

# DOES SO<sub>3</sub> FLUE GAS CONDITIONING HAVE AN IMPACT ON THE ENVIRONMENT – AN ASSESSMENT

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## ABSTRACT

The impact of SO<sub>3</sub> flue gas conditioning on the environment has been a topic that has not received a lot of attention in the past. This is mainly due to the huge improvements in ESP performance that can be achieved by the utilisation of this technology. The amount of SO<sub>3</sub> being injected only forms between 2% and 4% of the total SO<sub>x</sub> (total SO<sub>2</sub> and SO<sub>3</sub>) concentration and it was accepted that all the SO<sub>3</sub> reacted with the fly ash in order to achieve the improved ESP performance. SO<sub>3</sub> FGC is a very effective way of reducing the particulate emissions and has been effective in doing so at all the Eskom Power Stations where it has been implemented. There are however some exceptions where SO<sub>3</sub> FGC alone will not be able to achieve the low emission levels that will be required by the Chief Air Pollution Control Officer (CAPCO). These are typically the older power stations with small ESP's that have been sized to achieve the emission required at the time of construction and are not acceptable for current requirements. These power stations normally have to install SO<sub>3</sub> FGC and upgrade their existing ESP's to be capable of reliably giving emissions below 50mg.S.m<sup>3</sup> or they have to install fabric filters. SO<sub>3</sub> FGC forms an integral part of Eskom's drive in the reduction the particulate emissions and it was therefore decided to evaluate its impact as part of the Eskom Emissions Research Portfolio. This paper reports on the results obtained during this assessment.

**Keywords:** Electrostatic Precipitator, ESP, Flue gas conditioning, FGC, Sulphur trioxide, environmental impact.

## INTRODUCTION

The initial aim of the assessment was to determine whether or not SO<sub>3</sub> FGC emitted additional SO<sub>3</sub> to the atmosphere. Any additional SO<sub>3</sub> being emitted was to be quantified and a risk assessment would be performed based on ambient (ground level) concentrations and its impact on various structural materials. In order to obtain ground level concentrations, use would be made of a dispersion model of Kendal to convert the point source emission increase in SO<sub>3</sub> concentration to actual increase in SO<sub>3</sub> concentration at ground level. The risk assessment would ultimately reveal whether or not FGC had any impact of significance on the surrounding environment.

Although the SO<sub>3</sub> is present in small concentrations in comparison to SO<sub>2</sub>, the major concern about SO<sub>3</sub> was the fact that it is very reactive, and that it would, unlike SO<sub>2</sub>, impact on the immediate surrounding environment. Due to the fact that SO<sub>2</sub> remains in a gaseous form until it is oxidized by various atmospheric processes to SO<sub>3</sub>, it remains above the inversion layer and is carried over long distances before it drops out of the atmosphere. This allows for sufficient dilution and dispersion of the high SO<sub>2</sub> concentrations resulting in an almost insignificant impact on the immediate surrounding environment.

Internationally it was accepted that none of the injected SO<sub>3</sub> is being emitted to atmosphere. This is mainly due to the fact that SO<sub>3</sub> flue gas conditioning has been implemented since 1912 and was a well developed technology before its implementation at Kriel Power Station in the 1980's. Tests were performed at Kriel Power Station when the original SO<sub>3</sub> FGC plant

