BRINDISI POWER PLANT

Dust emission reduction benchmark study

Enel Produzione S.p.A.

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EXECUTIVE SUMMARY

The revised environmental permit for Brindisi South or "Frederico II" power plant (further: Brindisi power plant), issued at July 24th 2017, requires a report on electrostatic precipitators (ESP) efficiency on units BS1 and BS2 when compared to fabric filter (FF) as installed on units BS3 and BS4, considering total dust emission levels and the PM_{10} and $PM_{2.5}$ share. The new dust emission limit value (ELV) for the four units is 15 mg/Nm^3, whereas the previous ELV was 20 mg/Nm^3.

The aim of this report is to provide Enel with general information on the performance and operations of ESPs and FFs for dust emission reduction. This information, together with operational and maintenance experiences in Brindisi, is applied to prepare a benchmark on the use of ESPs and FFs at the Brindisi power plant.

Based on the assessment presented in this report, the following conclusions are drawn with respect to the application of ESPs and FFs at the Brindisi power plant:

- The BREF LCP reports hardly any difference between ESPs and FFs. It reports the potential for a higher removal of fine dust ($PM_{2.5}$ and PM_{10}) by FFs, while the costs and the electricity consumption of FFs are higher than for ESPs
- BAT 22 specifies the BAT-associated emission levels (BAT-AELs) for dust emissions to air from coal/lignite fired LCPs. In these BAT-AELs no difference is made between ESPs and FFs: the BAT conclusions do not make a distinction between the application of ESPs and FFs in large coal fired power plants
- Based on CEMS dust measurements, guarantee measurements and quarterly PM_{10} and $PM_{2.5}$ measurements at the four units of the Brindisi power plant it can be concluded that the performance of the ESPs and the FFs at Brindisi power station are well comparable and lead to similar emissions of dust, PM_{10} and $PM_{2.5}$
- At the Brindisi power plant, FFs show a high number of annual failures – about 4 times higher than for ESPs - and no improvement has been observed over the years. This observation is in line with general experiences on ESPs and FFs as reported in open literature and may lead to additional emissions.

Overall, based on operational, maintenance and performance aspects, it is concluded that the FFs do not outperform the ESPs at the Brindisi power plant. As the BAT conclusions do not make a distinction between ESPs and FFs for the application at large (coal fired) combustion plants, DNV GL believes that Enel is free in selecting ESPs or FFs to reduce emissions of dust at the Brindisi power plant.

1 INTRODUCTION AND BACKGROUND

The revised environmental permit for Brindisi South or “Frederico II” power plant (further: Brindisi power plant), issued at July 24th 2017, requires a report on electrostatic precipitators (ESP) efficiency on units BS1 and BS2 when compared to fabric filter (FF) as installed on units BS3 and BS4, considering total dust emission levels and the PM_{10} and $PM_{2.5}$ share. The new dust ELV for the four units is 15 mg/Nm^3, whereas the previous ELV was 20 mg/Nm^3.

The aim of this report is to provide Enel with general information on the performance and operations of ESPs and FFs for dust emission reduction. This information, together with operational and maintenance experiences in Brindisi, is applied to prepare a benchmark on the use of ESPs and FFs at the Brindisi power plant.

Chapter 2 of this report describes the general emission reduction performance and the associated emission values of ESPs and FFs. This information is based on open literature, such as the BREF documents and supplemental information on ESPs and FFs operational experiences. The impact of combining ESPs or FFs with wet flue gas desulphurization (FGD) on dust emissions is discussed too.

Chapter 3 focusses on the Brindisi power plant and includes general power plant characteristics, historical dust emission levels and operational and maintenance experiences with both ESPs and FFs.

Chapter 4 holds the discussion of the results and includes the benchmark between the performance and operation of ESPs versus FFs at the Brindisi power plant.

In Chapter 5 the conclusions of this report are presented.

2 GENERAL BENCHMARK ON ESP AND FF PERFORMANCE

2.1 BAT reference document for Large Combustion Plants

The European Industrial Emission Directive (IED 2010/75/EU) requires that environmental performance of industrial installations shall be based on the emission levels associated with the Best Available Techniques (BAT) as laid down in the BAT conclusions of the BAT reference documents (BREFs). For large combustion plants (LCPs) the BREF LCP is the relevant reference document. Recently (August 17, 2017), these BAT conclusions have been published in the European Journal [EU 2017/1442].

These BAT conclusions form the reference for setting permit conditions for LCPs and competent authorities should set emission limit values which ensure that, under normal operating conditions, emissions do not exceed the BAT associated emission levels.

