basis is concentrated in the range 0.1-100 µm – only a few milligrams below this. Therefore, it is interesting to address the fine particles in this region separately to increase the total efficiency in the 0.1 to 5 µm range.

One way is to physically increase the particle size by agglomeration in combination or separately by chemical, electrical or mechanical principles. Such devices, known as agglomerators, are proven to have a positive effect on the collection efficiency – e.g. the Indigo-type [Truce, Harrison 2003] or low turbulent (laminar) type. [Feldman, Kumar Millford 1998]

Another way is purely electrical and is related to the necessity to provide a high particle charging and a good current distribution on the collecting plates. When applying high amplitude narrow pulses (70-120 µs) superimposed on a base voltage around the corona onset level, an intense corona discharge and dense ionic space charge are generated. Pulse energisation results in a better current distribution along the electrodes and hence in the whole pulse energized bus section. The saturation charge of the particles is determined by the maximum field strength created by the ionic space charge. As the maximum field strength achieved with pulse energization is much higher than with traditional DC energization, this power supply provides enhanced particle charging resulting in a better removal of fine particles. The FLS Coromax Pulse System has a proven record of this as reported in previous ICESP papers. [Elholm, Lund 1998 and 2001]

Finally, the fine particulate emission may by limited by barrier filtration in a fabric filter. This type to some extent suffers from the same reduced collection efficiency around 0.5µm due to particle diffusion properties.

NON-IDEAL PHENOMENA FOR DRY ESPs

From experience with small laboratory precipitator, e.g. the wind tunnel type, it is known that very high collection efficiencies can be achieved with short precipitators, indicating that the electrostatic process is very efficient provided no non-ideal effects are involved. I.e. basically an ESP has a great potential to be sought outside the laboratory.

The non-ideal effects described below degrade ESP efficiency by increasing the mass penetration, i.e. the number of coarse and fine particles, or by increasing the number of fine particles alone.

When describing and evaluating the actual particle size – inlet as well as outlet - it is, however, important to do it with the minimum of interference on the result. Most often, analysis of samples collected in the bottom hopper or retrieved mechanically and later analyzed in a laboratory will not be representative to the distribution in-situ. For this purpose, an in-situ instrument like a low pressure cascade impactor is appropriate (e.g. Berner, Dekati).

Sneakage

If part of the gases is forced to flow over or under the electrode system we have what is normally called 'sneakage'. This is extremely detrimental to efficiency because the sneaking gases are not cleaned at all. E.g. if 1% of the gases pass un-cleaned, the efficiency can never be increased above 99%. Sneaking dust may be both fine and coarse in nature. By controlling the gas velocity profiles, creating a proper gas distribution, and by introducing baffles it is possible even with ESP of large cross sections to reduce sneakage close to zero.

Re-entrainment

If the dust layer can't be kept adhered to the collecting plate between rapping cycles, lumps of dust fall off and particles may be re-dispersed into the flow. Likewise, large particles with high migration velocity towards the dust layer surface may re-disperse already precipitated dust, thus increasing the penetration. In this case the re-entrained particles may be large and small as well. A proper high and even current distribution should minimize the first type of re-entrainment, while the latter type may hardly be avoided.

Rapping re-entrainment

During rapping the plate buckles and dust lumps are broken loose and falling downwards due to gravity. The lumps fall close to the dust surface below and may scour off more dust from the layer. The velocity increases towards the hopper and re-entrainment from the hopper dust may occur if so-called hopper sweepage is present due to too high gas velocities below the electrode system. If large amounts of dust fall at one time, the induced downwards velocities may reach values several times the nominal axial gas velocity. Re-entrainment during rapping can't be totally avoided, but by proper rapping intensity and proper rapping frequency and strategy, e.g. synchronization, the re-entrainment may be minimized. The 'particle' size of the small dust lumps being carried away by the gas flow is of order 5 to 10 µm and these particles should be easily precipitated downstream, apart from those originating from the last field. Therefore, special attention should be paid to the rapping system of the last field in an ESP, and solutions with partial rapping of the collecting curtains have been seen through the years.

Back corona

High resistivity dust, and moderate resistivity dust with high current density, may cause back corona, where already precipitated dust is blown out in the inter electrode space, increasing the concentration of small particles, and de-charging particles already charged. Such an ESP must be operated in a way reducing the number of spots where back corona occurs, e.g. by intermittent energization control or by pulse control.

