Reducing Fine Particle Emissions from US Coals Using the Indigo Bi-Polar Agglomerator

Paper Number 04-A-42-AWMA

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ABSTRACT

This paper presents extensive test data showing a significant reduction in fine particle emissions (PM2.5) when an Indigo Agglomerator was installed at Watson Plant, a 250MW coal fired power station in Mississippi. Two U.S coals were tested, a western coal from Colorado and an eastern Illinois Basin coal. Both of these coals showed a significant reduction in fine particle emissions with the Indigo Agglomerator installed. The reduced fine particle emissions resulted in a two thirds reduction in Opacity and a one third reduction in Mass Emission. The Colorado coal was retested after twelve months operation with similar results, indicating a consistently large reduction in fine particle emission over an extended period.

In addition to Opacity and Mass Emission testing, an in-situ Process Metrix Laser based particle size measurement instrument was used to measure the change in particle size distribution produced by the Indigo Agglomerator. This measurement confirmed a 300% reduction in the emission of fine particles, less than 5um in diameter, with the Indigo Agglomerator installed. The Indigo Agglomerator technology uses a combination of electrostatic and fluidic processes to remove the fine particles from the gas stream immediately prior to entering an Electrostatic Precipitator. The fine particles are attached to the larger particles, which are more easily collected in the Electrostatic Precipitator. The Indigo Agglomerator provides a simple, low cost solution to reducing fine particle emissions and plume visibility or Opacity.

INTRODUCTION

An Indigo Agglomerator was installed at the Southern Company's Watson Plant, located at Gulfport, Mississippi, in February, 2003. The Indigo Agglomerator is installed on a 250 megawatt opposed wall fired boiler with two identical outlet gas systems using two Environmental Elements precipitators to collect the fly-ash. Both precipitators are identical with three mechanical zones and six electrical zones. An Indigo Agglomerator was installed in the inlet duct of the B Side Electrostatic Precipitator, as shown in Photo 1. This installation allowed excellent comparative testing of different coals over an extended period due to the extensive monitoring, including flow, temperature and Opacity, at the outlet of each Precipitator.

Photo 1. The Indigo Agglomerator installation at the Watson Plant.

The Indigo Agglomerator was developed five years ago in Australia to reduce the visible emissions from coal fired boilers. The key to reducing visible emissions is a reduction in the emission of fine particle less than 5um in diameter. The Indigo Agglomerator was designed to remove these fine particles and, hence, reduce the visible emissions and Opacity. It has been tested on a number of Australian, U.S. and South American coals. All of which have shown significant improvements in fine particle emissions over extended periods of time. The West Elk coal from Colorado was tested in April, 2003, and again in April, 2004, with very similar results confirming a consistent performance improvement over a twelve month period.

WHY FINE PARTICLES?

There are three key areas where fine particles are a cause for concern:

- The initial driver for the development of the Indigo Agglomerator is the fact that fine particles are a major component of visible emissions from coal fired power stations.

- Secondly, fine particles are potentially the most dangerous emission in that they may directly impact on human health.

- Finally there is increasing evidence that fine particles are a major contributor to global warming, generally referred to as the Greenhouse Effect.

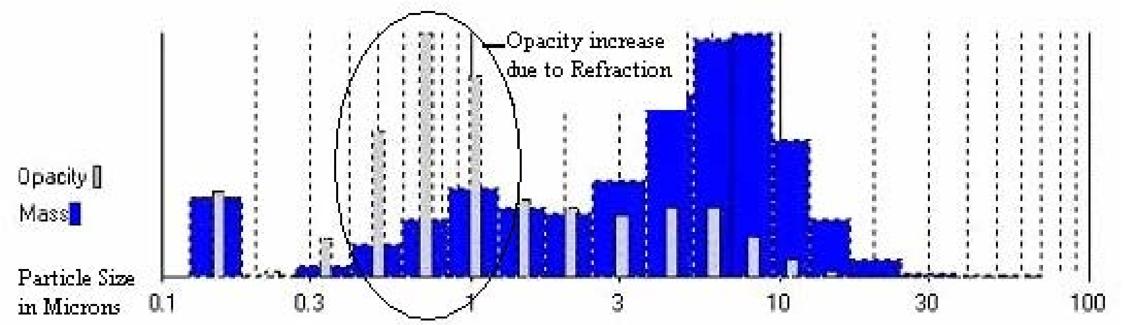
There are two factors that cause the greatly increased contribution of fine particles to the obscuration of white light, in other words plume visibility:

- The first factor is the increase in obscuration of a given mass of particles as the particle size reduces. This is because the mass is dependent upon volume, which is proportional to the cube of the particle diameter, while the obscuration is proportional to the cross sectional area, which is proportional to the square of the particle diameter. For given mass of particles, as size reduces from say 10 microns to 1 micron, the amount of obscuration will increase by a factor of 10.

