

# **Should I Replace my Electrostatic Precipitator (ESP) with a Fabric Filter (FF)?**

by

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## **Synopsis**

Lodge Sturtevant explore the pros and cons of moving from ESPs to Fabric Filters. The case to move to barrier filtration is not always as clear as it may seem.

For many industries ESPs remain the Best Available Technology (BAT) when taken in context with IPPC and BPEO.

Will the operating and maintenance costs increase?

Our process conditions fluctuate. How will these affect emissions?

Will the upgrade plant be "future-proof"?

Can the plant meet even lower emissions in say 10 years time?

These are frequently asked questions.

We try to unravel the complex technical and economic issues to make your decision easier.

# Should I Replace my Electrostatic Precipitator (ESP) with a Fabric Filter (FF)?

## 1. Introduction

Since the introduction of the Alkali Inspectorate and the Alkali Act in 1863 the pressure on UK industry to reduce its emissions to atmosphere has increased. The great smog of 1952 prompted perhaps the greatest change and the 1960's saw huge state investment in modern power stations and steel works with state of the art emissions control systems. These were predominantly Electrostatic Precipitators (ESPs).

However, continued environmental pressures require even greater emissions reductions. In the 1990 Environmental Protection Act introduced Integrated Pollution Control (IPC) requiring tighter control in most industries. At the same time the Large Combustion Plant Directive (LCPD) set clear goals for the power industry. More recently; the Waste Incineration Directive (WID) has imposed significant changes on any process burning waste materials; the introduction of Integrated Pollution Prevention Control (IPPC) has set out a programme of pollution reduction in all industries; and the Revised LCPD has forced all the power generators to reduce sulphur and nitrogen oxide emissions. In reality this means burning expensive low sulphur fuels, investing in Flue Gas Desulphurisation (FGD), fitting NO<sub>x</sub> control systems or setting out programmes to replace or close down the station.

At the same time privatisation of the power and other industries has reduced the capital available for investment. The challenge to meet these changes has been taken up by the Air Pollution Control (APC) system manufacturers. The last decade has seen innovative applications of ESP technologies and the introduction of barrier filters systems such as Fabric Filters (FF) to reduce dust emissions. There has also been wide scale use of FGD, sorbent injection and catalytic reactors to reduce acid gas emissions.

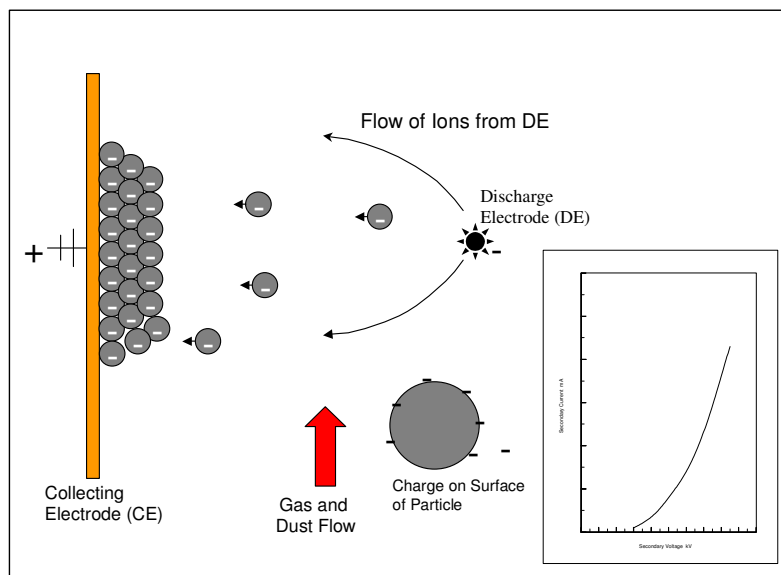
One frequent question often asked, and is difficult to assess and answer, is "Should I replace my Electrostatic Precipitator (ESP) with a Fabric Filter (FF)?"

This paper reviews key factors affecting ESP and FF performance and how this knowledge has been used to improve dust emissions from UK coal-fired power plants and cement kilns. In each case examples of both technical and commercial evaluations are presented and discussed.

All emissions quoted are at reference conditions; dry, 1 atm, 6%O<sub>2</sub> for power generation and 10% O<sub>2</sub> for cement.