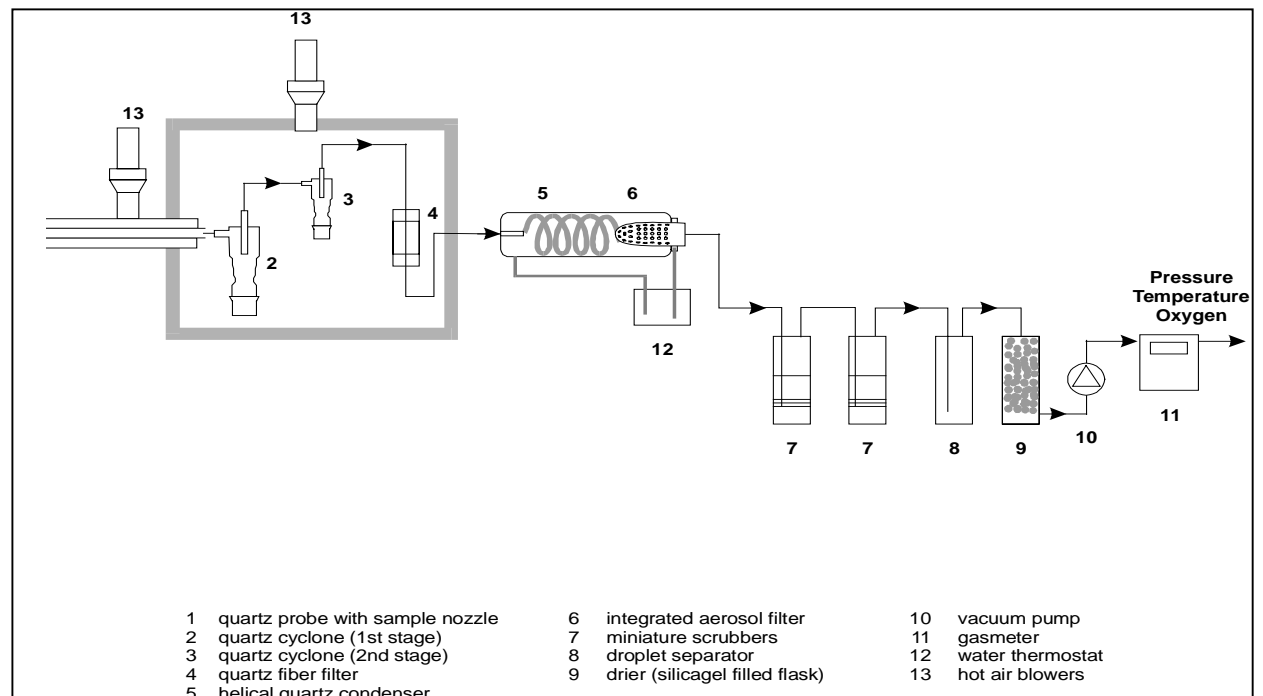
was evaluated. These tests did not indicate an increase in the  $\text{SO}_x$  emission.<sup>(1)</sup> The tests were however performed with equipment, which could not accurately differentiate between  $\text{SO}_2$  and  $\text{SO}_3$ . The tests attempted a  $\text{SO}_x$  balance across the ESP, but this was not determined simultaneously. Based on the available equipment at the time there was no concern. It can only be accepted that the international efforts had the same limitations with measuring equipment.

## METHODOLOGY AND TEST EQUIPMENT

The premature adsorption and/or condensation of  $\text{SO}_3$  as  $\text{H}_2\text{SO}_4$  on particles or in a fly ash dust cake have to be prevented in a  $\text{SO}_3$  measuring device. "Free flight condensation or adsorption", if not already existing in the flue gas itself, can be prevented by isothermal sampling. A substantial  $\text{SO}_3$  loss can also result when the sample gas traverses the fly ash cake and is adsorbed and potential chemical reactions with the alkaline substances occur. This is prevented by the use of a highly efficient dual stage cyclone filtering system.

The  $\text{SO}_3$  is then collected from the "dust free" sample gas by controlled condensation (Shell method) at a temperature of  $80^\circ\text{C}$  in a helical quartz tube condenser. In the condenser there are no condensation nuclei, which results in  $\text{H}_2\text{SO}_4$  super saturation and aerosol formation. An aerosol filter is also fitted to the tube condenser to prevent any  $\text{H}_2\text{SO}_4$  that was condensed to traverse the helical tube, as this could result in an under estimation of the  $\text{SO}_3$  concentration.

Figure 1 gives a graphical representation of the equipment developed by Emissionmeßtechnik und Strömungsmechanik (ESG) and now used by Eskom to determine the  $\text{SO}_3$  concentration. The acid dew point temperatures are subsequently calculated from the  $\text{SO}_3$  concentrations using thermodynamic equations.



**FIGURE 1: SHELL  $\text{SO}_3$  MEASUREMENT SYSTEM**

The flue gas velocities are measured at pre-determined sampling positions to establish an average velocity profile for the measurements to be performed. The probe and the cyclones

are electrically heated before being immersed into the flue gas stream in order to prevent any condensation prior to sampling.

The insulated box temperature is measured by the use of a K-type thermocouple, which is placed inside the box. The temperature inside the box is controlled by the use of electrically operated blowers.

The condenser used to condense the SO<sub>3</sub> as H<sub>2</sub>SO<sub>4</sub> from the flue gas is placed on the outside of the heated box. The temperature through the condenser is controlled by the use of a circulating water bath with an electrical heating element. The temperature of the condenser is controlled at 80°C as this temperature is calculated to be the minimum sulphuric acid dew point temperature from the thermodynamic equations used for the calculation of the acid dew point. With a minimum concentration of 0.01mg SO<sub>3</sub> the acid dew point temperature will be 80°C.