- The second factor contributing to the increased obscuration of fine particles is the fact that white light has a wave length of about 0.8 microns. Thus particles about this size will have a significantly increased obscuration due to refraction of the light. This results in these particles being over three times as visible.

Thus the emission of 0.8 micron particles will be over thirty times as visible as the emission of the same mass of eight micron particles. This effect is shown in Figure 1, a graphic from a simulation of the Watson Precipitator using the EPRI ESPM performance modelling program (Reference 1). It can be seen that although the majority of the particulate mass is in the 5um to 10 um size range the main contributor to the Opacity are the 0.5um to 1 um size particles.

Figure 1. EPSM Model estimates of Opacity and Mass Emissions**.**



There are three factors that contribute to the health concerns regarding fine particles, namely:

- The fact that fine particles are more respirable, that is they are more likely to enter and remain in the human lung than larger particles.
- Secondly fine particles tend to contain more heavy metals than larger particles, due to the fact that heavy metals vaporise in the combustion process, then condense based on surface area and there is a lot more surface area in a given mass of fine particles than in the same mass of large particles.
- The final factor is due to the low mass and high surface area of fine particles that ensures these particles remain suspended in the air for long periods of time allowing for inhalation.

Thus we have a highly respirable particle with significant heavy metal contamination available for inhalation. The EPA estimates that there are over 15 000 premature deaths annually in the US that are linked to fine particle exposure.

Global warming or the green house effect is now a significant concern around the world. Researchers believe that fine particles, carried by the wind high into the upper atmosphere, contribute a significant component towards global warming. Between 15 and 30 per cent of global warming may be ascribed to the fine particles contribution, according to one expert, Professor Mark Z. Jacobson of Stanford University.

The large contribution of fine particles towards Opacity or visible emissions, the concerns regarding health issues and their potential contribution towards global warming are all good reasons for reducing fine particle emission to the atmosphere.

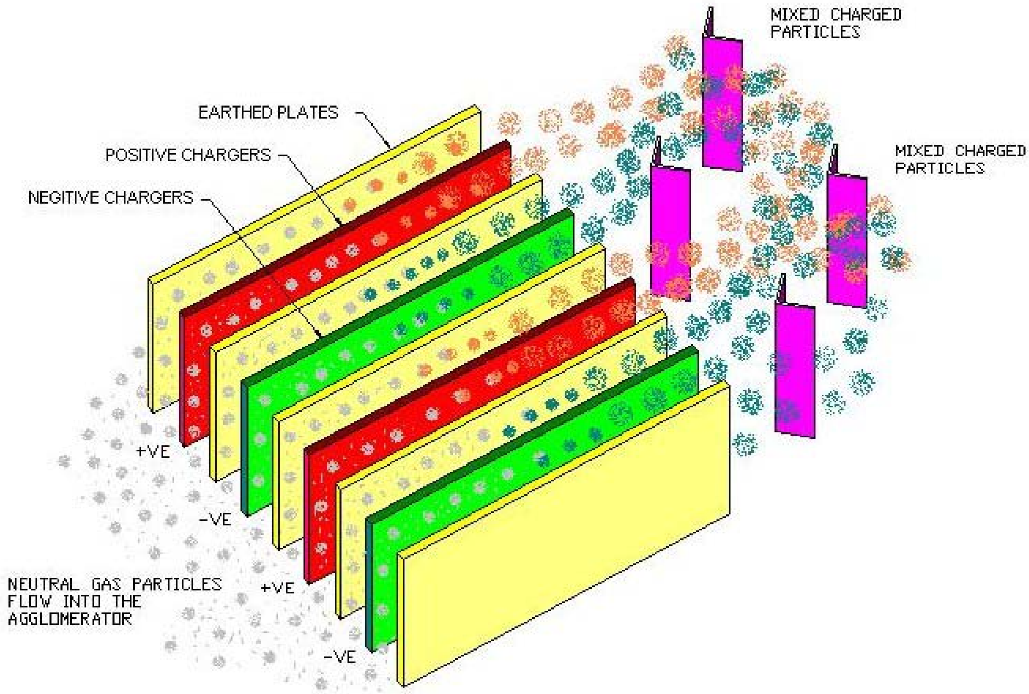
WHAT IS THE INDIGO AGGLOMERATOR?