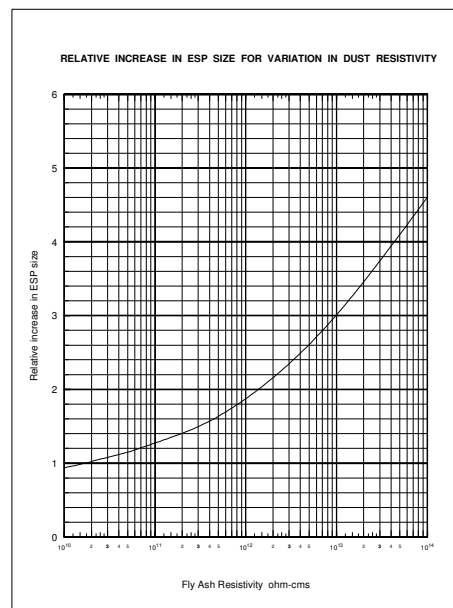
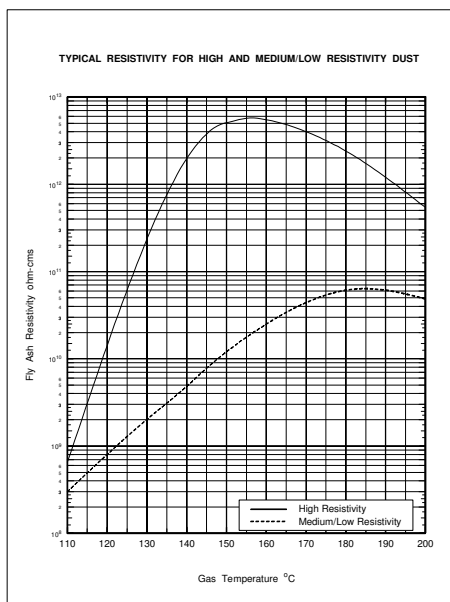
## 2. Factors Affecting Electrostatic Precipitators Performance

The single most important factor influencing the Electrostatic Precipitator (ESP) performance, is the resistivity of the dust being caught. The resistivity is only relevant when the dust is caught on the Collecting Electrodes (CEs). Fig 1 is a plan view showing a Collecting Electrode with an energised Discharge Electrode (DE). The Voltage on the DE is raised to some tens of thousands of volts such that the gas in the space between the DE and the CE is ionised and a current flow takes place between the negatively charged DE and the positively earthed CE. Any dust entering the space between the DE and CE is bombarded with ions, negatively charged and migrates to the CE. It is at this point that the resistivity of the dust becomes relevant.



**Fig 1. Ion Flow in an ESP**

It is important for efficient operation that the charge is able to pass from the dust into the earthed CE. The inset graph in Fig 1, shows a typical 'healthy' Voltage/Current characteristic where power levels are good and performance is optimised. The charge is on the surface of the dust and therefore the ability of the charge to migrate to the CE is very dependant upon the surface conductivity of the dust.



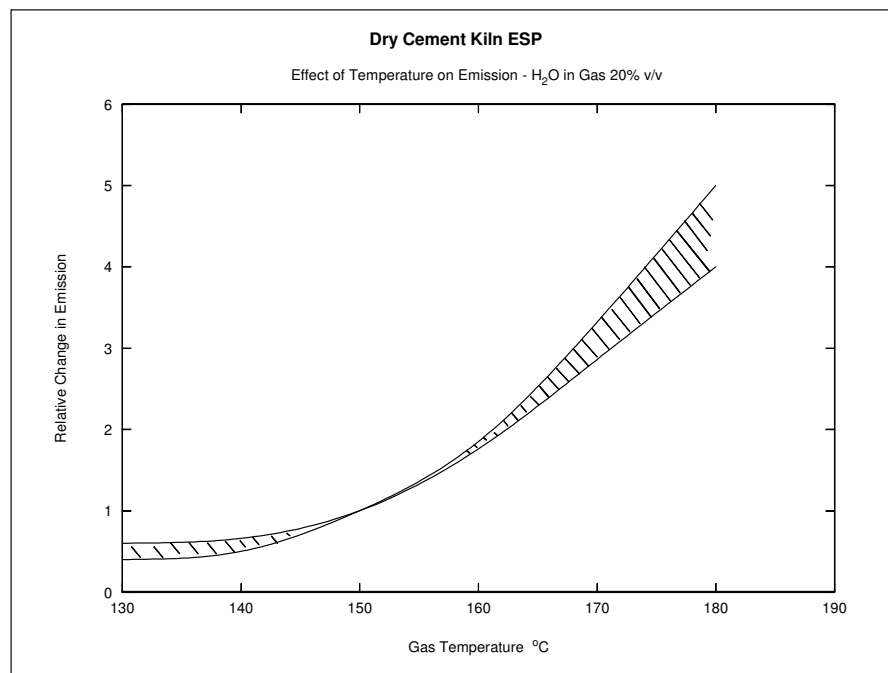
**Figs 2 & 3. Resistivity Curves**

Fig 2 shows typical resistivity curves for high and low resistivity dusts. It can be seen that temperature is an important parameter. As the resistivity increases the charge finds it more difficult to migrate to the earthed CE. This results in the ion flow (current) being inhibited and the overall power input is reduced leading to a reduction in collection efficiency. If this is a normal operating condition then the ESP will have to be designed with an increased Treatment Time to compensate for the lower effective power input. Fig 3 shows the relative increase in ESP size as resistivity increases. Very high resistivity levels will result in a phenomena called 'back ionisation' or 'back corona', where effective power output is severely restricted by a corona discharge taking place in the dust on the CE.

