Electrostatic precipitator for broad band coal with 6 mg outlet dust

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As lower and lower limit values for the emission of dusts and other air polluting substances are established, it is necessary when building new power plants, to respond to the requirements with new constructural measures.

GDF Suez ordered two power plants for which the outlet dust density of the electrostatic precipitators should be less than six milligrams per normal cubic meter. The boilers for the generators of 790 MW each, should be fed with broad band types of black coal. The power plants are located in Wilhelmshaven in Germany and in Rotterdam in the Netherlands.

To achieve the challenging goal of six milligrams, particularly in combination with the broad band coal fuel, it was decided to build a six zone ESP and equip it with some kind of high voltage system with a low ripple outlet voltage.

A second limit which was specified for the electrostatic precipitator, was the maximum power which is permitted for the precipitation process. The electrostatic precipitator must not exceed 880 kW electrical input power.

1 Power Plant Technology

The coal fired power plants in Rotterdam in Netherlands and in Wilhelmshaven in Germany have been planned to be the most efficient and least air polluting ones which have ever been built [1]. The planning and approval process started in 2007. In 2015 the power plant in Wilhelmshaven started its commercial production of electrical energy, the power plant in Rotterdam went to commercial operation at a similar time (Sources for the start of commercial operation name different dates between 2014 and 2015 [2]).

The power plants are located close to the Sea, therefore cost and energy consuming cooling towers are not necessary, the cooling water is put directly from the Sea.

The nominal power of the generator is 790 MWel (there can be found different numbers for the nominal electrical power in different publications, but 790 MWel seems the correct one), the specified power efficiency is 46 %. For comparison, the average power efficiency of coal fired power plants in Germany is about 38 %; with reference to other German power plants, that increase in efficiency rate reduces the emission of carbon dioxide by 900 thousand tons per year. To achieve that challenging efficiency rate, there had to be used some technical specialties:

- Take the cooling water from the Sea instead usage of a cooling tower,
- Increase temperature and pressure in the boiler, use special steels and welding procedures to achieve the required values,
- Use latest technologies in the flue gas cleaning process, e.g. three phase current technology in the electrostatic precipitator.

The emission values for the power plant in Wilhelmshaven are listed in table 1 with comparison to the legal limits [3].

<table>
<thead>
<tr>
<th>Emission</th>
<th>Legal Limits</th>
<th>Limits at CFPP Wilhelmshaven</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOₓ</td>
<td>200</td>
<td>80</td>
</tr>
<tr>
<td>SOₓ</td>
<td>200</td>
<td>70</td>
</tr>
<tr>
<td>Dust</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 1: Limit values of the Engie power plant in Wilhelmshaven with comparison to legal values according 13. BImSchV; the dust limit in the table for CFPP Wilhelmshaven differs from the required dust limit of the specification which is 6 mg/Nm³

The waste gas purification system is a three stage system. In the first stage a denitrification system with catalyst removes the nitric oxides, in the second stage the electrostatic precipitator takes care for dust removal, and in the third stage the desulfuration system takes out the sulfur oxides.

For further improvements in the future a carbon dioxide accumulator can be added to collect the CO₂. The necessary place for the system is already included in the structure.

As is normal today in the Global Network thinking, the fuel for the power plant shall not be of a specific coal type, but be taken from where ever the price is the lowest, e.g. Columbia, South Africa, Australia etc. Each of that coal types has its special attributes, regarding the dust resistance, the sulfur content etc. Therefore the technics and technologies which are taken for the power plant, have to consider the worst conditions which can occur, e.g. low or high dust resistance values, with or without sulfur content etc.
2 The Electrostatic Precipitator

The electrostatic precipitator for the CFPP Wilhelmshaven and Rotterdam are a dry type with horizontal air movement. They are divided in four chambers with six fields each (figure 2) [4].

![Figure 1: Principle scheme of the electrostatic precipitator which has different wall distances and field lengths to adjust the fields to the different precipitation behavior of different dust particles in the fly ash](image1)

The fluid velocity in the waste gas duct is according construction calculations 12.5 m/s in full load operation [5]. Inside the electrostatic precipitator the fluid velocity is reduced to < 1 m/s, which leads to a real treatment time of > 27 s for the dust particles (the time the particles move inside an electrical field).

There are two different mechanisms for the charging of the particles [6]. With the so called impact charging the bigger particles are charged within less than a second. But the small particles (d < 0.2 µm) which are charged with the diffusion charge process, need some seconds of treatment time. Therefore it is necessary to have a certain length of the ESP.

To achieve that low fluid velocity for the long treatment time, the width x height dimension is 56.4 m x 14.24 m, the total length is 34,615 m. The fields 1 to 5 have a length of 5,645 m, while the last field has a length of 6.39 m. The wall distance of the fields 1 and 2 is 400 mm, in the other fields it is 486 mm. The discharge electrodes are pipe and spike types in the Balcke Dürr specific bi-corona technology [7]. Bi-corona technology means that the shape of the discharge electrodes are different for the ionization and for the collection area inside the electrostatic precipitator fields. The all over pressure loss of the waste gas through the electrostatic precipitator shall be less than 3 mbar.

The precipitation area of the fields 1 and 2 is 4589 m², for the fields 3 to 5 it is 3779 m² each and for the field 6 it is 4377 m². In total the precipitation area is 99568 m².

The rapping systems for the discharge electrodes and the high voltage power supplies are placed on top of the cold roof in special housings, which dimensions are adjusted to the required sizes to minimize masses.