The condenser is also equipped with an aerosol filter to stop any condensate that is formed inside the condenser from being carried over to the scrubbers.

Adjusting the flow on the vacuum pump, controls the volume of gas sampled. Once the vacuum pump is switched on the sampling can begin. The ash is filtered from the flue gas by the dual stage cyclones. Once all the ash is removed, the gas passes through the temperature controlled condenser where the SO<sub>3</sub> is condensed as H<sub>2</sub>SO<sub>4</sub> at 80°C. The condensed sample is removed from the condenser after the entire sampling period and sent for analysis. The condensate is analysed in the laboratory making use of ion chromatography (IC) to establish the sulphate (SO<sub>4</sub>) concentration.

The concentration of the SO<sub>3</sub> in the flue gas is then calculated by working the measured SO<sub>4</sub> concentration back to the actual volume of gas that was sampled.

## RESULTS

The results obtained for assessments carried out at Kendal and Lethabo Power Stations are presented in this section.

**TABLE 1: KENDAL POWER STATION UNIT 4 TEST RESULTS**

DESCRIPTION	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5
SO <sub>3</sub> FGC plant condition	On 12ppm	Off	Off	Off	Off
SO <sub>4</sub> concentration (I.C. result)	120mg.l <sup>-1</sup>	48mg.l <sup>-1</sup>	40mg.l <sup>-1</sup>	15mg.l <sup>-1</sup>	21mg.l <sup>-1</sup>
Converted SO <sub>3</sub> concentration	100mg.l <sup>-1</sup>	40.0mg.l <sup>-1</sup>	33.3mg.l <sup>-1</sup>	12.5Mg.l <sup>-1</sup>	17.5mg.l <sup>-1</sup>
Gas temperature	129.6°C	126.3°C	126.9°C	119.7°C	119.0°C
Barometric pressure	82.8kPa	82.7kPa	82.6kPa	82.2kPa	82.2kPa
Duct pressure	82.61kPa	82.42kPa	82.35kPa	81.96kPa	81.96kPa
Moisture	6.3%	8.4%	7.2%	7.2%	8.0%
Velocity	24.35m.s <sup>-1</sup>	23.91m.s <sup>-1</sup>	26.41m.s <sup>-1</sup>	22.85m.s <sup>-1</sup>	23.25m.s <sup>-1</sup>
Gas volume flow (Actual)	1107.03m <sup>3</sup>	1087.38m <sup>3</sup>	1201.03m <sup>3</sup>	1039.25m <sup>3</sup>	1057.69m <sup>3</sup>
Gas volume sampled (Actual)	2.7515 m <sup>3</sup>	4.5635 m <sup>3</sup>	5.0116 m <sup>3</sup>	1.8060 m <sup>3</sup>	1.8592 m <sup>3</sup>
<b>SO<sub>3</sub> CONCENTRATION AT STP (0°C AND 101,3 kPa)</b>	<b>9.95ppm</b>	<b>2.42ppm</b>	<b>2.62ppm</b>	<b>2.27ppm</b>	<b>3.09ppm</b>

**TABLE 2: LETHABO POWER STATION UNIT 2 TEST RESULTS**

DESCRIPTION	TEST 1	TEST 2	TEST 3	TEST 4
SO <sub>3</sub> FGC plant condition	On 20 ppm	On 20 ppm	Off	Off
SO <sub>4</sub> concentration (I.C. result)	35.3mg.l <sup>-1</sup>	32.3mg.l <sup>-1</sup>	16.7mg.l <sup>-1</sup>	16.7mg.l <sup>-1</sup>
Converted SO <sub>3</sub> concentration	mg.l <sup>-1</sup>	mg.l <sup>-1</sup>	mg.l <sup>-1</sup>	mg.l <sup>-1</sup>
Gas temperature	133.7°C	134.0°C	131.2°C	132.3°C