The Indigo Agglomerator is a new technology initially developed five years ago in Australia. It has been tested on a range of Australian, U.S. and South American coals with significant success in reducing fine particles emissions. The Indigo Agglomerator is installed in the inlet duct immediately prior to the electrostatic precipitator. Fine particles entering the Agglomerator are attached to the larger particles by a combination of electrostatic and fluidic processes. These large agglomerates are then easily collected in the electrostatic precipitator that follows the Agglomerator.

As shown in Figure 2, the Indigo Agglomerator has two sections, the bipolar charger followed by the mixing section. The gas flow is split into a number of streams, each of which enters a passage in the charger section of the Agglomerator. Alternate passages are positive or negative charging. That is, the even passages may be positive and the odd passages negative, or visa versa.

Following the charger a mixing process takes place, such that the fine particles leaving the positive passages are diverted into the stream of large particles leaving the negative passage and the fine particles from the negative passage are diverted into the stream of large particles leaving the positive passage. Thus the oppositely charged particles are brought within close proximity of each other causing them to electrostatically attach to each other. These agglomerates then enter the precipitator where they are easily collected.

Figure 2. The Indigo Agglomerator.



THE U.S. COALS TESTED

Two U.S. coals were tested, the Western Basin West Elk and the Eastern Basin Emerald. The details of the coal analysis for both coals are given in Table 1 and the ash analysis is given in Table 2. The West Elk coal is one of the coals that are normally burnt at Watson power station and it was possible to carry out repeat test over an extended period of time with this coal. The West Elk coal is from Colorado and has low sulphur content but it also has a low calcium content in the ash.

The second coal tested was the Emerald coal from the Illinois Basin on the eastern side of the U.S. Emerald has a much higher sulphur content and the ash has a much higher iron content, giving it significantly different combustion properties to the West Elk coal. Emerald's grindability index is higher and the ash fusion temperature much lower than the West Elk coal.

Table 1. Coal Properties (As Received).

	West Elk	Emerald
Carbon (%)	65.00	63.93
Volatiles (%)	34.20	31.24
Moisture (%)	9.00	11.69
Ash (%)	8.20	10.76
Sulphur (%)	0.50	2.34
HHV (btu/lb)	11500	11317

Table 2. Ash Properties (Reported as % Oxides).

	West Elk	Emerald		West Elk	Emerald
AL_3O_3	28.57	19.71	K_2O	0.77	2.48
SiO_2	52.79	48.17	MgO	1.47	1.14
Fe_2O_3	6.54	19.03	TiO_2	0.52	1.08
Na_2O	1.94	0.78	CaO	3.83	4.88
P_2O_5	0.66	0.27	SO_3	2.90	2.47

The first series of tests on West Elk coal was carried out in April, 2003, following the initial installation of the Indigo Agglomerator in February, 2003. A second series of tests was carried out twelve months later in April, 2004 with coal from the same coal supplier. This repeat testing shows consistent performance over this extended period of time. The Emerald coal was a trial coal and was only available for testing during a short period in April 2004.

METHOD 17 MASS EMISSION AND OPACITY TEST RESULTS

The measurement results reported are the average of two consecutive Method 17 Mass Emission Tests performed concurrently at each of A and B Electrostatic Precipitator outlets by Sanders Engineering and Analytical Services. Averaging two consecutive tests provides a more accurate result and simultaneous testing of both A and B Precipitator outlets ensures the comparison is valid, since both A Precipitator and the Indigo Agglomerator, installed in the inlet duct to B Precipitator, will have the same gas and dust loading conditions at the inlet. Thus, this test program provides an accurate and valid comparison of the improvement gained with the installation of the Indigo Agglomerator.

The results of the West Elk Method 17 Mass Emissions Tests, along with the Opacities measured over the period of these tests, are given in Table 3 for both the April, 2003, and the April, 2004 series of tests. These results show very similar data for both April, 2003, and April, 2004. This shows that the significant reduction in Mass Emissions and the large reduction in Opacity are consistent over an extended period of time.

The Mass Emission and Opacity data for the Emerald test is given in Table 4. Again the data is the average of two consecutive tests and the tests were carried out simultaneously on both A and B Electrostatic Precipitators. This shows similar reductions to those obtained with the West Elk coal. Thus it can be said that the improvement is consistent over a range of different coals, having both low and high sulphur content.

Table 3. Method 17 Mass Emission Test Results for West Elk Coal.