2.1.1 Description of Techniques

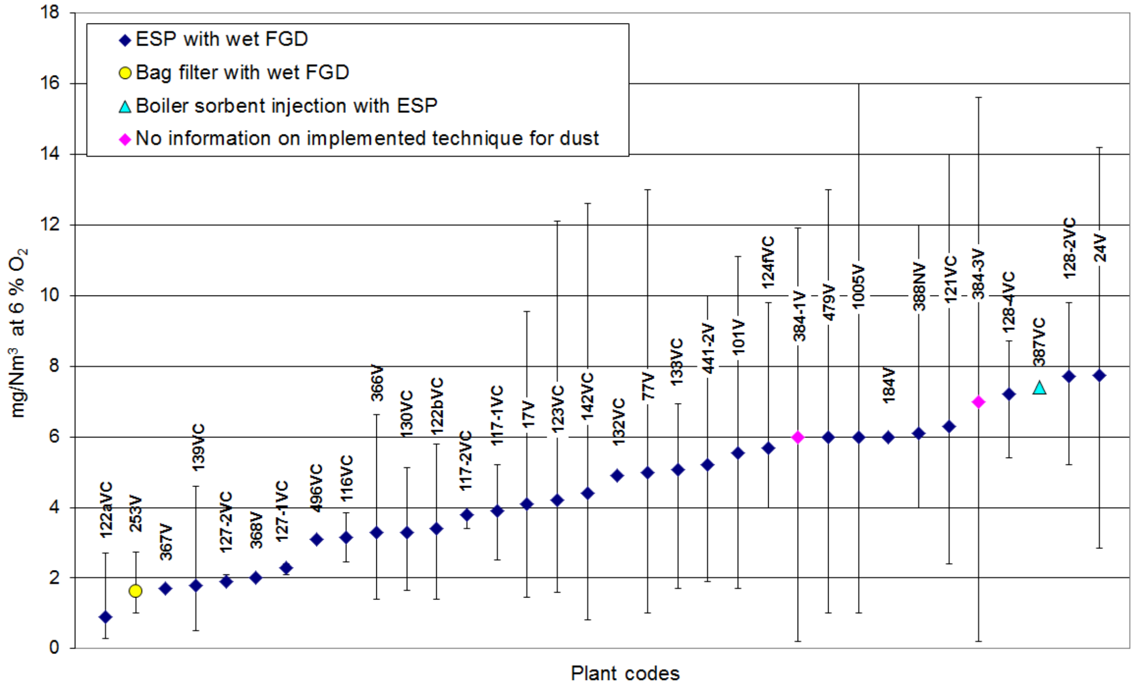
The BREF LCP describes in Chapter 3 general techniques and in Chapter 5 applied techniques and techniques to consider in the determination of BAT. In this chapter these techniques are summarized and commented on.

These techniques are based on a data collection in 2012 at the start of the update of the BREF LCP. Figure 2-1 shows the results of this data collection for yearly average dust emissions from well-performing coal- and/or lignite-fired combustion plants of more than 1,000 MW_{th}, operated between 2,400 h/a and 8,700 h/a, with an equivalent full load factor in general above 62%. The reported plants were commissioned between 1968 and 2009 and they monitor their dust emissions continuously. It should be noted that apart from plant no. 253 (Enel Centrale Torrervaldaliga Nord Canna Gruppo 4) all plants are equipped with ESPs.

Different techniques, such as ESPs, FFs and wet scrubbers, are commonly used to remove dust from the flue gas. As also can be derived from figure 2-1, the ESP is (by far) the most commonly used technique in Europe in large combustion plants using coal or lignite as a fuel. FFs are also relatively common, mainly used downstream of dry and semi-dry techniques to reduce SO_x emissions.

ESPs operate over a temperature range of 80–220 °C (cold-side ESPs) or 300–450 °C (hot-side ESPs), while FFs generally operate over a temperature range of 120–220 °C.

The choice between applying an ESP or a FF generally depends on among the fuel type, plant size and configuration, and boiler type. Both technologies are highly efficient devices for dust removal, which can be further improved by flue gas conditioning.



* 5th and 95th percentile of short-term values are represented as span bars

Figure 2-1 Dust emissions from well-performing coal- and/or lignite-fired plants of more than 1,000 MW_{th}

Table 2-1 gives an overview of the removal efficiencies of ESPs and FFs based on the tables 3.5 and 3.6 of respectively section 3.2.2.1.1 and section 3.2.2.1.2 of the BREF LCP. Wet scrubbers downstream of the ESPs or FFs generally remove >50% of particulate matter present in the flue gases downstream of the ESPs/FFs.

Table 2-1 Removal efficiency (%) of ESPs and FFs

Particle size	< 1 µm	2 µm	5 µm	> 10 µm
ESP	> 96.5	> 98.3	> 99.95	> 99.95
FF	> 99.6	> 99.6	> 99.90	> 99.95

Table 2-2 provides a comparison between ESPs and FFs based on table 5.31 in section 5.1.3.4.1 of the BREF LCP (the general techniques to be considered for the determination of BAT for the prevention and control of dust emissions).

Based on the above, one can conclude that the operating experiences as reported in the BREF LCP make hardly any difference between ESPs and FFs. The BREF LCP reports especially the removal of fine dust ($PM_{2.5}$ and PM_{10}) by FFs, while the costs and electricity consumption of FFs are higher than for ESPs.