For PC Boiler applications the resistivity of the dust will primarily depend upon the Sulphur in the Coal, the chemical constituents in the ash, the gas temperature and the moisture in the gas. The single most important parameter is the Sulphur in the coal. When the coal is burned,  $\text{SO}_2$  is produced. A small proportion of the  $\text{SO}_2$  is converted into  $\text{SO}_3$  that in turn combines with the water in the flue gas to form  $\text{H}_2\text{SO}_4$ . Sulphuric Acid has a great affinity for fly ash and it is an excellent conductor of charge. So the higher the Sulphur in the coal the more  $\text{H}_2\text{SO}_4$  is formed and the resistivity is lowered. In the fly ash the Sodium Oxide level is also important for lowering the resistivity. Traditional UK coals generally had high Sulphur levels and relatively high Sodium levels. This resulted in ESPs that were relatively small.

Due to environmental and economic pressures, the majority of coal burned in the UK is low Sulphur imported coal. In order to compensate for the higher resistivity fly ash produced by these coals, SO<sub>3</sub> conditioning systems have been installed on the majority of UK stations. The direct injection of SO<sub>3</sub> into the flue gas increases the level of H<sub>2</sub>SO<sub>4</sub> on the dust, reduces the resistivity and enables relatively small ESPs to operate effectively.

For Cement Kilns the two key factors that affect resistivity, are the gas temperature and moisture in the gas. Dry Process Kilns have gas temperatures at the kiln exit of 350 to 400 °C and moisture levels less than 10 % v/v. This would result in very large ESPs due to high volumes and difficult gas/dust conditions. In order to reduce the gas volume and increase the moisture levels, a Gas Conditioning Tower (GCT) is installed before the ESP. The gas temperature is reduced to 150 to 160 °C and the moisture content increased to around 20 %v/v. These conditions result in stable ESP operation.

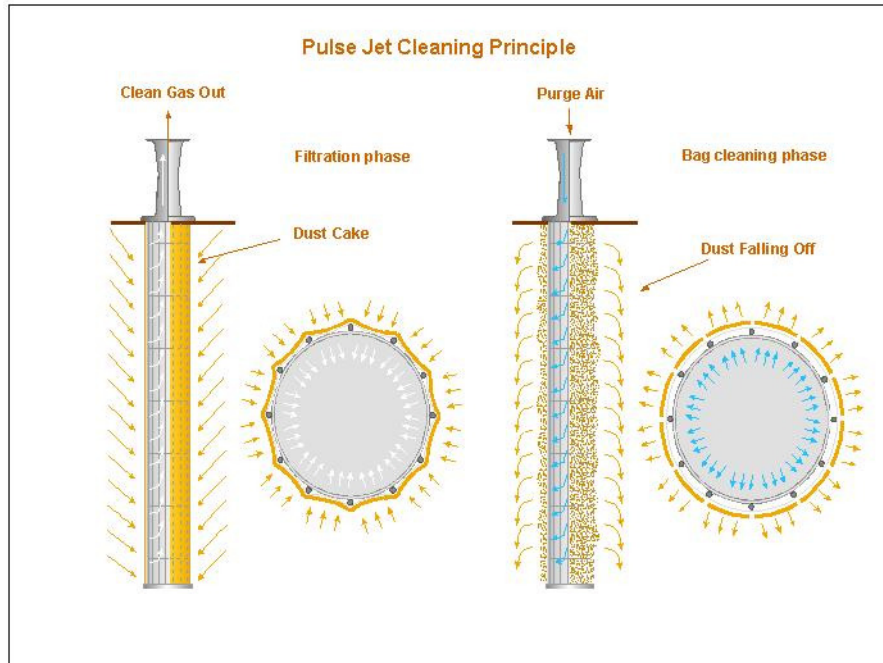


**Fig 4. Effect of Temperature on ESP Emissions**

Due to operational considerations there is a tendency for Kiln operators to increase the GCT outlet temperature. Fig 4 shows how this can result in higher emissions. It is then possible to have the situation where the Kiln/GCT operation is 'fighting' with the ESP operation.

### 3. Factors Affecting FF Performance

Fabric Filters remove dust from a gas stream by passing the gas through a fabric and leaving the dust on the surface of the fabric. The Fabric Filter is therefore not sensitive to dust resistivity. However due to the 'barrier' nature of the dust removal, the Fabric Filter is more sensitive to contamination due to the process. Fig 5 shows the principle of operation of a Pulse Jet Filter.