Barometric pressure	84.4kPa	84.4kPa	84.6kPa	84.5Kpa
Duct pressure	84.2kPa	84.2kPa	84.3kPa	84.2Kpa
Moisture	8.7%	8.0%	7.1%	6.2%
Velocity	27.08m.s <sup>-1</sup>	27.9m.s <sup>-1</sup>	27.51m.s <sup>-1</sup>	27.48m.s <sup>-1</sup>
Gas volume flow (Actual)	1009.47m <sup>3</sup>	1039.96m <sup>3</sup>	1025.36m <sup>3</sup>	1024.42m <sup>3</sup>
Gas volume sampled (Actual)	0.8323m <sup>3</sup>	0.9738m <sup>3</sup>	0.9989m <sup>3</sup>	0.9681m <sup>3</sup>
<b>SO<sub>3</sub> CONCENTRATION AT STP (0°C AND 101,3 kPa)</b>	<b>14.3ppm</b>	<b>13.2ppm</b>	<b>6.7ppm</b>	<b>6.8ppm</b>

**TABLE 3: LETHABO POWER STATION UNIT 2 TEST RESULTS (CONT.)**

DESCRIPTION	TEST 5	TEST 6
SO <sub>3</sub> FGC plant condition	Off	Off
SO <sub>4</sub> concentration (I.C. result)	14.7mg.l <sup>-1</sup>	15.8mg.l <sup>-1</sup>
Converted SO <sub>3</sub> concentration	mg.l <sup>-1</sup>	mg.l <sup>-1</sup>
Gas temperature	129.4°C	131.8°C
Barometric pressure	84.6kPa	84.5kPa
Duct pressure	84.3kPa	84.3kPa
Moisture	8.1%	6.9%
Velocity	27.79m.s <sup>-1</sup>	27.71m.s <sup>-1</sup>
Gas volume flow (Actual)	1035.97m <sup>3</sup>	1033m <sup>3</sup>
Gas volume sampled (Actual)	1.0219m <sup>3</sup>	0.9734m <sup>3</sup>
<b>SO<sub>3</sub> CONCENTRATION AT STP (0°C AND 101,3 kPa)</b>	<b>5.9ppm</b>	<b>6.4ppm</b>

## DISCUSSION OF RESULTS

The results presented in Section 3 show the same trend for both Kendal and Lethabo Power Stations. It is observed that some of the SO<sub>3</sub> that is injected reacts with, or coats the fly ash particles, while some of it is being emitted to atmosphere through the smoke stack. The amount is quantified by subtracting the naturally occurring SO<sub>3</sub> concentration (as this would under normal circumstances be emitted to atmosphere, without the addition of SO<sub>3</sub> FGC) from the measured SO<sub>3</sub> concentration with the SO<sub>3</sub> FGC plant in service.

The additional SO<sub>3</sub> being emitted as a result of SO<sub>3</sub> FGC at Kendal amounts to 6.7 ppm, while at Lethabo it amounts to 7.5ppm. The concentrations are relatively close to each other and it shows that there is a definite increase in the SO<sub>3</sub> emissions.

Great concern was placed on the Kendal results as it seemed that only 5.1 ppm of the 12 ppm SO<sub>3</sub> being injected remained in the ESP. This meant that only 5.1 ppm of SO<sub>3</sub> was contributing to significant improvements observed in the ESP particulate collection efficiency. This defied all conventional wisdom about the operation of SO<sub>3</sub> FGC plants, as it was thought that more of the injected SO<sub>3</sub> would have an active part in reducing the particulate emissions.

The same reasoning for Lethabo shows that only 12.5 ppm of the injected 20 ppm SO<sub>3</sub> contributed to the improvements observed in the ESP particulate removal efficiency.

Closer evaluation of the results indicated that there was a definite trend that determined the amount of SO<sub>3</sub> that was being emitted to atmosphere. The trend was identified by calculating the acid dew point temperatures from the measured SO<sub>3</sub> and moisture concentrations together with the atmospheric conditions in the stack. In all cases the calculated acid dew point corresponded to the actual gas temperatures that were measured during the sampling.

- Kendal operating temperature in stack = 129.6°C
- Kendal acid dew point for 9.95ppm SO<sub>3</sub> and 6.3% moisture = 129.8°C
- Lethabo operating temperature in stack = 133.7°C

- Lethabo acid dew point for 14.3ppm SO<sub>3</sub> and 8.7% moisture = 134.1°C

The acid dew point temperature is the temperature at which an equilibrium phase is reached between gaseous sulphur trioxide (SO<sub>3</sub>) and the formation of liquid sulphuric acid (H<sub>2</sub>SO<sub>4</sub>) in a flue gas stream.