Table 2-2 Comparison between ESPs and FFs on topics relevant for the determination of BAT

	ESP	FF
Achieved environmental benefits	Reduction of particulate emissions. Removal of metals as a co-benefit	Reduction of particulate emissions, particularly fine dust ($PM_{2.5}$ and PM_{10}). Removal of metals as a co-benefit
Environmental performance and operational data	High operational experience. The dust reduction rate associated with the use of an ESP is considered to be 99.5% or higher	High operational experience. The dust reduction rate associated with the use of a BF is considered to be 99.95% or higher
Cross-media effects	Energy consumption (0.1–0.2 percentage points). Increased waste generation	The efficiency of the power plant is reduced by 0.1–0.4 percentage points. Bag life decreases with higher sulphur content in the fuel and when using upstream dry sorbent injection
Technical considerations relevant to applicability	Generally applicable	Generally applicable
Economics	Costs from EUR 13–60 per kW are reported. The figures do not include investment costs for the collected ash handling and transportation systems, which for high ash content lignite are significantly high	Operating and maintenance costs are higher than for an ESP

2.1.2 BAT conclusions for large combustion plants

For dust emissions to air from coal fired power plants the BAT conclusion BAT 22 is relevant. BAT 22 describes that amongst others ESPs, FFs, wet flue gas desulphurisation, or combinations of these techniques are BAT. ESPs and FFs are generally applicable. Furthermore, BAT 22 specifies the BAT-associated emission levels (BAT-AELs) for dust emissions to air from coal/lignite fired LCPs. In these BAT-AELs no difference is made between ESPs and FFs.

Based on the above one can conclude that the BAT conclusions do not make a distinction between ESPs and FFs.

2.2 Additional information from open literature

In the previous paragraph information from BREF LCP (BAT document) on the use of ESPs and FFs at large coal fired combustion plants has been provided and discussed. Additional open literature was assessed to collect more information on the (dis)advantages of the use of both ESPs and FFs at coal fired power plants [ICESP, 2006], [CPCB, 2007], [Steag, 2013], [Black & Veitch, 2013], [Amec FW, 2016].

As indicated earlier in this report, the ESP is by far the most commonly applied dust abatement technology at coal fired power plants in Europe. In the US FFs are more commonly applied, but its market share – particularly for large coal fired power plants – is limited too. The situation is even more pronounced in China, where the share of FFs was <0.3% and the share of ESPs was 88.9% for dust abatement in coal fired power plants [CSEP, 2003].

There are four main reasons for the high level of power industry penetration of ESPs versus FFs:

a) ESPs show a higher reliability and require less maintenance when compared to FFs

b) ESPs show favorable operational characteristics when compared to FFs

c) ESPs show favorable overall economics when compared to FFs

d) Modern and upgraded ESPs show similar removal performance when compared to FFs.

a) Higher reliability and less maintenance of ESPs

When compared to FFs, ESPs show a higher reliability and less maintenance as:

- The construction of FFs is complicated when compared to ESPs and includes thousands of bags and dozens of valves that are used for the cleaning cycle of the bags
- The bags of a FF are susceptible to:
    - high flue gas temperatures, causing bag cloth material failure. ESPs are more flexible towards high flue gas temperature (peaks) up to 450 ºC [Steag, 2013]
    - low flue gas temperatures, causing clogging initiated by acid dew-point condensation. Both ESPs and FFs may show corrosion at low flue gas temperatures
    - flue gas flow rate boosts, initiated by e.g. boiler leakages or explosive boiler cleaning. ESPs can handle flue gas boosts more easily
    - high share of very fine dust, penetrating the bag cloth material requiring additional bag cleaning or even replacement
    - using heavy fuel oil for plant start-up
- The bags in a FF need to be replaced typically every 3-5 years, whereas the lifetime of ESP internals is 15-20 years. Careful selection of cloth material is very important. Examples are available where filter bags had a lifetime of 12,500 hours only [CPCB, 2007]
- Due to the higher maintenance frequency and the typical construction of a FF (holding high levels of deposited fly ash during a plant stop), maintenance personnel is more extensively exposed to fly ash during maintenance activities at a FF.

b) Favorable operational characteristics of ESP

- As the pressure drop across ESPs is much lower than for FFs, the capacity of the induced draught (ID) fan can be significantly lower. In case of a retrofit (from ESP to FF) the ID fan may reach the limit of its capacity over time (due to fouling of components), resulting in a limitation of the plant's power output and an increased specific CO_2 output
- ESPs are not susceptible to boosts in flue gas flowrate (see above)
- For FFs, bag failure rates of 10 to 300 bags per 1,000 operating hours have been reported in a large coal fired power plant in South Africa, dependent on the type of bag cloth material installed. ESP failures may generally be repaired during a major overhaul and do not require earlier action [ICESP, 2006].

c) Favorable economics of ESP

In general, ESPs show favorable economics when compared to FFs as:

- The overall power consumption is higher (typically 50%) for FFs when compared to ESPs, mainly caused by the additional pressure drop across the filter bags and thus the power consumption of the ID fans
- Maintenance costs are significantly higher for FFs (typically 50-100%) when compared to ESPs.

Although investment cost for FFs are in most cases lower when compared to ESPs, the net economics are clearly favorable for ESPs.

d) Similar dust removal performance of ESPs and FFs

In general, the removal rates of dust, and particularly of PM_{10} and $PM_{2.5}$, are slightly better for FFs when compared to ESPs (see Paragraph 2.1). However, the following remarks should be made:

- Modern ESPs can compete with FFs and can achieve dust emission levels at coal fired power plants of 1-3 mg/Nm^3, which is in the lowest range of FF capabilities
- Combustion of certain types of coal generates ashes with an unfavorable electric resistivity value, which are not effectively removed from the flue gases by ESPs. An example is Powder River Basis Coal in the US. In Europe, these types of coal are hardly applied and certainly not without blending with other types of hard coal
- Due to the higher reliability of ESPs, the annual dust emission may even be lower than for FFs: although measures will be taken soon after bag failure, additional emissions may occur in the meantime.