Secondary rolls

A special sort of 'short circuiting' in an ESP field is experienced if almost horizontally secondary rolls created by the ion current are present. Fine particles entrapped in the core of the roll can't escape because the flow forces are stronger than the electrical forces, causing higher emissions of fine particles. For longer electric fields this effect is be reduced due to the rolls breaking down into turbulence after a series of electrodes and between the ESP sections. [Larsen, Sørensen, 1986]

Process parameters

Process parameters such as inlet particle loading, particle size distribution, gas temperature, moisture and oxygen contents should be kept as constant as possible in order to ensure the best ESP operation. The electrical control should be able to cope with process variations, but the system as a rule must be designed in a way to reduce such fluctuations. The presence of explosive gas mixtures during upset operating conditions so far have not been solved with ESP alone in combination with maintaining a very low emission.

RECENT IMPROVEMENTS

The non-ideal phenomena listed have all been addressed by us ESP manufacturers – with varying success! We will describe how FLSmidth Airtech has taken steps on the road of improvement in terms of removal of sneakage and discharge electrode design.

Vortex Free Baffles

In order to avoid sneakage almost all ESP types have some kind of baffling system before and after each electrical field – in top and bottom. Furthermore, shielding towards the casing from the outer collecting plate rows (before and after each field) is essential. The most common way to address the problem in top and bottom is by installing partially open plates (e.g. perforated plates), but for many applications dust will close the perforations and the plates will act as barriers. In this case back flow vortices will form behind the obstacle as indicated below.

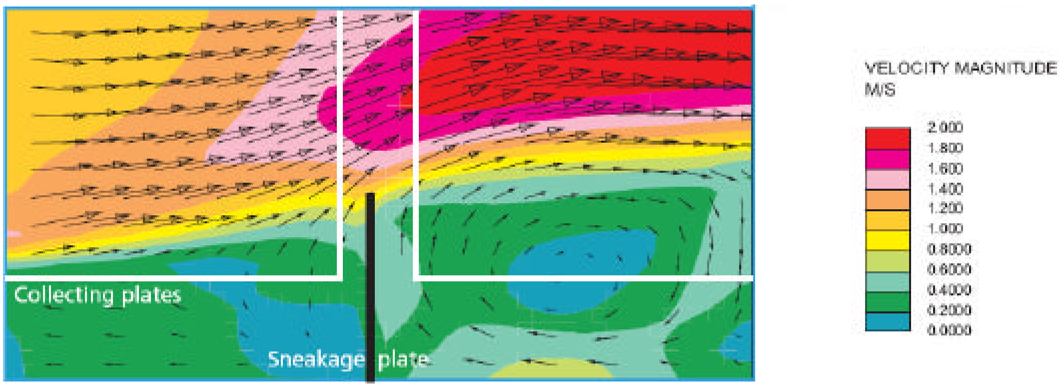

Figure 1: Flow pattern with traditional anti sneakage baffles (StarCD flow simulation)

In order to obtain full benefit of the installed collecting area and at the same time completely eliminate sneakage FLSmidth Airtech has developed a Vortex Free Baffle that remains partly open during operation and not forms a sharp barrier.

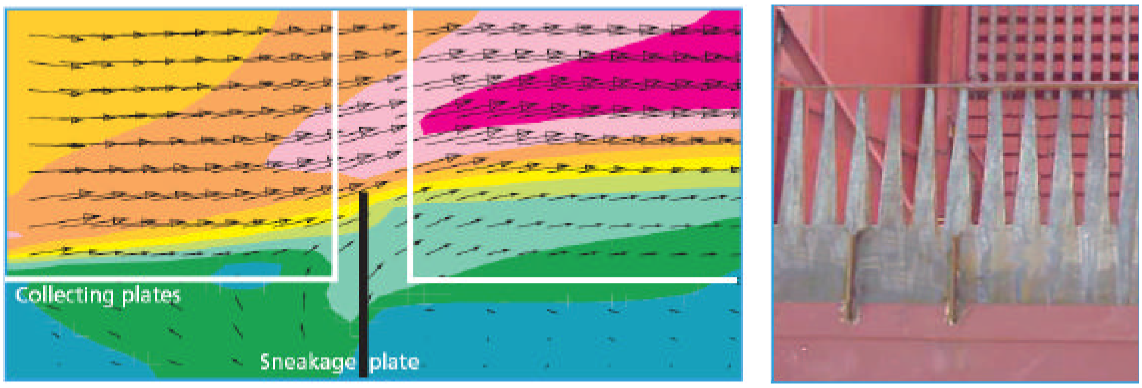

Figure 2: Flow pattern with FLSmidth Airtech Vortex Free Baffles

This type of baffle has been installed on a series of plants and is now standard in all new ESPs as well as retrofit jobs. As described later this new device has a positive effect on the dust emission.