**Fig 5 Pulse Jet Cleaning Principle**

An important consideration is the choice of bag material. Gas Temperature and gas conditions are major factors in this decision.

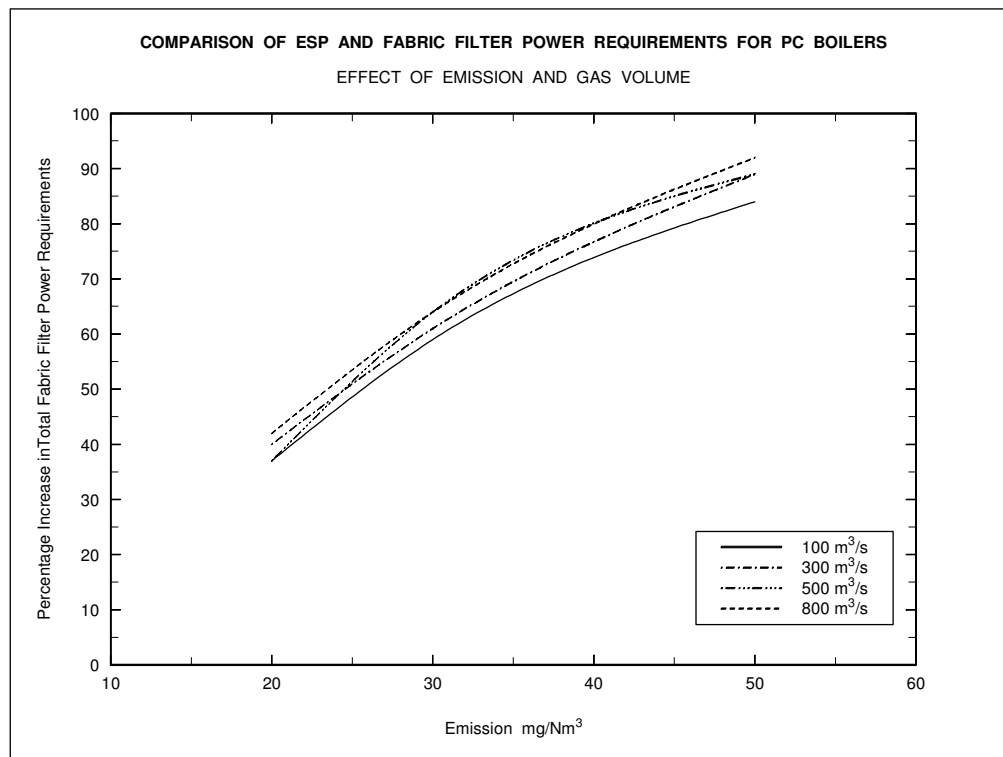
For PC Boilers the Filter is treating acid gases at 140 to 150 °C. A commonly applied fibre is Polyphenylensulphide (PPS). This has good filtration properties, acid resistance and operational temperatures up to 180 °C. As far as achieving specific emission levels is concerned most fibres used on needlefelt bags, can achieve 15 to 20 mg/Nm<sup>3</sup>. For emissions of 10 mg/Nm<sup>3</sup> or below, consideration should be given to fine denier fibres and/or surface coatings and membranes. All of these considerations will tend to increase the cost of the bag.

Filters treating major process gases prefer to be operated under constant process conditions. Most UK PC fired Boilers work on a two shift system so the gas cleaning equipment is subject to many stops and starts. This is not a problem for ESPs but is an important consideration for a Fabric Filter. Insulation should be of high quality to maintain heat and bags should be kept 'dirty' so that fibres are protected from Dew Point transitions.

For Kiln applications the relatively stable Kiln operation suits the Fabric Filter. It is also possible to operate the Filter at relatively high temperatures (200 °C) with high temperature bags so that GCT operation is simplified and back end corrosion problems are reduced.

Consideration has to be given to the sectionalisation / redundancy of the Filter. A well designed/specified Filter is capable of having bags changed/inspected on line.