2.3 Impact of wet FGD operation on additional dust emission reduction

At large coal fired power plants the dust collection unit (ESP or FF) is generally followed by a flue gas desulphurization (FGD) unit. In modern power plants the clear majority of the FGD unit is of the wet lime(stone) gypsum type. In the scrubber system of these FGD units, additional removal of fly ash from the flue gases is established. The typical fly ash removal efficiency of a wet FGD scrubber is 50-70%. As an example: if the fly ash concentration in the flue gases downstream of the ESP or FF is 10 mg/Nm^3, a stack fly ash emission in the range of 3-5 mg/Nm^3 can be expected.

3 PERFORMANCE OF ESP AND FF AT BRINDISI POWER PLANT

3.1 Characteristics of the Brindisi power plant

The Brindisi South or “Frederico II” power plant consists of four coal fired units, each generating 660 MW electricity, adding up to a total plant capacity of 2640 MW. The four units have been commissioned between 1991 and 1993. Selective Catalytic Reduction (SCR) and wet flue gas desulphurization (FGD) are in operation since 1998.

It is to be noted that the units BS1 and BS2 are equipped with a FGD unit based on Lurgi Bischoff gas/liquid countercurrent scrubber technology, whereas the units BS3 and BS4 are equipped with Mitsubishi gas/liquid co-current scrubber technology. This difference in applied FGD technology may have impact on the emissions of dust.

The units BS1 and BS2 are equipped with ESPs to remove fly ash from the flue gases. The existing ESPs have been upgraded in 2015-2016 by installing Switched Integrated Rectifiers (SIR). Further information on SIR is available from [Alstom, 2001] and on the website of GE power [GE Power, 2017]. Guarantee measurements have been executed (2015-2016) and the results of these are presented in Paragraph 3.2. Optimization of the SIR systems has been accomplished in March 2017.

In 2010-2012 the existing ESPs of the units BS3 and BS4 have been replaced by FFs. Guarantee measurements have been executed (2012) and the results of these are presented in Paragraph 3.2.

3.2 Emission data from the Brindisi power plant

DNV GL has received the following documents on the performance of the ESPs and the FFs at Brindisi power plant:

- Report PM_{10} and $PM_{2.5}$ emissions (Prova IV, 2016 and Prova I, 2017)
- Commissioning report of FF installation (Brindisi 3 + Brindisi 4, Report FF test)
- Commissioning report of Alstom/SIR ESP upgrade (Brindisi 1 + Brindisi 2, Report ESP SIR test)
- QAL2 reports 2017 review as by EN 14181:2014
- Synthesis of PM_{10} and $PM_{2.5}$ yearly trials results
- QAL1 on Dusthunter SB100
- Reported emissions (based on CEMS) 2010-2017

Table 3-1 provides an overview of the reported annual average emission values (calculated from hourly average values provided by the CEMS) in the period 2010-2017. Table 3-2 shows the efficiencies as measured during performance guarantee tests executed after installing the FFs at the units BS3 and BS4 (2012) and after providing the fields 3 and 4 of the ESPs at the units BS1 and BS2 with SIR-type power supply (2016 respectively 2015).

Table 3-1 Emission of dust at Brindisi power plant, units BS1 to BS4

Dust emission (mg/Nm³ ref 6% O_2)								
Year	2010	2011	2012	2013	2014	2015	2016	2017*)
BS1	8.2	8.4	6.6	7.3	3.9	3.9	3.1	2.3
BS2	11.6	9.5	9.3	6.7	5.5	7.5	7.5	4.9
BS3	9.9	2.5	2.6	2.6	2.9	2.4	3.6	4.3
BS4	13.2	10.5	7.0	4.0	5.2	5.6	4.2	1.8

*) Until 10-09-2017

Table 3-2 Dust concentration and efficiency guarantee measurements

Unit	Inlet filter (mg/Nm³)	Outlet filter (mg/Nm³)	Efficiency (%)	Date
BS1	9931	6.22	99.937	July 2016
BS2	12571	5.4	99.960	July 2015
BS3	18150	14.85	99.918	Feb 2012
BS4	13013	9.92	99.924	Oct 2012

From these tables the following can be observed:

- Replacement of the existing ESPs by FFs in 2010-2012 has significantly reduced stack emission values at units BS3 and BS4 from about 12 mg/Nm³ (2010 annual average) down to 4 mg/Nm³ (annual average 2013-2017)
- Upgrading of the ESPs in 2015-2016 has reduced stack emission values at units BS1 and BS2 from around 7 mg/Nm³ (annual average 2010-2014) down to 2.3–4.9 mg/Nm³ (2017 average)
- The guarantee measurements for the new FFs in 2012 show a removal efficiency of 99.92%
- The guarantee measurements of the upgraded ESPs in 2015-2016 show a removal efficiency of 99.95%.

In table 3-3 the PM_{10} and $PM_{2.5}$ measurement results of the Quarterly Emission Reports (Prova IV, 2016 and Prova I, 2017) are presented. From this table, it can be observed that in 2016 the performance of the FFs was slightly better than the performance of the ESP's. In 2017, after optimization of the SIR systems, no significant difference in FF and ESP performance is observed.