	Test Date 4/17/03			Test date 4/1/04		
Measurement	**A Pass**	**B Pass**	**B Pass Reduction Compared to A Pass**	**A Pass**	**B Pass**	**B Pass Reduction Compared to A Pass**
Opacity %	15	4	**73.3%**	20.2	7.25	**64.1%**
Mass Emission						
Grains/Act Cubic Ft.	0.012	0.0066	**45.0%**	0.02369	0.0159	**32.9%**
Milligrams/Cubic Metre	27.5	15.1	**45.1%**	54.3	36.3	**33.1%**
Pounds/Million BTU	0.0382	0.0231	**39.5%**	0.0735	0.0475	**35.4%**
Gas Flow						
Actual Cubic Ft/Min	408,718	450,700	-10.3%	433,093	395,412	8.7%
Actual Cubic M/Min	11,575	12,764	-10.3%	12,265	11,198	8.7%
Gas Temperature						
Degrees F.	276	273	1.1%	280	264	5.7%
Degrees C.	135	134	0.7%	138	129	6.5%

Table 4. Method 17 Mass Emission Test Results for Emerald Coal.

	Test date 4/13/04		
Measurement	**A Pass**	**B Pass**	**B Pass Reduction Compared to A Pass**
Opacity %	13.25	2.3	**82.6%**
Mass Emission			
Grains/Act Cubic Ft.	0.0137	0.0082	**40.1%**
Milligrams/Cubic Metre	31.3	18.8	**39.9%**
Pounds/Million BTU	0.045	0.026	**42.2%**
Gas Flow			
Actual Cubic Ft/Min	443,609	406,455	8.4%
Actual Cubic M/Min	12,563	11,511	8.4%
Gas Temperature			
Degrees F.	269	260.5	3.2%
Degrees C.	132	127	3.8%

PARTICLE SIZE DISTRIBUTION TEST RESULTS

The testing was done with a unique laser particle size analyser by Process Metrix, model PMC PCSV-P. This device measures particle count concentration, rather than particle mass, and operates most effectively in the range of 0.3 to 20 um. The PMC PCSV-P instrument uses a laser based single particle count process for in-situ particle size measurement across an aperture in a water cooled probe (see Figure 3), which is inserted into the gas stream to eliminate extraction problems encountered with other particle size analysers. Measurements were taken at a number of positions in the gas flow at each of the five sample locations shown in Figure 4. The multiple measurements gave consistent results indicating a reliable and repeatable test process.

Figure 3. The PMC PCSV-P Instrument Probe

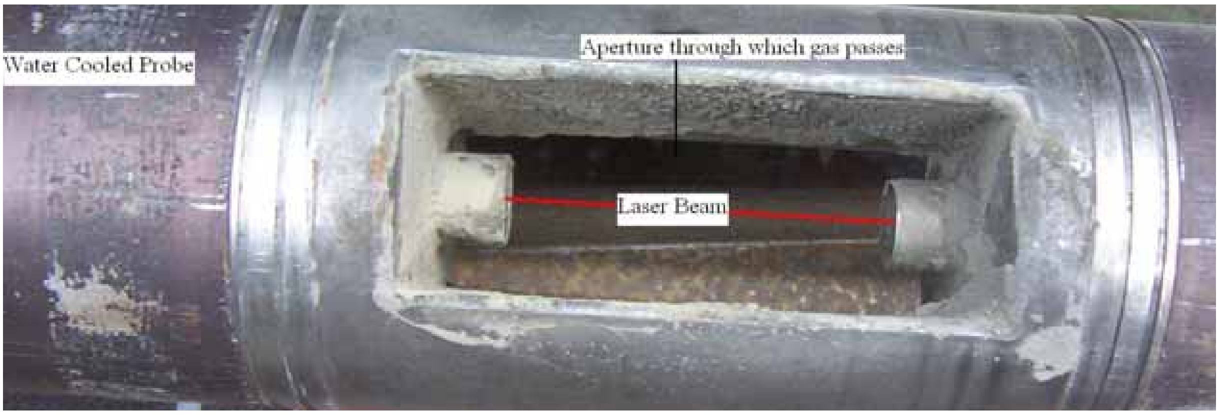
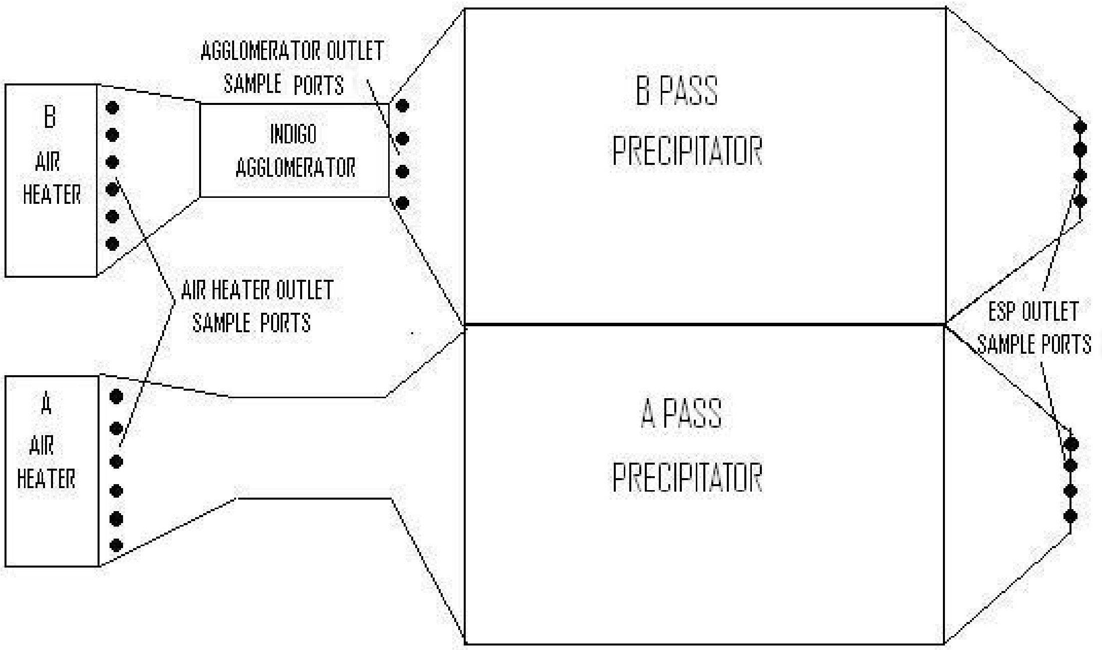