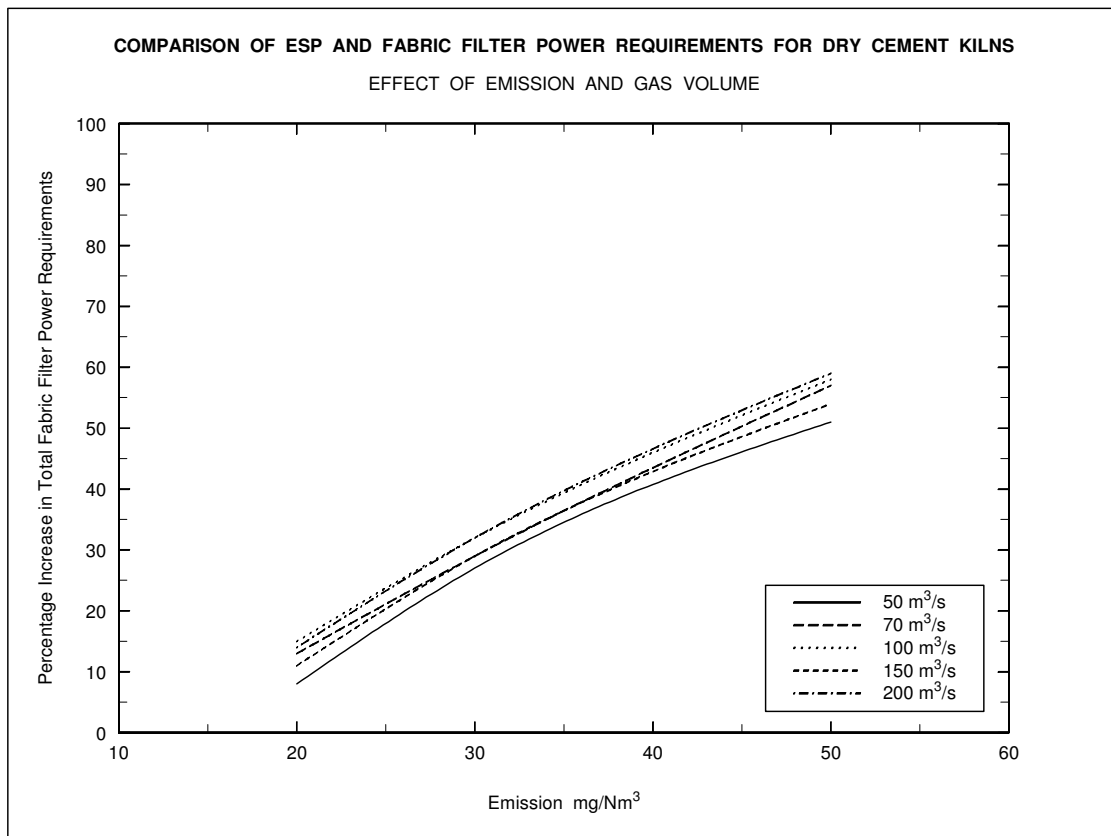
By far the biggest consideration for a PC Boiler is the extra running cost due to the Increased power requirements of the Filter. Also there are the increased maintenance costs associated with bag changes every 4 years or so. An ESP only requires a major overhaul every 15 to 20 years. A graph showing the increased power required by a Fabric Filter compared to an ESP with SO<sub>3</sub> Conditioning, is shown in Fig 6.



**Fig 6. ESP and FF Power Requirements - Power Boilers**

It can be seen that at 50 mg/Nm<sup>3</sup> the Fabric Filter requires 80 to 90% more power. On a 500 MW Boiler this represents an extra 660 kW of operating power. As the emission requirements are reduced, the power differential decreases and the Fabric Filter would require 400 kW extra.

For Cement Kilns, the power difference is relatively less. This is due to the ESPs on Kilns being relatively larger than ESPs on PC Boilers with conditioning. A kiln ESP to achieve 50 mg is 50 to 60% larger (in Treatment Time) than the PC Boiler ESP. Fig 7 illustrates the extra power required for fabric filters on kilns .



**Fig 7. ESP and FF Power Requirements – Cement Kilns**

With the current trends to burn alternative fuels and increased environmental pressures, it is easy to see the viability of Fabric Filters when emissions of less than 20 mg/Nm<sup>3</sup> are being considered.

#### 4. Techno- Economic Assessment of ESPs and FF for Power Generation

Within the UK there are around 30,000 MWe of coal / oil fired power generating units.

Owner	Site	Size MWe (ref 1)	Dust Abatement	FGD
E.ON	Kingsnorth	4 x 500	ESPs	None
	Ratcliffe	4 x 500	ESPs	Limestone/Gypsum
	Ironbridge	2 x 500	ESPs	None
RWE	Aberthaw	3 x 350	ESPs	Planned
	Didcot	3 x 350	ESPs	None
	Tilbury	3 x 350	ESPs	None
	Littlebrook	2 x 685	ESPs	None
Carron Energy	Fifoots Point	3 x 120	FF	Semi-dry
Scottish Power	Cockenzie	4 x 300	ESPs	None
	Longannet	4 x 600	ESPs	Planned
	Fiddlers Ferry	4 x 500	ESPs	None
	Ferrybridge	4 x 500	ESPs	Planned
EdF	Cottam	4 x 500	ESPs	Limestone/Gypsum
	West Burton	4 x 500	ESPs	Limestone/Gypsum
Drax Power	Drax	6 x 660	ESPs	Limestone/Gypsum
Alcan	Lynemouth	1 x 245	ESPs	None
AES	Kilroot	1 x 520	ESPs	Planned
British Energy	Eggborough	4 x 500	ESPs	Limestone/Gypsum
Int. Power	Rugeley	2 x 500	ESPs	Planned
Sembcorp	Wilton	4 x 33	ESPs	None