Table 3-3 Quarterly PM_{10} and $PM_{2.5}$ measurement results (Prova IV, 2016 and Prova I, 2017)

		Q4, 2016 (mg/Nm³)			Q1, 2017 (mg/Nm³)		
BS1	PM_{10}	2.00	2.30	2.42	1.53	1.87	1.67
	$PM_{2.5}$	1.89	1.94	2.08	1.25	1.57	1.38
BS2	PM_{10}	1.91	2.06	2.07	1.88	2.06	2.05
	$PM_{2.5}$	1.41	1.38	1.44	1.62	1.75	1.71
BS3	PM_{10}	1.26	1.01	0.80	1.43	1.49	1.95
	$PM_{2.5}$	1.09	0.90	0.70	1.24	1.22	1.66
BS4	PM_{10}	1.54	1.4	1.71	1.62	1.81	1.99
	$PM_{2.5}$	1.32	1.12	1.4	1.63	1.49	1.70

3.3 Operational and maintenance experiences at Brindisi power plant

3.3.1 Operational experiences

Enel has provided DNV GL with general operational experiences on their ESPs and FFs. The most relevant experiences include:

- The ESPs have minor impact on the pressure drop measurement equipment in the flue gas path when compared to FF
- The FF bags blowing system must be thoroughly monitored to avoid high upstream/downstream delta pressure values, which may require unit shut down
- The performance of FF auxiliary line and bypass duct valves must be monitored carefully to avoid leakage in the downstream ducts. Attentive operation is particularly relevant during start-up and shut down of the units
- As the dust removal efficiency in ESPs depends on coal ash quality and composition, the ESP fields sometimes need optimization by adjusting of operating parameters in the electric voltage control system
- The ESPs do not require specific start-up operations and/or preliminary procedures. LFO combustion during start-up phases can be managed directly by fields modularity and lines selective switch off, avoiding any effect on general efficiency during following coal combustion. The FFs, on the contrary, cannot be operated effectively for long time while the liquid/solid fuel ratio is over 20%
- FF pre-coating is deemed necessary before any start-up occurring after around 3 days of unit shut down. This procedure takes 12 hours, having high impact on units warm/cold start-up time
- Failure in ash removal system and (as a result) high ash levels in the hoppers of the ESPs can significantly affect dust removal performance

- Although there is sufficient redundancy in ESP fields to ensure continuous high efficiency performances, attentive monitoring of fields is required to ensure that the number of failures in a single flue gas line does not exceed a critical value.

Form these experiences, it can be concluded that both ESP and FF have several less favourable properties with respect to operations. The number and the impact of operational issues is, though, higher for FFs than for ESPs, which is well in line with the general experiences as described in Chapter 2.

3.3.2 Maintenance experiences

Enel has provided DNV GL with failure data for the ESPs and FFs in the period 2013-2016. A summary of the results is presented in Figure 3-1. In this figure the annual number of failures that required maintenance work is indicated. The total number of maintenance or lost operation hours cannot be derived from this figure. The failures have been classified as:

- Electrical failures (ELE)
- Mechanical failures (MEC)
- Failures related to process control (REG).

This figure shows clearly that FFs have a much higher failure rate than ESPs, particularly caused by mechanical failures and process control failures. The number of electric failures is lower for FFs, as this category holds a very limited number of components for a FFs: most the electronic components of FFs (such as control valves) have been assigned to the process control category (REG).

In Appendix A, a full overview of failures in each of the three failure categories is presented, both for preventive and accidental maintenance activities.

