Flue gas conditioning system for dust emission control
and improvement of wet FGD performance

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Keywords: Electrostatic Precipitator, Gas Cleaning, Flue Gas Conditioning, Gypsum Whiteness, Wet FGD

1. Introduction
It is already a worldwide trend that decade by decade the emission standards are getting more strict. It is of course extremely important that humanity takes care of the environment. Nevertheless, for majority of existing combustion plants, it means that whenever new environment regulations appear they have to either invest lot of money to meet these regulations or close the plant. In the second case, a decision to shut down the plant may sometimes be very prosaic; it may be due to lack of space for example.

In fact, this is a typical problem for power plants equipped with electrostatic precipitators (ESP). Usually, when new standard for dust emission cannot be reached, the first idea is to upgrade transformer rectifier system or to replace it on a modern one. It is not a cheap solution, however sometimes it brings positive effects. If it does not work, most probably the second thought would be to add additional field(s) to the ESP or to build a bag filter unit after (as second step of gas cleaning process). But what if there is no enough space for them? What if the plant was built in a time when nobody was aware that it may be necessary to expand it (so much) in future? Let’s be honest: who could expect that the legislation will change so much in the last 20 or 30 years?

This paper describes flue gas conditioning process (FGC) - a technology which was developed in order to increase performance of ESPs suffering with high resistivity dust. In many cases flue gas conditioning can be a very good remedy for the situation described above. Compared to the other “options” it is relatively cheap and does not require too much space, moreover its application is easy and fast. Selected case studies will be presented in Chapter 6.

2. Principle of operation
Flue gas conditioning (FGC) is an effective and developed technology used to enhance the performance of Electrostatic Precipitators dealing with high resistivity dust. An ESP equipped with FGC system can work at or even above its design efficiency and collect more fly ash.

 Burning high sulfur coal (over 2% of sulfur content) creates sufficient amount of SO₃ in flue gases to achieve optimum ash resistivity. As nowadays most of boilers burn low sulfur coal, the aim of conditioning process is to inject “missing” quantity of SO₃ into the flue gas stream at ESP inlet. Presence of sulfur trioxide in fumes influences ash properties; reduces its resistivity, increases cohesiveness and to certain degree change particle size [1]. All these modifications are important from precipitation effectiveness point of view, however dust resistivity has greatest potential to be used. Figure 1 shows how dust resistivity depends on SO₃ content and temperature of flue gas. Even small quantity (few ppm) of SO₃ added to flue gas stream causes significant drop of ash resistivity particularly in temperature range typical for flue gas temperature on ESP inlet.

![Fig. 1. Ash resistivity versus SO₃ content and gas temperature [2]](image)

It is commonly regarded that the resistivity 10¹⁰ to 10¹¹ Ω·cm is an optimal range. When ash resistivity is below this range (blue strip in the figure 1), the charged particles too easily release the charge which in consequence cause excessive entrainment of the collected ash. On the other hand, fly ash with
resistivity over $10^{11}$ Ω·cm exhibit opposite phenomena: dust is held on the collecting plates very tight leading to back corona which reduces ESP collecting efficiency [3].

Sulfur trioxide naturally combines with the moisture in the flue gas to create mist of sulfuric acid. Then, sulfuric acid immediately reacts with the fly ash particles to form a thin conductive film, which eventually lowers the fly ash resistivity. Therefore, the main aim of FGC is to keep the fly ash resistivity in a good precipitation range, allowing constantly low emission with a broad range of coal types. Required concentration of SO$_3$ in flue gas depends on many factors but usually does not exceed 10 to 15 ppm.

Figure 2 shows an example of how ESP efficiency depends on two factors: dust resistivity and specific collection area (SCA) of ESP.

![ESP efficiency vs. dust resistivity and SCA](image)

Fig. 2. ESP efficiency vs. dust resistivity and SCA [4]

Assuming that the target is to improve poor efficiency of existing ESP of low SCA (point A on green curve) there are two alternative solutions (not neglecting upgrade steps like e.g. CFD or SPC): either to increase size of ESP (see point B) or to reduce dust resistivity via flue gas conditioning (point C on green curve).