Figure 4. Locations of Particle Size Distribution Test Ports.



A graph particle size, using a linear scale, against the average number of that size particle per cubic centimetre, using a log scale, for each of the five test points is given in Figure 5 for the 2003 West Elk test, Figure 6 for the 2004 West Elk test and Figure 7 for the Emerald test. This data also shows consistent results both over time by comparing the two West Elk tests and between coals. These graphs show the following:

- The fine particle concentration at the Air-heater outlet is the same on both A Side and B Side for all tests; hence the reduced outlet emission from B Side Precipitator is due to the fine particle removal by the Indigo Agglomerator.

- The fine particle concentration at the Air-heater outlet is similar for both West Elk tests, indicating that the coal and combustion process was similar.

- The fine particle concentration at the Air-heater outlet is less about 1um for the Emerald test, hence the reduced in the Opacity.

Figure 5. West Elk 2003 Particle Size Distribution.

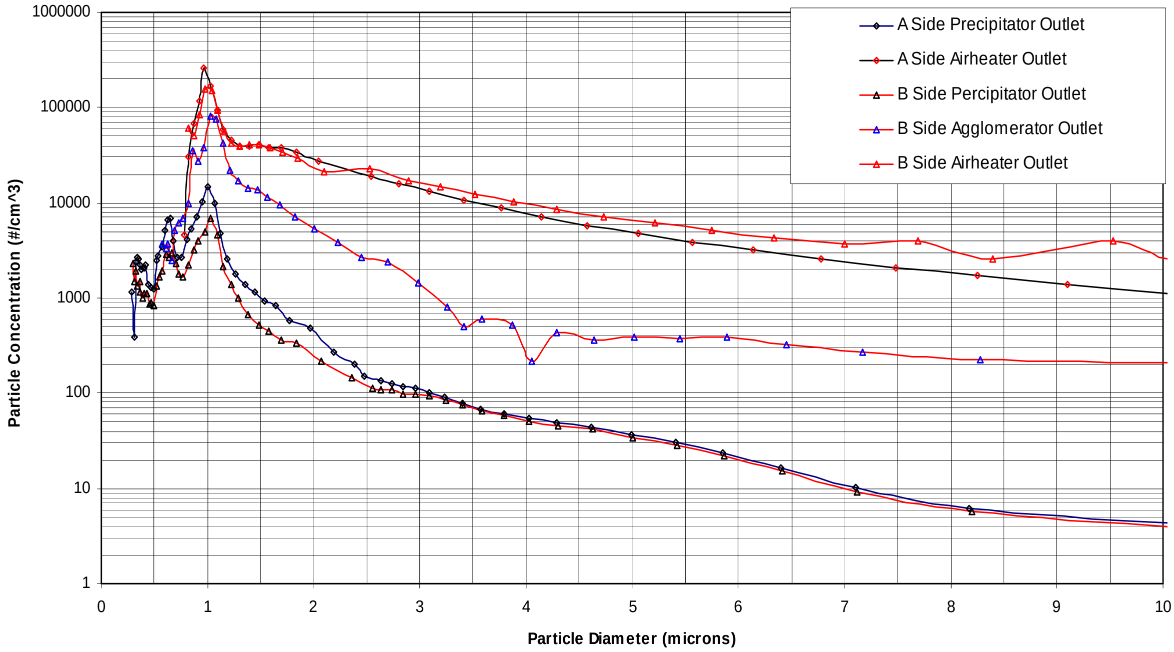


Figure 6. West Elk 2004 Particle Size Distribution.