Under normal operating conditions without SO<sub>3</sub> FGC the acid dew point temperature is significantly below the flue gas operating temperature (this is due to the low SO<sub>3</sub> concentration naturally occurring in the flue gas). The phase distribution is therefore predominantly towards the gaseous SO<sub>3</sub> phase and no condensation of liquid H<sub>2</sub>SO<sub>4</sub> will occur. Condensation of the naturally occurring SO<sub>3</sub> under normal operating conditions without SO<sub>3</sub> FGC will only occur if the gas temperature falls below the acid dew point temperature.

When SO<sub>3</sub> FGC is implemented, the phase equilibrium is adjusted due to the increased concentration of SO<sub>3</sub>. In other words the acid dew point temperature is increased and the flue gas temperature remains constant, therefore resulting in the condensation of some of the gaseous SO<sub>3</sub> as liquid H<sub>2</sub>SO<sub>4</sub> which will react with/ or coat the fly ash particles. The flue gas temperature therefore becomes the equilibrium point in the phase equilibrium distribution between gaseous SO<sub>3</sub>/ H<sub>2</sub>SO<sub>4</sub> and liquid H<sub>2</sub>SO<sub>4</sub>.

In simplified terms, only the SO<sub>3</sub> that can be converted to liquid H<sub>2</sub>SO<sub>4</sub> as a result of the phase equilibrium that is reached in the flue gas environment will be able to react with, or coat the ash particles. The remaining SO<sub>3</sub> concentration still present in the gaseous phase will therefore emit from the stack, as it is not capable of absorbing onto condensation nuclei in the gaseous form. That is the main reason why the measured SO<sub>3</sub> concentration in the stack corresponds very closely with the actual flue gas temperature.

The assessment provided an insight into the actual mechanisms involved with SO<sub>3</sub> FGC and a possible explanation for the questions listed below:

- Why does Kendal Power Station require less conditioning agent than the other Eskom Power Stations and what resulted in the fact that the actual required injection rate was less than what was originally predicted with the SO<sub>3</sub> FGC models?
- Why are differences observed in the effectiveness of SO<sub>3</sub> FGC at different Eskom Power Stations for the reduction of particulate emissions? (Even though each application is operated at its optimal injection rate).

The SO<sub>3</sub> FGC process is concerned with the application of an acid film to the surface of the fly ash particles. The ash concentration will therefore affect the amount of SO<sub>3</sub> required to condition the ash. The ash concentration is taken into consideration in the SO<sub>3</sub> injection prediction models and can therefore not be used to explain Kendal's behaviour.

It has been shown that the formation of the acidic layer on the fly ash particles occurs, as part of the acid dew point phase equilibrium that is reached in the flue gas. The acid is absorbed onto the ash surface by a condensation / partial pressure deposition process that is temperature sensitive. This only explains what has already been discussed in this paper and does not give insight into the questions that are being addressed.

It is however of importance to show that the surface composition of the fly ash particles can affect acid attachment. The surface composition has two distinct aspects, the physical and chemical properties of the fly ash. The physical properties include shape, size, density, resistivity, etc while the chemical properties are clearly related to the fly ash chemistry.

Specific attention will be given to the surface chemistry of the fly ash as most of the physical properties are also dealt with in the prediction models and can't be used to explain the specific behaviour observed at Kendal. The chemical composition used in the prediction models concentrates on the entire fly ash particle composition and not on the surface composition which in almost all cases is significantly different to the overall ash particle composition. This is mainly due to the heterogeneous composition and distribution of minerals in the coal that is burnt.

The low sulphur coals typically used in Eskom have a high percentage of acidic compounds in the ash (aluminium oxide, iron oxide and silicone oxide). This same problem was stumbled against in work performed as part of the fabric filter research. The ash appeared to be very alkaline when immersed into water and the pH was determined. All Eskom fly ashes tested had a pH of approximately 11.5. It was only as part of the research that it was determined that some of the Eskom fly ashes had a very low buffering capacity. This means that although the fly ash appears to be very alkaline, it only has a very small concentration of reactive alkaline species. Kendal, Duvha and Lethabo were identified to be some of these power stations. When the fly ashes are analysed using X-Ray fluorescence spectroscopy the total Ca concentrations are all comparable to each other. Duvha in fact has the highest Ca content of all the fly ashes that were tested, but proved to have a very low buffering capacity. This meant that the calcium measured analytically had to be either encapsulated somehow in the ash particles or that it had formed a calcium compound that was not being capable of being dissolved / reacted.