3. Modern FGC system
A layout of modern Pentol’s FGC installation is shown in the figure 3.

![FGC plant layout](image)

Fig. 3. FGC plant layout [2]:
(1) sulfur tank, (2) pumps, (3) flue gas duct,
(4) converter unit, (5) air blower, (6) air heater,
(7) sulfur burner, (8) catalytic converter

Depending on the availability of liquid or granulated sulfur, an appropriate sulfur storage tank (1) is chosen. The tank is heated up to approx. 130°C (process steam is usually used as heating medium) in order to reduce sulfur density. Also the sulfur transportation pipeline from the tank to the burner must be heated. The metering pump (2) transports liquid sulfur from the tank to the burner (7). Combustion air to the burner is first preheated by means of electrical heaters (6) and then delivered (by fan(5)) to the burner. Heating the air stream well above the self-ignition temperature of sulfur assures that there is no need of using additional sulfur ignition system. Next, SO$_2$ from the burner is converted to SO$_3$ by means of the catalyzer (8). The last stage of the process is injection of SO3/air mixture to the flue gas duct via injection probes (3).

Nowadays, FGC installations work automatically (following the boiler load) and are controlled via remote access. Therefore they require minimum attention from the Operator staff - in practice maintenance works are limited to periodic check-ups and refilling of the sulfur tank.

4. ESP condition before FGC trial
General rule says that optimum performance of FGC is achieved when ESP mechanical and electrical conditions are good, however case C in table 1 below shows that even in case of extremely poor ESP conditions FGC may result in significant reduction in dust emissions.

Thorough check of ESP condition is necessary to determine feasibility of FGC and to agree with the plant operator necessary scope of works to be done to achieve its optimum performance. One of the most efficient diagnostic tools are current/voltage characteristics. Figure 4 shows characteristics representative for normal and abnormal operation of ESP [5]. Curve 4 indicates properly working ESP with high resistivity ash and this is an ideal application for FGC, also ESPs associated with curves 3 (typical example of back corona) and 5 can be considered. In case of the other curves:

- curve 1 represents short circuit, often caused by problems with ash evacuation system,
- curve 2 is associated with sparking, probably caused by uneven spacing between electrodes and plates,
- curve 6 reflects symptoms of electrodes covered by excessive layer of ash (possibly caused by the failure of rapping system).
leading to significant reduction of ESP efficiency. Long term practice in one of Polish biggest steelworks supported by scientifically supervised trial in another Polish steelworks confirm this rule [5, 6]. Sintering plants are a real challenge for ESP designers. Their efficiency is always lower in comparison with coal fired boilers. Some ESPs in sintering plants even being in decent technical condition reach without FGC efficiency as low as 70-80%. Flue gas from sintering process is much more difficult to be treated due to dust composition and altering process parameters. There are, however, several positive applications of FGC in sintering plants. Among others, a successful trial in Poland (performed in early 90’s) has been documented [5]. In that case reduction of solids emission by approx. 60% was achieved. It is, however, to point out that similar trial conducted in the same plant 25 years later did not yet bring similarly spectacular result. Tests are still in progress and it is too early to summarize its results but factors objectively limiting the performance of FGC are already known: first of all very fine structure of dust (resulting from sintering strand modification) and changed composition of sinter (among others relatively high chlorine content).

Nowadays, more and more often FGCs are used in combination with wet FGD. Flue gas desulfurization plants downstream of the ESP receive less fly ash. With reduced dust load arriving in the FGD, the gypsum can grow to a larger size containing less moisture. In addition the color of gypsum is much whiter. These are critical parameters determining gypsum quality and its price. In countries like Germany or France majority of conditioning installations are recently installed to protect wet FGD plants. Experiences from existing power unit equipped with FGD is described in next chapter.

6. Case studies

Pentol is a worldwide well-known brand (group of companies under the Pentomag AG Holding), offering its own products for power industry (among others FGC installations and variety of fuel additives). In the last 30 years the company has delivered over 130 of FGC units to Customers worldwide.