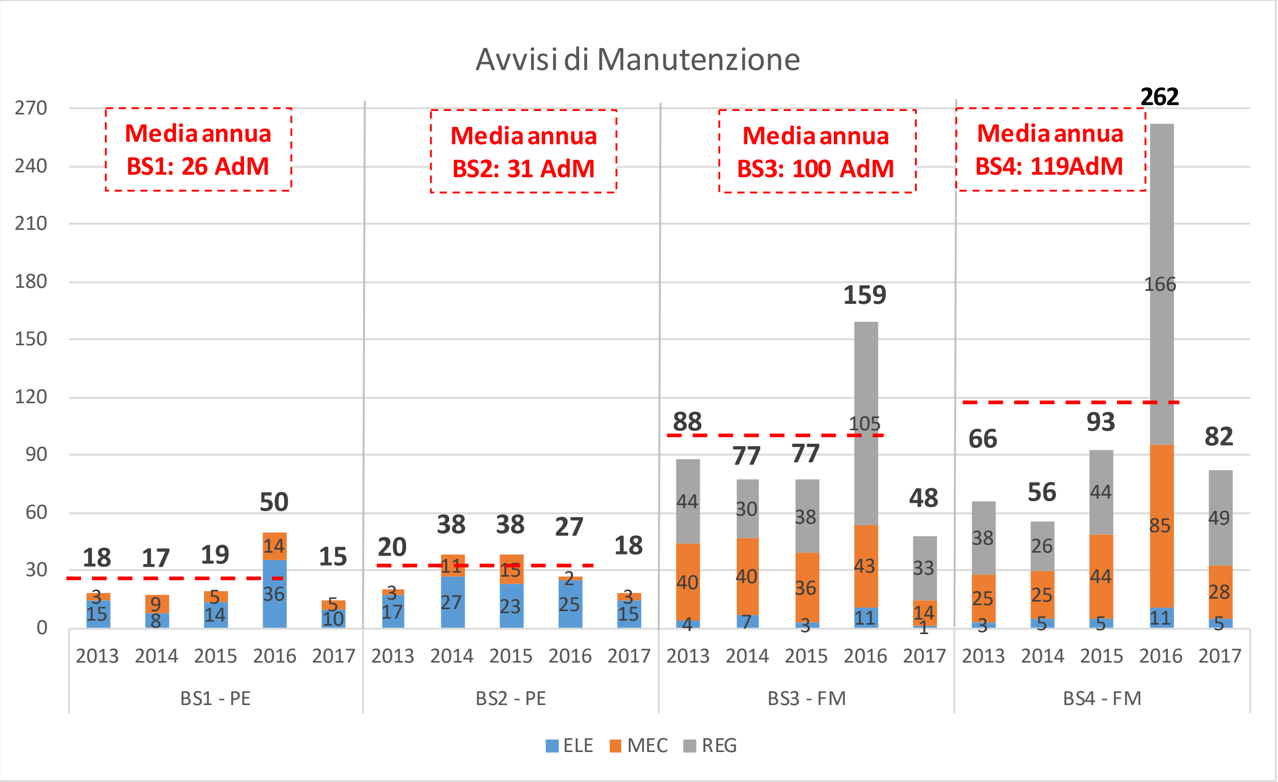


Figure 3-1 Frequency of maintenance at ESPs and FFs at the Brindisi power plant

Mechanical failures at FFs include among others filter bag replacement, maintenance on compressors and maintenance on hoppers. Process control failures at FFs include among electrical control valves and electronics of compressor valves.

Electrical failures at ESPs include among others transformers, cables and connector failures and repair of electrodes. Mechanical failures on ESPs include among others emptying of clogged ash lines, maintenance on hoppers, replacement of internals such as hammers, shafts and supports.

Summarizing, it is clear that the failure rate of FFs at the Brindisi power plant is about 4 times higher than for ESPs. This may result in additional emissions during these failure periods.

4 DISCUSSION OF RESULTS

4.1 General comparison of ESP and FF performance

In Chapter 2 it is indicated that the BAT conclusions do not make a distinction between ESPs and FFs for the removal of dust from flue gases at coal fired large combustion plants. Both technologies may be applied in new as well as in existing power plants. However, it is also concluded that FFs show a higher removal efficiency for small dust particles, including PM_{10} and $PM_{2.5}$.

General experiences with ESPs and FFs, which are available from open literature, generally support the BAT conclusions. However, it is reported in multiple sources that operational and maintenance aspects, which influence emissions of dust as well, are more favourable for ESPs: ESPs are more reliable and require less maintenance, resulting in shorter operation periods per year at which increased dust emissions may take place. For flue gas cleaning equipment, which has a high removal efficiency (> 99%), this represents a significant contribution to annual emission rates.

Further, the influence of a downstream FGD must not be underestimated as it removes additional fly ash from the flue gases. As a result, CEMS measurements are influenced by the dust removal efficiency of both the ESP/FF and the FGD unit. CEMS measurements therefore do not provide information on the sheer performance of the ESPs or the FFs as they are always biased by the dust removal in the FGD unit.

Finally, it is remarked that the discussion on the performance of ESPs versus FFs is often based on the performance of older ESPs, which was clearly inferior when compared to the performance of FFs. In the open literature emission values for older ESPs are generally in the range between 10 and 100 mg/Nm^3 and these values are often wrongly used in today's discussions: modern and upgraded ESPs do show that much lower emission values can be achieved in the range of 1-10 mg/Nm^3. Only for particular types of coal, such as Powder River Basin coal from the US, ESPs are not capable of achieving very low fly ash emissions.

4.2 Operational and maintenance experiences with ESPs and FFs at Brindisi power plant

With respect to operation and maintenance, the ESPs at Brindisi power plant are superior when compared with the FFs, which is in line with general experience with these dust emission reduction techniques as described in open literature. The number of annual operating failures requiring maintenance is much lower for the ESPs, even though the ESPs have recently been upgraded with SIR: this upgrade has apparently not resulted in "teething" problems during the first 12 months after installing of SIR. Since they were installed in 2010-2012, the FFs show a high number of annual failures – about 4 times higher than for ESPs - and no improvement has been observed over the years. In general, ESPs and FFs will show higher emissions during failures periods. However, this could not be verified from available operating data of the Brindisi power plant.

4.3 Emission reduction performance of ESPs and FFs at Brindisi power plant

The assessment on the emission reduction performance of the ESPs and FFs at Brindisi power plant is based on the emission data as presented in Chapter 3 of this report. The following paragraphs elaborate on the CEMS dust measurements, the guarantee measurements and the quarterly PM_{10} and $PM_{2.5}$ measurements in 2016/2017.

4.3.1 Emission of dust (CEMS)

Dust is measured continuously with four CEMS (Continuous Emission Monitoring System) at Brindisi power plant. The quality of the CEMS is controlled through the European Standard EN 14181 “Quality Assurance of AMS”. Important steps in this standard are the calibration of the CEMS against the Standard Reference Methods performed every five years and annual testing every year. The maximum permissible uncertainty during this test is provided in the Industrial Emissions Directive, 30 percent of the daily emission limit value (20 mg/Nm^3): 6 mg/Nm^3.