Surface chemistry techniques provided answers on the low buffering capacities that were measured for these power stations. It was determined that calcium present in these coals reacted to form various types of Calcium-Aluminium-silicate compounds. These compounds are very stable and cannot be easily dissociated.

Fly ashes that contain high concentrations of reactive calcium species on the surface tend to require more SO<sub>3</sub> flue gas conditioning agent than fly ashes with low buffer capacities/ low concentrations of reactive calcium species. This is mainly due to the fact that the SO<sub>3</sub> absorbed on the surface of the high reactive calcium concentration fly ashes, initially reacts with the calcium species that are readily available to form an inert CaSO<sub>4</sub> layer. A SO<sub>3</sub> coating is then only deposited on the inert layer to reduce the resistivity. With the ashes containing a low concentration of reactive alkali species the SO<sub>3</sub> is directly absorbed onto the surface and no SO<sub>3</sub> is consumed in neutralisation reactions.

## CONCLUSIONS

- SO<sub>3</sub> FGC is and will remain an economically viable option to Eskom for the reduction of particulate emissions.
- The standard SHELL methodology for SO<sub>3</sub> measurements cannot be used to determine the SO<sub>3</sub> concentration behind an ESP with SO<sub>3</sub> FGC. This is mainly due to the fact that the injected SO<sub>3</sub> acts to lower the resistivity of the fly ash and is only absorbed onto the surface of the fly ash particles and not reacted to physically bind with the fly ash. The standard method requires that the equipment be heated to temperatures above 200°C, which allows some of the SO<sub>3</sub> deposited on the fly ash to be released and misrepresented in the actual measurements.
- Contrary to popular belief a small portion of the injected SO<sub>3</sub> is released to atmosphere. This has been shown to occur at two of Eskom's Power Stations utilizing SO<sub>3</sub> FGC.
- The additional amount of SO<sub>3</sub> being released to atmosphere is highly dependant on the naturally occurring amount of SO<sub>3</sub> in the flue gas, the FGC injection rate, the fly ash physical and chemical composition and the operating temperatures of the ESP.
- The SO<sub>3</sub> being released to atmosphere acts as aerosol particles and remain above the inversion layer being diluted and dispersed to such an extent that it has a non-detectable/negligible impact on the surrounding environment.
- The enormous reduction in particulate emissions and the benefits being achieved towards health issues as a result thereof far exceeds any impact SO<sub>3</sub> FGC might have on the environment.

## REFERENCES

1. WURZ D, "SO<sub>3</sub> measurements at Duvha Power Station", ESG report, 1997.
2. W.T. Davis, H.E. Harper and K.E. Noll, "Fabric Filters for Fly Ash Collection, Filtration & Separation", May/June 1977, pp 232 - 237.
3. P. Vann Bush, T.R. Snyder and R.L. Chang (EPRI), "Determination of Baghouse Performance from Coal and Ash Properties: Part II", Control Technology, Volume 39, no. 3, March 1989, pp 361 - 372.
4. P. Vann Bush, T.R. Snyder and R.L. Chang (EPRI), "Determination of Baghouse Performance from Coal and Ash Properties: Part I", Control Technology, Vol. 39, No. 2, February 1989.
5. W. Humpries and J.J. Madden, "Fabric Filtration for Coal Fired Boilers: Nature of Fabric Failures in Pulse Jet Filters", Filtration & Separation, Nov./ Dec., 1981, pp 503 - 505.
6. M. de Ravin, W. Humphries and R. Postle, "A Model For the Performance of a Pulse Jet Filter", Filtration & Separation, May/ June 1988.
7. R.J. Davis and D.S. Tedone, "Designing a High Performance Baghouse to Minimise its Lifetime Costs and Maximise its Availability", Presented at the ASME Joint International Power Generation Conference, Phoenix, October 2-6, 1994.
8. J.A. Raper and A Papagelis, "Evaluation of Fabric Filter Cleaning Performance by Shaking and Pulse Jet", Final Report, School of Chemical Engineering and Industrial Chemistry, University of New South Wales, NERDDC Project No. C1275.
9. D. Houi and R. Lenormand, "Particle accumulation at the Surface of a Filter", Filtration & Separation, July/ August, 1986.
10. M.J. Beeslaar and C. Greyling, "Bag Filter Research Part I: Baghouse Chemistry", Eskom Report No. TRR/S96/004.
11. M. Blenkinsop, M. Beeslaar, B. Yafele, P. Gildenhuis, "Ash Chemistry", Eskom Report No. TRR/P95/002.

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