Discharge Electrode Optimisation

Once the disturbing boundary conditions – top/bottom/left/right - are removed, the centre of the cross section remains to be optimized. Here the discharge electrode design has an influence. Especially “the wrong” DE configuration has great influence e.g. on soda recovery boiler ESP performance [Christensen, Poulsen, Lind 1998] where secondary flow led to scouring of the collected dust layer - and in many cases “the right” has a similar positive effect.

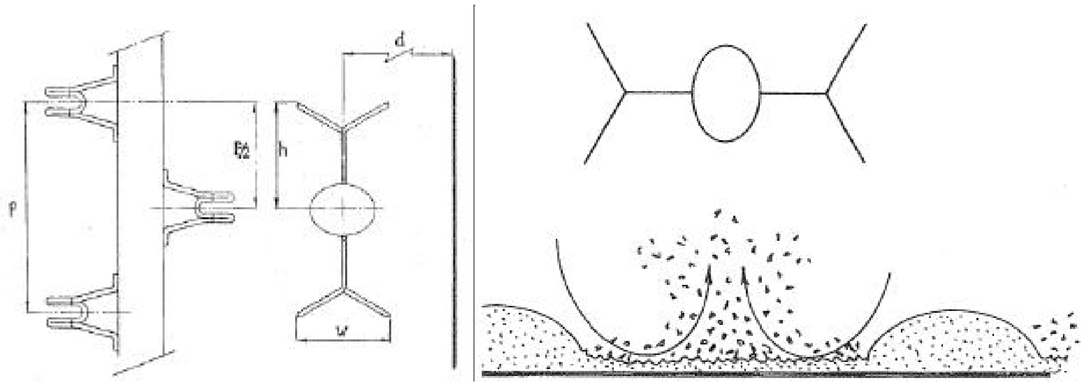

Figure 3: Sketch of the Fibulax M2035 and the secondary flow and the scouring of the dust layer by the ionic wind

Important parameters may by summarized

i. Appropriate corona onset voltage
ii. High current before corona quench
iii. Current and field distribution at the collecting plate
iv. Suitable design for mechanical cleaning
v. Mechanical stability (anti swing) and lifetime

Furthermore, the level of corona induced turbulence and secondary rolls needs to be considered.

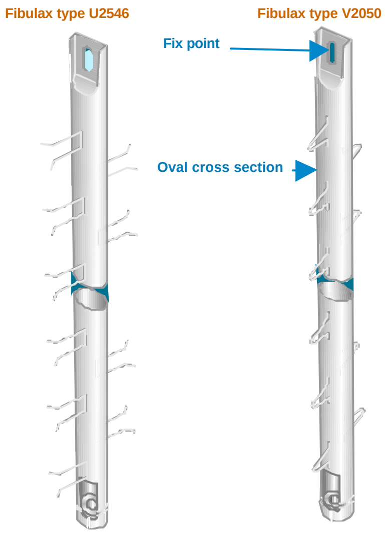

Figure 4: Discharge electrodes – the new Fibulax U2546 and Fibulax V2050

FLSmidth Airtech has developed a new type of electrode addressing the points listed. The Fibulax U2546 is based on the same design as other models in the Fibulax ridgid electrode series with special emitters attached to an oval pipe in order to minimize oscillations towards the collecting plate. This electrode has a low corona onset voltage and works excellent on inlet fields in an environment of high fine particle loadings and high gas velocities (>1.4 m/s) without corona quenching. The Fibulax V2050 having a higher corona onset voltage and excellent current distribution, therefore, is very effective on the subsequent fields and gives basis for a high efficiency on fine particle removal.

CASE STORIES

In the following case stories we describe where FLSmidth Airtech has installed new ESPs or upgraded existing installations by means of combinations of remedies described that enable very low dust emissions – and therefore low emissions of fine particles - for a wide range of industries.

Iron Ore Pelletizer in Sweden

The waste gases from the down draft drying zone (DDD) and the tempered preheating zone (TPH) of a travelling grate pelletizing process are cleaned in two individual ESPs each with 3 fields. The dust emission levels for the last 5 years are 1-5 mg/Nm^3.