During the latest calibrations in 2016 the acquired uncertainties were: BS1: 2.19 mg/Nm^3, BS2: 1.40 mg/Nm^3, BS3: 2.38 mg/Nm^3 and BS4; 1.01 mg/Nm^3. This gives an average uncertainty over the four units of 1.7 mg/Nm^3, for the concentration range 2 - 10 mg/Nm^3. This average uncertainty is very plausible considering the measurement uncertainty of the CEMS, the Reference Method, the calculation to normalized conditions and the inhomogeneity. This average uncertainty is used as an estimate for the uncertainty of the measured dust concentrations. The average dust emission concentration of the four units, is around 4 mg/Nm^3 and thus the uncertainty range is 4 ± 1.7 mg/Nm^3. From a statistical perspective, this means that at this dust concentration, the measured result has a 95% probability that it is between 2.3 and 5.7 mg/Nm^3.

When applying this uncertainty range on the 2016/2017 CEMS data as presented in table 3-1, it can be observed that there is no significant difference between the performance of the FFs and ESPs: there is a clear overlap in the emission values of the ESPs and the FFs when taking into account the 95% uncertainty range.

4.3.2 Emission of dust (guarantee measurements)

From table 3-2 it can be observed that the dust removal efficiency of the ESPs is slightly higher than for the FFs. However, the differences are small and it must be noted that the dust inlet concentration during the FF guarantee measurements was higher than during the ESP guarantee measurements, which is not favourable for the dust removal efficiency rate. Thus, it is concluded that the ESPs and the FFs have shown a comparable performance during the guarantee measurements.

4.3.3 Emission of PM_{10} and $PM_{2.5}$ (quarterly measurements)

The concentration of PM_{10} and $PM_{2.5}$ is periodically measured every quarter of a year at each unit. A quarterly measurement consists of three consecutive measurements of about three hours each.

The measured concentration of PM_{10} is around 1.7 mg/Nm^3 and the measured concentration of $PM_{2.5}$ is around 1.4 mg/Nm^3. These are the averages of all four units in quarter three and four of 2016 and quarter one in 2017 for PM_{10} and for $PM_{2.5}$. These emission measurements are performed by the accredited emission monitoring laboratory of Enel. The standard reference method, for these components, does not provide any information on the uncertainty as a performance characteristic. Enel's emission laboratory has evaluated its own uncertainty, which at this concentration is around 0.3 mg/Nm^3, for both PM_{10} and $PM_{2.5}$. This is the "within laboratory" uncertainty. The "between laboratory" uncertainty is always substantially larger (at least two times = 0.6 mg/Nm^3). Thus, at a level of 1.7 mg/Nm^3, the uncertainty range is 1.7 ± 0.6 mg/Nm^3, when measured by an arbitrary laboratory. From a statistical perspective, this means that at this concentration, a measured result has a 95% probability that it is between 1.1 and 2.3 mg/Nm^3 for PM_{10} and between 0.8 and 2.0 mg/Nm^3 for $PM_{2.5}$.

When applying this uncertainty range on the data as presented in table 3-3, it can be observed that there is no significant difference between the performance of the FFs and ESPs: there is a clear overlap in the performance of the ESPs and the FFs for both PM_{10} and $PM_{2.5}$ when taking into account the 95% uncertainty range.

4.3.4 Additional remarks on emission measurements

The assessments in the previous paragraphs include an elaboration of the uncertainty of measured emissions. However, it does not take into account that a specific implemented BAT technique will have a varying performance in time. A quick analysis on the last three quarters already shows a variability of ±0.3 mg/Nm^3 as a standard deviation. Expanded to a 95% confidence interval over this short time it is about equal to the measurement uncertainty (0.6 mg/Nm^3), and over longer time it will even be larger. The same BAT technique, implemented at different units, will then deliver even larger variations compared to one single unit. This is also clearly visible in figure 2-1.

Summarizing, and based on CEMS dust measurements, guarantee measurements and quarterly PM_{10} and $PM_{2.5}$ measurements it can be concluded that the performance of the ESPs and the FFs at Brindisi power station are well comparable and lead to similar emissions of dust, PM_{10} and $PM_{2.5}$.

4.4 Overall ESP versus FF benchmark at Brindisi power plant

Based on the previous paragraphs, it is concluded that the FFs do not outperform the ESPs at the Brindisi power plant when it comes to emission reduction performance: CEMS dust emission measurements, guarantee measurements and Quarterly Reports show similar performance for ESPs and FFs.

Based on operational and maintenance data, it is concluded that the ESPs outperform the FFs as the number of operational failures requiring maintenance is significantly lower for the ESPs. Failures in dust emission reduction equipment may (temporarily) lead to additional emissions of fly ash. This cannot be verified with the available data, but it is obvious that failures may contribute to additional dust emissions.

Overall, based on operational, maintenance and performance aspects, it is concluded that the FFs do not outperform the ESPs at the Brindisi power plant. As the BAT conclusions do not make a distinction between ESPs and FFs for the application at large (coal fired) combustion plants, DNV GL believes that Enel is free in selecting ESPs or FFs to reduce emissions of dust at the Brindisi power plant.