**Table 1. UK Coal and Oil fired Power Generation**

Other oil-fired power stations such as Indian Queens, Grain and Fawley generate infrequently are not required to fit APC

## 4.1 Improving Emissions on Large Utility Boilers - Typically 500 MWe

The majority of the UK utility coal fired generation is produced from large pulverised fuel boilers, typically 500 MWe, developed and installed by the CEGB in the 1960's and 1970's. All were originally fitted with ESPs to meet the emission limits of the day of circa 240 mg/Nm<sup>3</sup>. The ESPs were designed to meet this emission using medium / high sulphur indigenous UK coals.

In the 1980's pressure was put on the CEGB to reduce emission further to around 115 mg/ Nm<sup>3</sup>. At the same time low sulphur imported fuels were being used as UK coal mines closed. The prime solution used at the time to improve emission was to install gas conditioning systems. Liquid sulphur is burned to form SO<sub>2</sub> and then passed over a catalyst to make SO<sub>3</sub>. The SO<sub>3</sub> is then injected into the flue gas stream immediately upstream of the ESP. SO<sub>3</sub> reduces the resistivity of the ash allowing improved collection in the ESP.

The publication of the Large Combustion Plant Directive (LCPD) in the late 1990's added new pressures to the now privatised utility companies with the introduction of a new lower limit of 50 mg/Nm<sup>3</sup> for all large boilers. This was to be carried out by 2001. At the same time stations were installing low NOx burners resulting in a larger proportion of unburned carbon particles entering the ESP. A significant increase in ESP treatment time and reduction in gas velocity was required to meet these new demands.

## 4.2 Options to improve Emissions Performance

5 - 30 % Reduction

- New improved internals
- Improved control systems
- Gas distribution modifications

These are relatively low cost options and have been implemented at many stations. However, generally greater reduction was required to meet the emissions target on the full range of internationally available fuels and more substantial upgrades were required. For each station various solutions were considered including the use of fabric filters.

>30% Reduction

- Enlarged casing, increased height
- Additional inlet or outlet fields

- Additional series or parallel ESPs
- Use of Fabric Filters
  - Replace and / or convert ESP to Fabric Filter
  - Install series or parallel FF

#### 4.3 Evaluation of Options to achieve >30 % reduction

In evaluating the technical and economic merits of each of the above options the following criteria were taken in the account.

- Operation and performance characteristics
- Capital costs
- Space requirements
- Complexity
- Outage required i.e. loss of generation
- Power consumption including ID fan power
- O&M Costs
- Future proof – ability to meet lower emissions in the future

This information is summarised in Tables 2 & 3 below.



**Fig 8. Additional Parallel ESPs on 4 x 500 MWe Boiler**

<b>Parameter</b>	<b>Fabric Filter</b>	<b>ESP</b>
<b>Disturbance to process</b>	High Has potential to 'block' process. Flow / PD can cycle with pulse cleaning. This is minimal with intelligent operation of cleaning cycle.	Low
<b>Emission levels</b>	10 to 20 mg/Nm <sup>3</sup> .	Size to suit requirements. 10 mg/Nm <sup>3</sup> is possible
<b>Emission sensitivity to process</b>	Low, except during start up	Low with SO <sub>3</sub> Conditioning Medium to High without
<b>Explosion risk</b>	Low	Low
<b>Fire risk</b>	Medium	Low
<b>Over temperature risk</b>	High for mechanical damage. Safety measures required. Low for emission	Low for mechanical damage Medium for emission
<b>Maintainability</b>	With correct design, On Line is possible.	Typically Off Line, On Line maintenance is possible with some designs.
<b>Service Intervals</b>	Bags change - 4 years Cages - 8 years	Typically every 4 years for routine maintenance. 15 to 20 years for major overhaul
<b>Cold Start capability</b>	Yes with Pre coat.	Yes
<b>Power consumption (see Table 3)</b>	High Pressure Drop 100 to 150 mmWG	Low Pressure Drop 20 to 25 mmWG
<b>Long term reliability and emission compliance</b>	Good, but if bag life reduces prematurely the emission rises rapidly	Good