From the burning zone the gas passes through a semi-dry SO_2 removal system (gas suspension absorber, GSA) before a three field ESP which has for the last 10 years operated below 5 mg/Nm^3.

Unit	**Process** Temperature (°C) / inlet dust (g/Nm^3)	**ESP** Gas velocity / kV / mA/m²	**Emission** mg/Nm^3
DDD 1 chamber with 3 fields	95 / 1.5	1.1 / 53 / 0.33	<5
TPH 1 chamber with 3 fields	140 / 1.5	0.75 / 48 / 0.30	<5
GSA 1 chamber with 3 fields	70 / 3.5	0.70 / 55-70 / 0.30	<5

Table 1: ESPs installed at Iron ore pelletizer in Sweden

Zinc Roaster in Australia

The zinc roaster plant consists of 2 separate fluid bed roasters. The hot furnace gases are utilised in a boiler compartment, bringing down the gas temperature from almost 1000° to around 340° at the inlet of two ESP chambers each with two fields. The ESPs were upgraded with new internals and FLSmidth Airtech Vortex Free Baffles. After the upgrade the emission was in the range 1-10 mg/Nm^3 (dry).

The inlet particle size distribution measured by a Berner low pressure cascade impactor is bimodal with a distinct top around 0.5 µm.

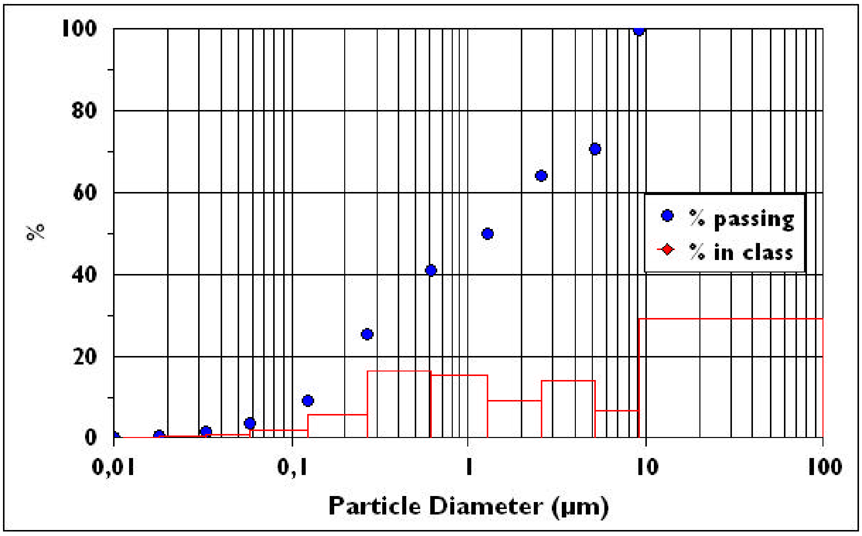

Figure 5: Typical particle size distribution at ESP inlet (1-3 g/Nm^3, 63%<2.5 µm)

The outlet particle size distribution was only measured on an original ESP configuration at 50 mg/Nm^3.

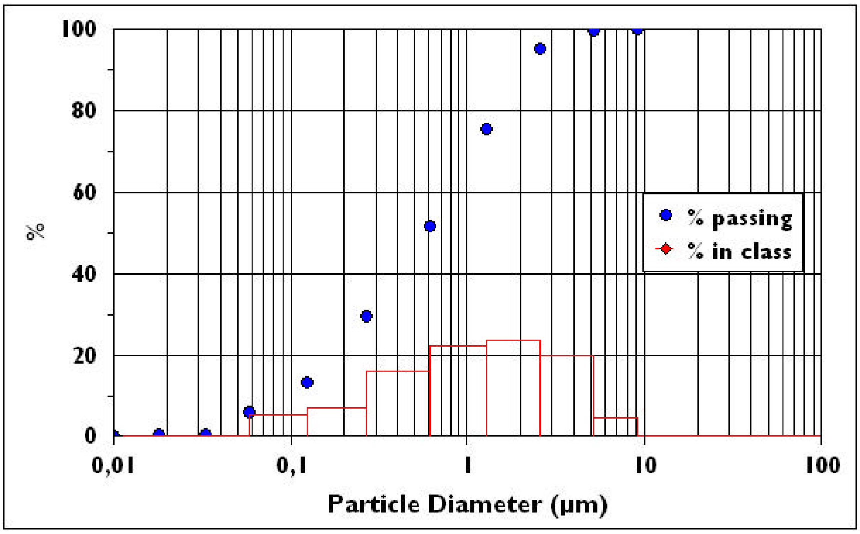

Figure 6: Outlet particle size distribution – original ESP (50 mg/Nm^3, 94%<2.5µm)

When the emission is reduced from 50 to 10 mg/Nm^3 it is appropriate to believe that nearly 100% of the emission is less than 2.5µm. In other words the PM2.5 emission is fully under control for this application.