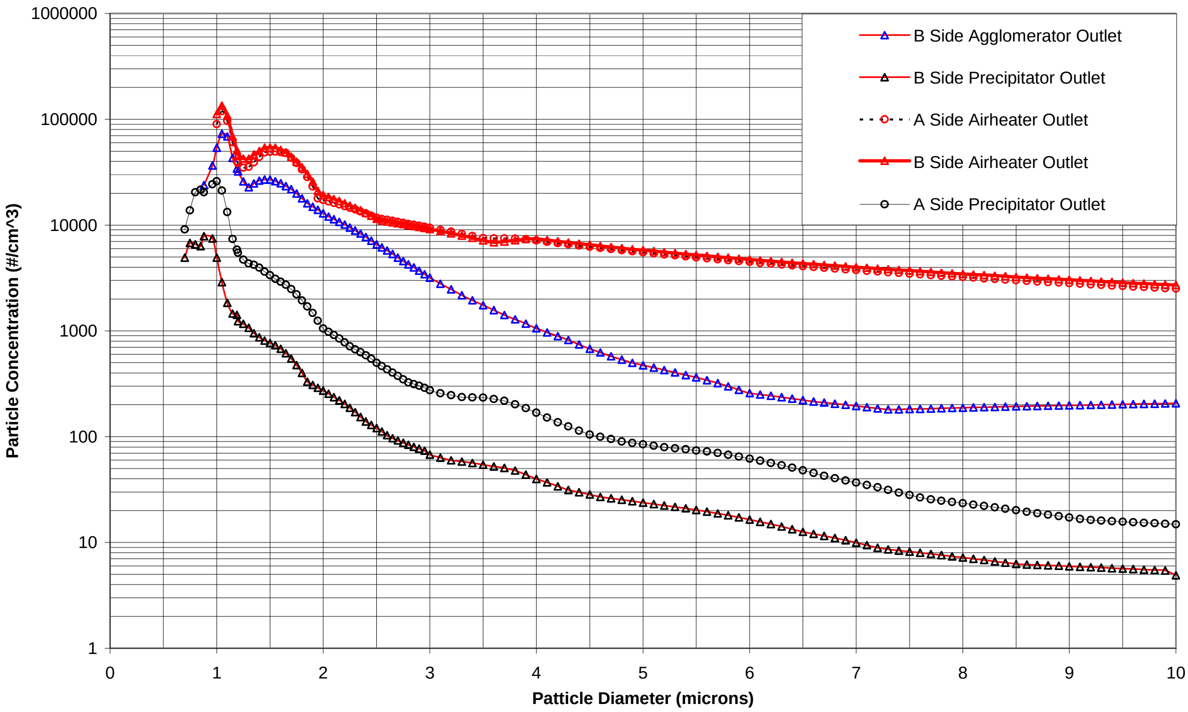
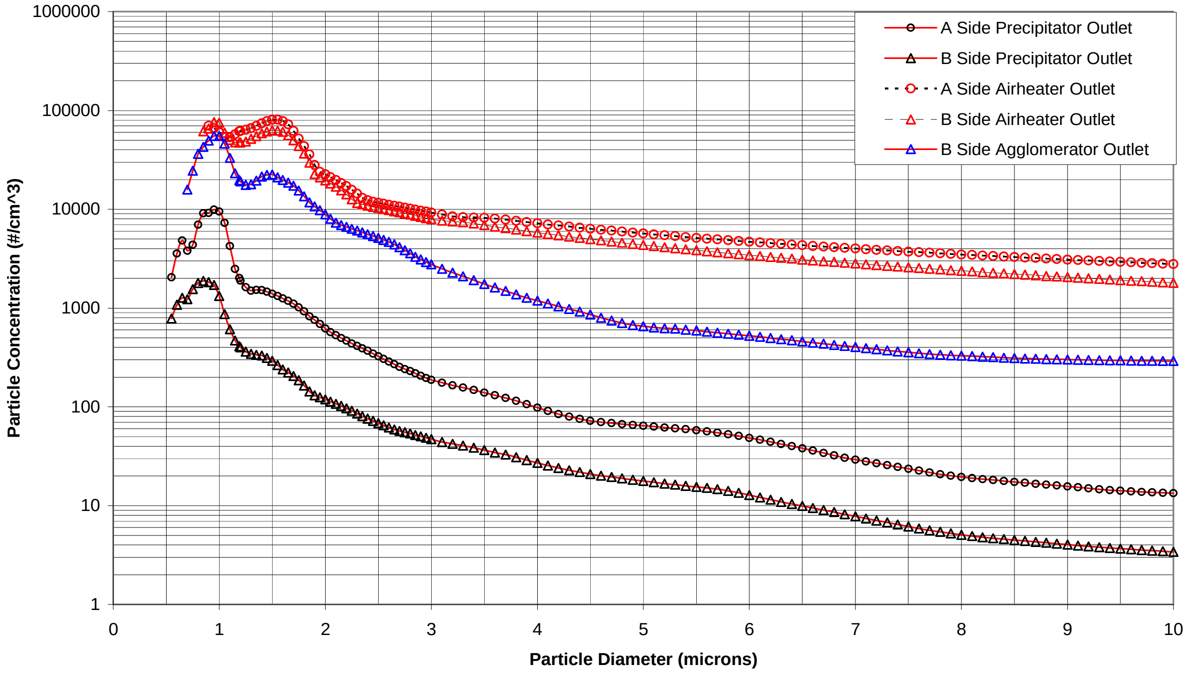