5 CONCLUSIONS

Based on the assessment presented in this report, the following conclusions are drawn with respect to the application of ESPs and FFs at the Brindisi power plant:

- The BREF LCP reports hardly any difference between ESPs and FFs. It reports the potential for a higher removal of fine dust ($PM_{2.5}$ and PM_{10}) by FFs, while the costs and the electricity consumption of FFs are higher than for ESPs
- BAT 22 specifies the BAT-associated emission levels (BAT-AELs) for dust emissions to air from coal/lignite fired LCPs. In these BAT-AELs no difference is made between ESPs and FFs: the BAT conclusions do not make a distinction between the application of ESPs and FFs in large coal fired power plants
- Based on CEMS dust measurements, guarantee measurements and quarterly PM_{10} and $PM_{2.5}$ measurements at the four units of the Brindisi power plant it can be concluded that the performance of the ESPs and the FFs at Brindisi power station are well comparable and lead to similar emissions of dust, PM_{10} and $PM_{2.5}$
- At the Brindisi power plant, FFs show a high number of annual failures – about 4 times higher than for ESPs - and no improvement has been observed over the years. This observation is in line with general experiences on ESPs and FFs as reported in open literature and may lead to additional emissions.

Overall, based on operational, maintenance and performance aspects, it is concluded that the FFs do not outperform the ESPs at the Brindisi power plant. As the BAT conclusions do not make a distinction between ESPs and FFs for the application at large (coal fired) combustion plants, DNV GL believes that Enel is free in selecting ESPs or FFs to reduce emissions of dust at the Brindisi power plant.

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APPENDIX A

Overview of different type of failures at ESPs and FFs of the Brindisi power plant.

	ESP		FF	
maintenance line	Accidental maintenance	Preventive maintenance (not-operating group)	Accidental maintenance	Preventive maintenance (not-operating group)
MECHANICAL LINE	. EMPTYNG OF THE EVACUATION LINES OF THE ASHES	. INTERNAL COMPLETE INSPECTION OF CAPTURE ROOMS	. CURVE REPAIR / FABRIC FILTER'S MEMBRANE OF AIR BLOWING	. CURVE REPAIR / SOFTWARE MEMBRANE SIZE COMPARISON
	. MAINTENANCE OF SHUTTER ON THE HOPPER FUND	. REPLACEMENT HAMMER, COLLARS, SHAFTS, SUPPORTS DISTANCE, ANGLES	. ORDINARY MAINTENANCE (h OPERATION) AND EXTRAORDINARY ON BLOWER COMPRESSORS	. PROGRAMM ORDINARY MANUTENCY (h OPERATION) AND EXTRAORDINARY SOFTWARE COMPRESSORS
	. EXTERIOR CARPENTERIES' REINSTATEMENTS	. OPEN / CLOSING AND REINSTATEMENTS ACCESS DOORS	. MAINTENANCE OF SHUTTER ON THE HOPPER FUND	.MINUTING SERIOUS SLIDING SLIDE SLIDES
		. EXTERIOR CARPENTERIES' REINSTATEMENTS	. EXTERIOR CARPENTERIES' REINSTATEMENTS	REPLACEMENT OF DAMAGED SLEEVE AND DRUMS
		. RESTORE POSITION OF ELECTRODES IN SHORT CIRCUIT	. GAS SERRANDING MAINTENANCE	
	. GAS SHUTTER MAINTENANCE			
ELECTRICAL LINE	.MAINTENANCE INTERVENTIONS ON TRANSFORMERS AND SIR (REPLACING THE PACKAGE CARD, CABLES, ADJUSTMENT OF COUPLING VOLTAGE)	. MAINTENANCE INTERVENTIONS ON TRANSFORMERS AND SIR (REPLACING THE PACKAGE CARD, CABLES, ADJUSTMENT OF COUPLING VOLTAGE)	. ORDINARY CHECK ON ELECTRIC POWER	.PRODUCTION ORDINARY CHECK
		. ELECTRIC REPAIR ELECTRODES IN SHORT CIRCUIT		
ELECTRO-REGULATION MAINTENANCE LINE	.HOPPER LIMIT'S MAINTENANCE	.HOPPER LIMIT'S MAINTENANCE	.MINUTING FINANCIAL STEAMING	.MINUTING ELECTRIC VALVE BLOWING
	. ELECTRICAL VALVES' MAINTENANCE	. ELECTRICAL VALVES' MAINTENANCE	. ELECTRICAL VALVES' MAINTENANCE	MAINTENANCE OF AIR DRYERS
	. MAINTENANCE OF ESP OUTPUT FUMES ANALYSIS CAB (DESOX INPUT)	. MAINTENANCE OF ESP OUTPUT FUMES ANALYSIS CAB (DESOX INPUT)	.MAINTENANCE OF BLOWING ELECTRIC VALVE	COMPRESSOR PLC MAINTENANCE
		. EXTRAORDINARY CLEANING OF ELECTRODISTRIBUTORS OF STAMPS OF HOPPERS		.MINUTING FINANCIAL STEAMING
				. ELECTRIC VALVES MAINTENANCE FAN TRAMOGGE
				.MINUTION OF BLOWING ELECTRIC VALVES

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