Unit	**Process** Temperature (°C) / inlet dust (g/Nm^3)	**ESP** Gas velocity / kV / mA/m²	**Emission** mg/Nm^3
2 chambers with 3 fields	340 / 1-3	1.20 / 55 / 0.90	1-10

Table 2: ESPs installed at Zink Roaster in Australia

Cement Kiln in the Netherlands

The plant consists of a 2 stage cement kiln with marl dryer in series (always in operation). The inlet loading to the four field ESP is 360 g/Nm^3 around 150°C. The plant has operated below 10 mg/Nm^3 for more than 8 years. The corona power is controlled and interlocked with the dust emission at a set point below 10 mg/Nm^3 in order to save electrical power, but with the ability to go lower.

Unit	**Process** Temperature (°C) / inlet dust (g/Nm^3)	**ESP** Gas velocity / kV / mA/m²	**Emission** mg/Nm^3
1 chamber with 4 fields	150 / 360	0.90 / 80 / 0.39	<10

Table 3: ESPs installed at Cement Kiln in the Netherlands

Lime Kiln in Sweden

Originally the long dry rotary lime kiln had a hot ESP operating at 70-120 mg/Nm^3. In order to meet the project objective of less than 20 mg/Nm^3 the client investigated if a FF or an ESP should be installed. The selected solution included to condition the gases from the kiln by water injection in the smoke chamber and in a standard 2-phase gas conditioning tower (GCT) before the new four field ESP. The plant operates at 2-6 mg/Nm^3 with PM10 at 0.33

mg/Nm^3 dry @ 11 % O_2. Furthermore, a benefit was that the levels of heavy metal and dioxin were reduced significantly. [Wikander and Elholm].

Unit	**Process** Temperature (°C) / inlet dust (g/Nm^3)	**ESP** Gas velocity / kV / mA/m²	**Emission** mg/Nm^3
1 chamber with 4 fields	150-200 / 56	1.05 / 80-55 / 0.5	<10

Table 4: ESPs installed at Lime Kiln in Sweden

Lime Kiln in Denmark

A four field hot ESP (280°C) equipped with Coromax pulse on the two outlet fields is installed after this long dry kiln. The emission before rebuild was 15-25 mg/Nm^3. After installation of the FLSmidth Airtech Vortex Free Baffles, the emission was reduced to 4-8 mg/Nm^3.

Unit	**Process** Temperature (°C) / inlet dust (g/Nm^3)	**ESP** Gas velocity / kV-DC / kV-pulse / pulse frq [Hz] / mA/m²	**Emission** mg/Nm^3
1 chamber with 4 fields	280 / 46	1.24 / 20 / 60 / 25 / 0.045	4-8

Table 5: ESPs installed at Lime Kiln in Denmark

CONCLUSIONS

This paper describes the great potential that an electrostatic precipitator has in order to achieve very high collecting efficiencies for most particle sizes. The reasons for lower performances with full scale ESP units are discussed and include aerodynamic re-entrainment and rapping re-entrainment, back corona and secondary rolls. These non-ideal effects in an ESP are part of the reason for the modern particulate removal equipment may have difficulties in reducing the PM2.5 emissions.

To mediate these effects FLSmidth Airtech has implemented a new Vortex Free Baffle plates that ensures a sneakage and vortex free environment in the electrical field at the top and bottom of the collecting plate. Furthermore, our resent feature within discharge electrode design has the ability to operate at high gas velocities with fine particulate loading without corona quenching.

The case stories presented in this paper shows that by appropriate measures, the actual performance gets closer to the "Ideal ESP" - improvements in the field of fine particle removal can be achieved. Typically a reduction of the existing emission with a factor 1/3 to ½ can be achieved, with a resulting emission in the range 1-10 mg/Nm^3 and with a low concentration of fine particles.

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