Figure 7. Emerald 2004 Particle Size Distribution.



The performance of Electrostatic Precipitators can be compared by calculating the percentage of the dust exiting the Air-heater that is not collected and is therefore emitted to the atmosphere, usually termed Slip. The graphs given in Figures 8, for the West Elk coal, and Figure 9, for the Emerald coal, compare the Slip from A Precipitator to that from the Indigo Agglomerator plus B Precipitators for particle sizes up to 10um using the 2004 test data.

Both coals show an increase in Slip with reducing particle size with a peak at one micron of 15% for A Precipitator, which is the size that has the most effect on Opacity and visibility of emissions. It is also this size range where the Indigo Agglomerator is most effective at reducing emissions, providing a reduction to less than 3% Slip at 1um for B Precipitator, including the Indigo Agglomerator. Both West Elk and Emerald coals have emissions of particles with a size less than 2.5um reduced by three quarters on B Side, with the Indigo Agglomerator, compared to A Side. This is consistent with the measured Opacity reductions, as would be expected due to the large impact that these fine particles have on Opacity. The improvement provided by the Indigo Agglomerator on West Elk coal is higher for the larger particles compared to that measured for Emerald coal but lower for the fine particles. This also correlates with the lower reduction in Opacity obtained for West Elk coal.

Figure 8. West Elk 2004 Slip.