With CFD (Computational Fluid Dynamics) analysis methods the shape and positions of the baffle plates was optimized in the design (figure 2).

![Figure 2: CFD model of the electrostatic precipitator to optimize the baffle plates](image2)

Later in the construction process there were built acrylic glass models for further optimization of the fluid current flow.

For the construction engineers of Balcke Dürr it was clear to use some kind of high voltage power supplies with an as high as possible voltage time area for the ambitious goal of 6 mg/Nm³ for the outlet dust density. At the same time there exists the requirement that the overall power used for the electrostatic precipitator must not exceed 880 kW.

3 The High Voltage Power Supply

There are mainly two different kinds of high voltage power supplies with a voltage time area close to 100 % available in the market [8]:

- The medium and high frequency controlled switched mode power supplies with IGBT technology.
- The grid frequency based three phase current systems which are power controlled by thyristors.

High voltage systems based on the switched mode power supply technology are rather complex in their architecture (figure 3).

The output voltage has a low ripple due to the comparably high frequency which is transformed, but the IGBT do not endure overcurrent situations very well; therefore the power supply switches off whenever a beginning spark is detected to avoid the high current of a spark over; even if that detected flash would not have resulted in a spark.

High voltage power supplies based on grid frequency technology are quite simple in their architecture (figures 4, 5).
Contrary to the IGBT, the thyristors are not able to switch off a flowing current whenever is needed. They keep conductive until the current goes down to zero, which happens in every zero crossing of the sine waves. But the thyristor is able to endure its multiple nominal current, at least for the time of a half wave; therefore a thyristor controlled system can operate very close to the limit voltage of an electrostatic precipitator.

The precipitation efficiency of an electrostatic precipitator depends on the electric field strength which is set up between the electrodes; the higher the field strength the better for the ESP. To detect the maximum field strength (which is the maximum voltage) it is necessary to have a spark over from time to time to find the limit voltage; as the situation inside the ESP is quite dynamic, the limit voltage is permanently changing; hence indicative sparks are necessary; a recommended spark rate is about 5 ... 10 per minute.

Another issue, especially in the situation of the power plants of Wilhelmshaven and of Rotterdam, is the required maximum power which is permitted for the operation: 880 kW. An estimation of the maximum power which can be put into the electrostatic precipitator for its operation, gives a number of far more than 2 MW. To reduce the power, it were a bad idea just to reduce the voltage, as the efficiency of the precipitation would decrease immediately and significantly. To reduce the power and at the same time keep the precipitation rate high, there is used the so called pulse mode at the high voltage supplies (figure 6).

With this operation mode, it is possible to keep the voltage inside the electrostatic precipitator as high as possible and at the same time reduce the power significantly, as in the areas between the voltage pulses, there is flowing nearly no electrical current.
which means there is consumed nearly no electrical power.

With a power control loop the voltage between the voltage pulses can even be adjusted to the level which is optimal for a required outlet dust level (figure 7).

When the pulse mode is chosen for the electrostatic precipitator, it is necessary, that the power supply is able to drive enough energy into the capacitance of the electrostatic precipitator to charge it to full voltage within the short pulse. That means that during the pulse a multiple of the nominal current is flowing out of the high voltage supply. That means further on, that despite the requirement of very low power consumption at the electrostatic precipitator, the investment for the equipment has to be adjusted to high power systems, beginning at the supply transformer station, over the power cabling down to the high voltage control cubicles and the transformer rectifier sets.

4 The Acceptance Tests

As mentioned before, there were two seemingly contrary requirements about the performance of the electrostatic precipitator of the power plants in Rotterdam and in Wilhelmshaven. At the one hand, the outlet dust density must not exceed 6 mg/Nm³, including the soot blowing phase, on the other hand that challenging result had to be achieved with a power of less than 880 kW for the high voltage supplies, for a wide variety of black coal types.

After a period of adjusting the parameters of the electrostatic precipitator, beginning at the pulse rates of the high voltage systems, depending on the field position in the ESP, over the regulation factors of the closed loop outlet dust control, up to the rapping cycle and break times, finally the acceptance tests were performed.

Wilhelmshaven: The minimum limit value for the input power was set to 400 kW. The set value for the outlet dust was 3 mg/Nm³. Over the test period the controller kept the power for the high voltage systems to 400 kW, as the actual value of the the outlet dust density was well below 3 mg/Nm³ all the time.

Rotterdam: In Rotterdam for the acceptance test one of the ESP fields was operated without electrical power. The set parameters were similar to the test in Wilhelmshaven. The average value for the outlet dust density over the test period was well below 3 mg/Nm³.

5 Conclusion

Electrostatic precipitators are a very well known technology to clean waste gases of many kinds of industrial processes. While in the old days the generation of the high voltage was a limiting factor for many other construction details in the ESP, the state of the art high voltage technology, based on fast and endurable semiconductor switches, in combination with high performance digital and analog controllers, enables the mechanical construction engineers to optimize the electrostatic precipitator also from the mechanical point of view, e.g. by increasing the wall distance to values of 500 mm.

Another improving factor for the electrostatic precipitator is the shaping of the high voltage according to the requirements of the process, and therefore fine tune the ESP for a maximum performance.

The two power plants of Wilhelmshaven and of Rotterdam can be taken as references that it is possible with a reasonable effort for the electrostatic precipitator, to meet the actual emission limits and still have reserves for the future.

5 References
[8] Handbuch Elektrofilter, von Stackelberg Josef, Schmoch Manfred, Springer Verlag, 01/2018