**Table 2. A comparison of Operational and Performance Characteristics**

	<b>New ESP (e)</b>	<b>Increased Height</b>	<b>New Field(s) (a)</b>	<b>Additional Parallel flow</b>	<b>New FF</b>	<b>Additional Parallel FF</b>	<b>Additional Series FF</b>
<b>Cost</b>	2.5	0.9	0.9	1.0	3.5	1.1	2.0
<b>Outage (weeks)</b>	–	12 - 20	2 - 3	<1	2-3	<1	2 – 3
<b>Space needed</b>	–	None	Medium	Medium	Large	Medium	Large
<b>Complexity</b>	–	Medium	High	Medium	High - New ID Fan		
<b>Power (b)</b>							
<b>Auxiliary</b>	45	45	50	50	55	60	100
<b>TRs Sets</b>	500	500	500	500	-	500	<400
<b>ID FAN (c)</b>	180	180	190	180	1320	600	1400
<b>KWs</b>							
<b>O&amp;M Costs (d)</b>	Low <0.5 %	Low <0.5%	Low <0.5 %	Low <0.5%	High 10 % over 4 years	Medium 4 % over 4 years	High 10 % over 4 years
<b>Future Proof</b>	May require further upgrades				Yes	No	Yes

- a. Not suitable where gas velocity is critical
- b. Total power consumed by APC system to deliver 50 mg/Nm<sup>3</sup>
- c. Includes only power used to overcome APC pressure drop.
- d. % of total cost of installed APC system per annum
- e. For comparison only – data given for green field site.

**Table 3. Data for a Typical 500 MWe pf Fired Boiler with SO<sub>3</sub> Conditioning Reducing Emissions from c.100 mg/Nm<sup>3</sup> to < 50 mg/Nm<sup>3</sup>**

#### **4.4 Overseas Plants using Fabric Filters**

In certain areas of the world use of ESPs has been displaced by the use of Fabric filters. Countries that have installed Fabric Filters on Utility power boilers include Australia, South Africa and USA. Why? There are a number of reasons.

1. The coals used have a very high ash resistivity and high ash content. This combination requires a very large ESP and therefore the capital and operating cost of Fabric Filter become favourable. SO<sub>3</sub> conditioning for large amounts of ash becomes expensive.
2. The emission required is very low and hence the additional capital cost of the ESP out weighs the increased operating costs of a fabric filter.
3. A new boiler is being installed with a semi dry FGD system.

#### **4.5 Power Generation Dust Abatement**

Almost all the UK power stations chose to upgrade the existing ESPs rather than replace them wholly or in part with Fabric Filters. The decision was complex. However, the overriding factors appeared to be the additional operation costs especially the additional fan power required and the cost of replacing the bags every 4 years or so. Each of the fabric filter options required an upgrade of the station ID fans or additional booster fans.

## 5. Techno- Economic Assessment of ESPs and FF for Cement Production

Owner	Site	Production 1000 Tonnes/year (Ref 2)	Type	Kiln FF or ESP	FGD	Fuel (other than coal and coke)
Lafarge UK	Aberthaw	500	Dry	FF	None	Tyres, MBM
	Barnstone	100	Special	ESP	None	
	Cauldon	920	Dry	ESP	None	Tyres
	Cookstown	470	Semi - dry	ESP	None	Tyres, RLF
	Dunbar	1000	Dry	ESP	Planned	Tyres, RLF
	Hope	2 x 700	Dry	FF	None	Tyres
	Northfleet	2 x 675	Semi Wet	ESP	None	Tyres
	Westbury	720	Wet	ESP	None	Tyres
Rugby	Barrington	250	Wet	ESP	None	RLF
	Rugby	1250	Wet	ESP	None	Tyres
	South Ferriby	750	Semi-dry	ESP	None	
Castle Cement	Ketton	300 1000	Dry Dry	ESP ESP	None None	
	Padeswood	2 x 250 300	Dry Dry	FF	None	
	Ribblesdale	1 x 750 2 x 300	Dry Wet	ESP ESP	Scrubber	RLF
BLI	Buxton	750	Dry	FF	None	
Quinn	Derrylin	500		ESP	None	

RLF - Recycled Liquid fuels

**Table 4. UK Cement Production**

## 5.1 Improving Emissions on Kiln Filters

Cement production on a commercial scale, dates back over 200 years in the UK. In the 1970's and 80's there was much investment in large dry cement kilns, replacing a multitude of smaller wet type kilns. Most UK works have only 1 or 2 kilns.

The new kilns were fitted with ESPs to meet the emissions requirement of the day of around 100 mg/Nm<sup>3</sup>. Subsequent improvements to the control systems and discharge electrodes in the 1990's saw most kilns achieving around 50 mg/Nm<sup>3</sup>, thereby meeting current legislation.