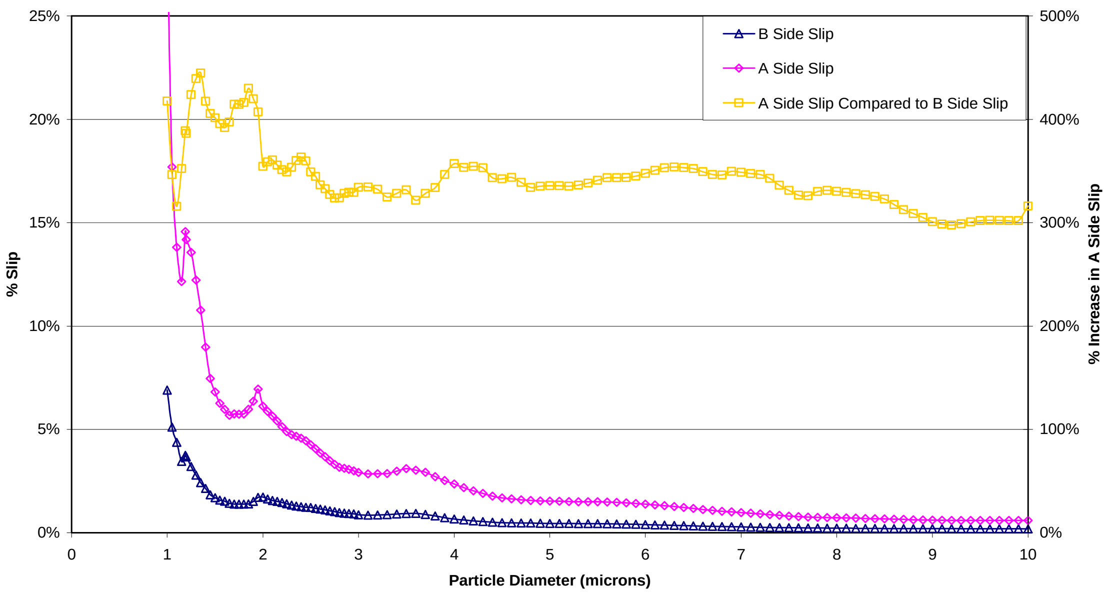
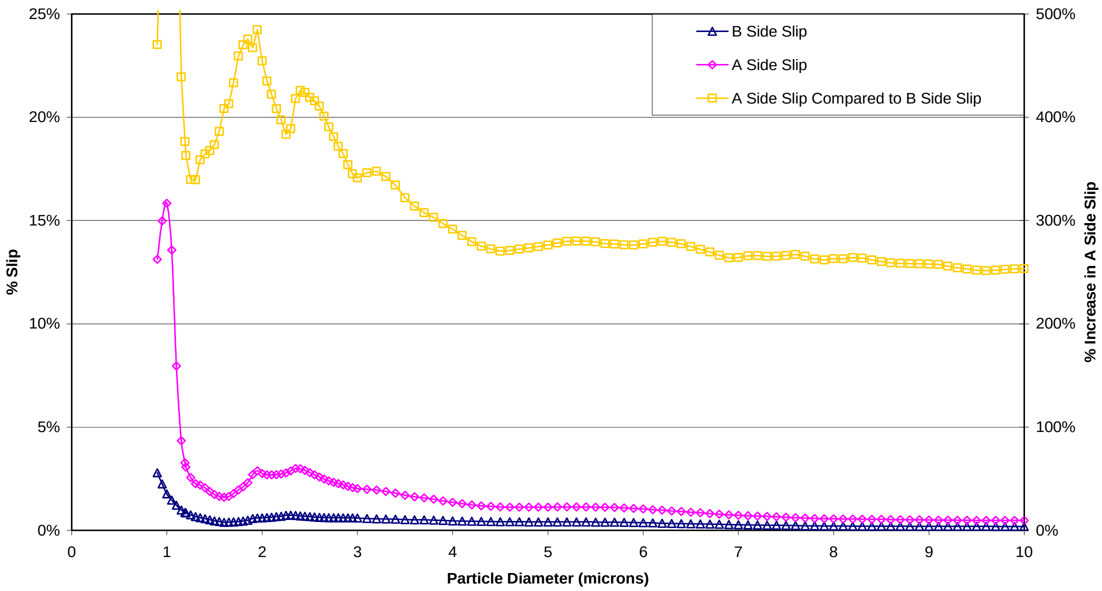


Figure 9. Emerald 2004 Slip.



CONCLUSION

The test results presented show that the Indigo Agglomerator provides a consistent long term reduction of fine particle emissions by a factor of four. The emission of fine particles, less than 2.5mu in diameter, from B Side Precipitator with the Indigo Agglomerator installed were less than a quarter of that emitted from A Side Precipitator operating without an Agglomerator. This resulted in Opacity reductions of 64% to 82%, providing up to a factor of five reduction to less than 2.5% Opacity. This is well below the visible limit, thus providing an invisible plume from the stack.

The Mass Emissions were also reduced by 33% to 45% as a result of the reduced fine particle emissions and improved Precipitator performance, due to increased front zone power levels. It was also found that the reduced fine particle load at the inlet to B Precipitator allowed the front zones of B Precipitator to operate at a higher power level (Ref 2). Over a twelve month period the reduced number of fine particles reaching the rear zones of B Precipitator also caused a reduction in the build-up on the rear zone Emitter Electrodes thereby allowing the rear zones to operate at a higher power for longer (Ref 2). Rear zone Emitter Electrode build-up, when collecting a low to medium resistivity coal, are mainly due fine particles being carried to the Emitter Electrode by the recirculating gas replacing the ionized molecules, which are carried away by the Electric Wind created by the Corona at the Emitter Electrodes. The reduction in Emitter Electrode build up is further proof of reduced fine particles and a further ESP enhancement of the Agglomerator.

The Indigo Agglomerator has proven to be a cost effective technology for reducing fine particles emissions, Opacity, visible emissions and Mass Emissions for a range of U.S. coals over an extended period of more than one year.

REFERENCES

1. Robert R. Crynack, Rodney J. Truce and Wallace A. Harrison, Use Of Computer Model To Predict ESP Enhancement With The Installation Of An Indigo Bio-Polar Agglomerator, Presented at the 9th International Conference on Electrostatic Precipitation in South Africa, (available at indigotechnologies.com.au).

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KEY WORDS
Fine Particles, PM2.5, Opacity, Dust Emissions, Indigo Agglomerator, Air Pollution