**Le Havre IV**[2] is a coal-fired Power Plant (with 600 MWe unit) commissioned in 1983. Before year 2000, dust emission was in the range of 30 and 40 mg/Nm³ – always below standard limit of 50 mg/Nm³. After 2000, the situation changed due to change of coal being fired. Partially switching to imported coal (South African) had a negative effect on ash resistivity: it rose up above 10·10¹¹ Ω·cm. With this kind of coal dust emission could easily reach 110mg/Nm³. Moreover, high concentration of dust at the ESP outlet resulted in very difficult operating conditions for desulfurization system limiting its performance and reliability. In 2004 SO₂ injection system has been implemented at the plant. The system included:

Tab. 1. Examples of ESP efficiency and dust emission improvement

<table>
<thead>
<tr>
<th>Case</th>
<th>Boiler size [t/h] and fuel</th>
<th>ESP efficiency with FGC</th>
<th>Dust emission [t/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>w/o FGC</td>
<td>with FGC</td>
</tr>
<tr>
<td>A</td>
<td>430 pf</td>
<td>98.0%</td>
<td>99.5%</td>
</tr>
<tr>
<td>B</td>
<td>380 pf</td>
<td>97.4%</td>
<td>99.4%</td>
</tr>
<tr>
<td>C</td>
<td>140 pf</td>
<td>79.5%</td>
<td>94.4%</td>
</tr>
<tr>
<td>D</td>
<td>230 pf+g</td>
<td>97</td>
<td>18</td>
</tr>
</tbody>
</table>

Key to the table: pf – pulverized coal, g – blend of blast furnace gas and coke gas.

Although, coal fired pulverized coal boilers are still the most common application of FGC, there are two other applications worth to mention: Boilers of CHPs installed in steelworks, usually burning blast furnace and coke gas together with coal. It looks like a paradox but ESP performance dramatically decreases when process gases are burnt together with coal (in comparison to burning coal only). Dust load before ESP in such case is lower but burning gas based on CO (instead of hydrocarbons) significantly reduces moisture content in flue gases.
- liquid sulphur storage and pumps,
- combustion chamber to oxidize sulphur to SO₂,
- catalytic converter to transform SO₂ to SO₃,
- nozzles for SO₃ injection into the flue gas upstream of the precipitator.

Application of FGC enabled the plant to decrease dust resistivity and (thus) meet dust emission limits <50 mg/Nm³ regardless of the coal being fired. Average dust abatement efficiency due to SO₃ injection is 50% with possibility of 75 to 85%. Low electrical consumption (50 kW) as well as low maintenance and sulfur costs (~0,0012 €/GJ and 0,001 €/GJ respectively) are undoubtedly advantageous of the system.

**Unit 3 of HKW Herne** [7], operated by STEAG AG was designed as a two Benson boilers with a thermal capacity of the firing system of 805 MW (300 MWe). Design coal was a high ash fuel with a calorific value of 19 MJ/kg and approx. 30 % LOI (related to ash free coal).

In 1986 the boiler was converted to burn 100% low volatile coal to support the coal mines on the west side of the Rhine. During the conversion of the boiler, ball mills were installed to grid the coal to very small size required to burn low volatile coal (<10% residual on a 90 µm sieve).

To compensate for the poor ignition behavior and lower burn-up rate of the low volatile coal, an additional ESP had to be installed. During the 80's, a desulfurization unit and a “low dust” SCR were installed.

In spite of the conversion from high ash to low volatile coal, the combustion remained the slag tap furnace with the advantage of a high primary ash retention.

Despite the high primary ash retention (50-60%) of the tap furnace, the ashes from stag tap furnaces are more difficult to collect in ESs because of the very fine grain sizes. In addition, the small dust particle size ad to the so called space charge effect and lower collection efficiency of the ESP.

After conversion to low volatile coal the design dust collection parameters were as specified in the table 1.

<table>
<thead>
<tr>
<th>Tab. 1. Dust collection parameters</th>
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<tbody>
<tr>
<td>Inlet dust loading</td>
</tr>
<tr>
<td>Outlet dust loading</td>
</tr>
<tr>
<td>Efficiency</td>
</tr>
<tr>
<td>Flue gas volume</td>
</tr>
<tr>
<td>LOI in filter dust</td>
</tr>
<tr>
<td>O₂ content</td>
</tr>
</tbody>
</table>

During commissioning, the outlet dust loading was 70 mg/Nm³ respectively 120 mg/Nm³ during soot blowing.