To reduce production costs, many works are substituting coal and gas with other materials such as tyres and recycled liquid fuels (RLF). These "wastes" often attract a "gate fee" and are therefore very attractive to cement plant owners. However, because these fuels are classed as wastes, the emission requirements are more stringent and governed by the WID. An emission of less than 30 mg/Nm<sup>3</sup> is required. The larger well designed and maintained ESPs already achieving less than 50 mg mg/Nm<sup>3</sup>, have been able to be further modified at relatively low cost by replacing internals, extending the roof height and improving the gas distribution systems. For others it became a question of replacement, either with another ESP or with a Fabric Filter.

## 5.2 Comparison of Fabric Filter (FF) and Electrostatic Precipitator (ESP) Operation and Performance on Cement Kiln Applications

The Table below summarises the key operating differences between Fabric Filters and ESPs.

Parameter	Fabric Filter	ESP
<b>Disturbance to Process</b>	High Has potential to 'block' process. Flow / DP can cycle with pulse cleaning. This is minimal with intelligent operation of cleaning cycle.	Low  However, will trip if CO levels high
<b>Emission Levels</b>	10 to 20 mg/Nm <sup>3</sup> . 5 mg/Nm <sup>3</sup> is possible.	Designed to suit 10 mg/Nm <sup>3</sup> is possible
<b>Emission sensitivity to process</b>	Low, except during start up	Medium to High
<b>Explosion risk</b>	Low	High

<b>Fire risk</b>	Medium	Low
<b>Over Temperature risk</b>	High for mechanical damage. Safety measures required.  Low for emission	Low for mechanical damage.  High for emission
<b>Maintainability</b>	With correct design, on line maintenance and bag changing is possible.	Typically off line, but Assuming safety regulations permit, then some on line maintenance is possible with some designs
<b>Service Intervals</b>	Bag change - 4 years  Cages - 8 years	Typically every 4 years for routine maintenance. 10 to 15 years for major overhaul
<b>Cold Start capability</b>	Yes, with precoat	Yes
<b>Power Consumption</b>	High Pressure Drop 100 to 150 mmWG	Low Pressure Drop 25 to 30 mmWG
<b>Long term reliability And Emission compliance</b>	Good, but if bag life reduces prematurely the emission rises rapidly	Good

**Table 5. Comparison of ESP and FF Performance Criteria**

### 5.3 Comparison of Costs

	<b>New ESP</b>	<b>New FF</b>
<b>Cost</b>	1.0	0.9
<b>Power (a) Consumption</b>		
<b>Auxiliary</b>	25	55
<b>TR Sets</b>	230	N/A
<b>ID FAN (b)</b>	45	330
<b>O&amp;M Costs (c)</b>	<0.5 %	~ 12% every 4 years

- a. Total power consumed by APC system to deliver 30 mg/Nm<sup>3</sup>
- b. Includes only power used to overcome APC pressure drop.
- c. % of total cost of installed APC system per annum

**Table 6. Data for Typical Large Dry Kiln Reducing Emissions to < 30 mg/Nm<sup>3</sup>**



**Fig 9. Cement Works Fabric Filters**

#### **5.4 Kiln Dust Abatement**

For many of the existing UK Kiln ESPs, it has been possible to carry out relatively low cost upgrades to reduce the emissions to below  $30 \text{ mg/Nm}^3$  allowing them to operate with “waste” fuels. These upgrades have included new internals, gas distribution modifications and installation of advanced control systems.

Where a complete replacement of the dust abatement system is required, generally the decision has been to install a fabric filter. The capital cost of the two options, both achieving  $30 \text{ mg/nm}^3$ , is very close.

A well designed Fabric Filter is a good fit with Kiln operation. In particular a Fabric Filter is insensitive to CO excursions, which can cause an ESP to trip and result in an emission breach. The dry cement kiln process is relatively stable. This will tend to minimise the potential to contaminate the bags, increasing their life beyond 4 years, reducing the overall maintenance costs.

The filter can be run at relatively high temperatures, thus ensuring that corrosion is minimised. This has the added benefit of being able to operate the Gas Cooling Tower at a higher back end Temperature for increased reliability.

The Kiln can be run at conditions to suit the production of cement, not the emission up the stack.

The additional pressure drop of the Fabric Filters is less important for cement works compared to a power station as the ESP is relatively larger compared to the Fabric Filter and therefore consumes relatively more power precipitating the dust.

Emissions below  $10 \text{ mg/Nm}^3$  are readily achievable with the correct bag material and the filter is therefore seen as future proof and likely to meet any future emissions legislation.

## **6. References**

1. [www.electricity.org.uk](http://www.electricity.org.uk)
2. [www.mineralsuk.com/britmin/mpfcement.pdf](http://www.mineralsuk.com/britmin/mpfcement.pdf)

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