Trials were conducted to find out if pulsing could solve the problem with high emission burning low volatile coal. However, no significant changes or improvements were measured on the outlet dust loadings.

From 1995, imported coals were burned in boiler no. 3. This led, the first time for the power plant Herne, to load restriction restrictions due to exceeding outlet dust loading from the ESPs.

Thereafter, various optimization measures were undertaken as remedy to the problem mentioned before:

- in 1996: extension of the 3rd ESP by approx. 10%,
- from 1998 to 2000: installation of a new ESP control system,
- in 2000: flow optimization with the aid of computer simulations,
- in 2001: optimization of air heater leakage to reduce the load to the flue gas side.

By the end of 2002, after closure of the low volatile coal mines in Germany, the increased usage of imported coals reactivated dust emission problem in new dimensions.

Trial to improve the dust collection in mixing high sulfur coal (sulfur content approx. 3%) with low sulfur coal, were not particularly successful.

Further usage of imported coals (also from South Africa), have limited the boiler availability due to increased dust loading into the FGD resulting in forced outages and expensive FGD cleaning actions.

Additionally, the high dust load to the FGD affects the whiteness of the gypsum. Instead of being able to sell the gypsum, it has to be disposed of at high costs.

To find out why the ESP did not collect the dust at its design level, flue gas dust resistivity measurements have been conducted. The results of the measurements showed a dust resistivity of up to 3·10¹³ Ω cm.

The measured SO₃ concentration of approx. 1 mg/Nm³ (equipment accuracy ±5 mg) shows that practically no SO₃ is reaching the ESP.

In view of these measurements, a trial with SO₃ FGC system was conducted in 2004. The FGC system was installed in boiler 3 during the boiler revision in June 2004. After the period of 3 months, the FGC system remained in operation and since then, SO₃ has been injected into the raw gas ahead of the ESP continuously.

The results of the FGC application can be summarized as follows:

- the FGC unit has been running continuously since June 2004 without failure,
- the dust emission levels are:
  - after FGC:
    - without FGC: 200-500 mg/Nm³,
    - with FGC: <30 mg/Nm³,
  - at the chimney (after FGD):
    - without FGC: >20 mg/Nm³,
    - with FGC: <5 mg/Nm³,
- ESP plates were cleaned by the conditioning
- whiteness of the gypsum was increased from 70% to 90%
- additional cleaning cycles for the FGD have not been required since June 2004
- no negative effects of the fly ash return to the furnace
there are no signs of any corrosion. Picture 5 shows trends of gypsum whiteness and dust concentration before and after application of FGD.

Another good example of strong confidence in FGC is Mannheim Power Station where not so long ago (in 2015) a new 911 MW power unit has been commissioned. At present, it is a final stage of erection/adaptation process of FGC unit on it. It is important, that most components of “new” FGC unit come from an old FGC unit which was operated on one of 2 recently decommissioned blocks. It would not be anything unusual, if new ESP was not able to meet current emission standards. However, the newly built ESP works fine and a problem with excessive dust emission does not exist. In this case, encouraged by the several years of positive experience with using FGC, the Plant management decided to stay with FGC in order to have a “plan B” in case of unexpected events in the future (e.g.: stricter emission standards or changing of coal on more resistive).

7. Summary

In the last two decades FGC underwent vigorous development and became fully automated process. With its long life-time and high reliability Pentol’s FGC installations are state-of-art product. In most cases, for new Customers it is a matter of 3 months trial, to evaluate advantageous of FGC, which are:

- great flexibility for coal quality,
- no load restriction by dust emission limit,
- decrease of wear and tear at the ID fans,
- decrease of dust load at FGD inlet:
  - possible whiteness of gypsum > 85%,
  - expected better crystal growth,
  - reduced FGD maintenance expenses,
- keeping the emission limit of 20 mg/Nm³ without expensive ESP extension,
- installation of the SO₃ conditioning plant during plant operation (only short outage necessary for assembly of injection nozzles),
- investment costs relatively low (particularly compared to ESP size increase),
- operation costs relatively low (the only consumable material is sulfur),
- SO₂ conditioning plant fully integrated with DCS. It is very rarely situation when after the trial Customer decide to not purchase or rent the FGC unit due to its many advantages.

References