Przedstawiamy naszym Czytelnikom tekst w dwóch językach: angielskim i polskim. Tekst angielski przygotowany został przez Autorów, pracowników australijskiej Firmy Indigo Technologies i jej amerykańskiego oddziału, którzy przygotowali go wspólnie z przedstawicielem amerykańskiej firmy Particulate Control Technologies.

Tłumaczenia polskiego z niewielkimi skrótami dokonał za zgodą Autorów i firmy Indigo Technologies Pan inż. Jan Pająk. W tłumaczeniu tabel pominięto podawanie wartości parametrów w jednostkach anglosaskich. Artykuły, zarówno w języku polskim jak i angielskim, otrzymaliśmy dzięki uprzejmości Pani dr inż. Marii Jędrusik z Politechniki Warszawskiej.

Redakcja

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THE INDIGO AGGLOMERATOR A PROVEN TECHNOLOGY FOR REDUCING VISIBLE EMISSION FROM ELECTROSTATIC PRECIPITATORS

The construction and testing of a full-scale prototype of the Indigo Agglomerator started in 1999 and testing of various configurations continued through to late 2002. In mid 2002 a commercial design for the Indigo Agglomerator was developed, based on the extensive test data obtained over the previous three years. The first installation was in November 2002 at Vales Point Power Station in Australia, the site of the prototype tests. At the invitation of the Southern Company, a second unit was installed at Watson Plant in Mississippi in March, 2003. The Southern Company has carried out extensive testing over a two year period at Watson Plant while burning a wide range of coals with the Indigo Agglomerator showing a consistent improvement in electrostatic precipitator emissions. The Southern Company placed a second order for an Indigo Agglomerator installation at the Hammond Plant in 2004 and this unit was commissioned in October, 2004. Hammond was the first Indigo Agglomerator installed in a vertical duct, both Vales Point and Watson were in horizontal gas ducts leading to the electrostatic precipitator.The Tarong Power Station in Australia also installed an Indigo Agglomerator in 2004 with final commissioning taking place in December. The fifth Indigo Agglomerator installation was commissioned in May, 2005 at the Empire Electric, Asbury Plant in Missouri.

A range of tests have been performed at each of these installations with results that show a consistent reduction in fine particle emission, the main contributor to visible emissions and Opacity. The independent test data shows:

- A factor of over 10 reduction in the emission of sub-micron particles.
- A factor of over 5 reduction in the emission of PM2.5 Particles, particles less than 2.5 micron in diameter.
- A factor of 2 to 8 reduction in Opacity readings, dependant upon the coal and plant conditions.
- A reduction in mass emissions of between one third and two thirds, using US Method 17 compliant testing.
- Extended testing at Watson Plant by the Southern Company shows that the improvements are consistent over a period in excess of two years.

An added benefit provided by the Indigo Agglomerator dramatically reducing the number of fine particles entering the electrostatic precipitator is significantly improved electrostatic precipitator energisation. In the front of the electrostatic precipitator the current can increase by over 40%, due to reduced Space Charge, while in the rear the reduced fine particle concentration can halve the power degradation with time, due to emitter build-up. This improvement in electrostatic precipitator energisation will improve the collection of all particles.

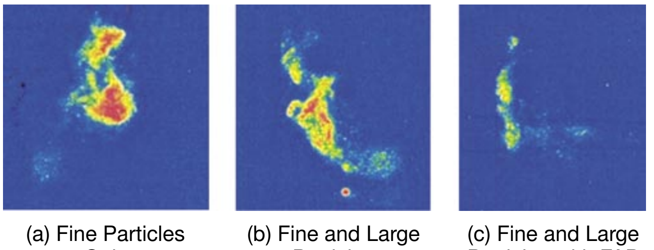
The impressive independent test results, coupled with an improvement that is consistent over both time and a range of plants burning a wide variety of coals, confirms the Indigo Agglomerator is a proven commercial option for reducing visible emissions, Opacity and PM2.5 Particulate emissions from electrostatic precipitators.

THE INDIGO AGGLOMERATOR TECHNOLOGY

The Indigo Agglomerator utilizes two patented processes that cause the fine particles to attach to the large particles, which are easily captured by the electrostatic precipitator. The first process is the Fluidic Agglomeration Process (FAP), a physical process that occurs without the need for electrical energisation. The Bipolar Electrostatic Agglomeration Process (BEAP) requires electrical energisation to charge the particles. It is the combination of these two processes that result in the massive reduction in fine particles shown in the test data.

The Fluidic Agglomeration Process (FAP), which uses enhanced fluidic based particle size selective mixing to increase the physical interaction between the fine particles and the large particles. This increased interaction vastly increases collisions between the fine and large particles resulting in the formation of agglomerates, which significantly reduces the number of fine particles. Extensive testing at the University of Adelaide using Laser Induced Fluorescence (LIF) has confirmed that FAP greatly reduces the number of fine particles. One micron water droplets, doped with a chemical that fluoresces when it passes through a laser sheet, were introduced into the gas flow in a wind tunnel. The intensity of the fluorescence, which is proportional to the total volume of fine particles passing through the laser sheet, was measured using a digital video camera with a filter set at the wavelength of the fluorescence. A computer was used to analyze this video data by averaging over time then scaling and color coding the fine particle spacial distribution from blue, indicating no fine particles, through the spectrum to red, as the number of fine particles increases. Larger un-doped droplets, of about ten microns, could be injected as required but appear blue in the LIF analysis due to the filter. When the fine droplets collide with the large droplets they are absorbed and cease to fluoresce, due to the high dilution of the un-doped large droplets.

Figure 1a, the color coded distribution of fine droplets without any large droplets or FAP, is the base condition for fine droplet mass comparison. Figure 1b, the distribution of fine droplets with large droplets injected but no FAP, shows increased fine droplet dispersion but little change in total fine droplet mass. Figure 1c, the distribution of fine droplets with large droplets injected and FAP operating shows a greatly reduced fine droplet mass. This data proves FAP greatly increases the collisions between fine and large droplets thereby significantly reducing the number of fine droplets. The percentage of collisions that result in agglomeration is, as yet unknown, but site test have shown FAP reduces fine particle count by more than half on the full size installation.



(a) Fine Particles Only | (b) Fine and Large Particles | (c) Fine and Large Particles with FAP

Figure 1 – LIF Analysis of Fine Particle Mass Density

The Bipolar Electrostatic Agglomeration Process (BEAP) uses two key processes to reduce fine particle emissions. A Bi-polar Charger is used to charge half of the dust with a positive charge and half negatively. The Bipolar Charger has a series of alternating positive and negative parallel passages that the gas and dust pass through to acquire a positive or negative charge. The second key process is a specially designed Size Selective Mixing System (SSMS) that causes the fine positive particles to be carried by the gas and mixed with the large negative particles emitting from the adjacent negative passage. The SSMS also causes the fine negatively charged particles to mix with the large positive particles, as shown in Figure 2.

Because electrostatic force decreases rapidly with distance, the SSMS is essential as it brings the fine particles close to the oppositely charged large particles so that the electrostatic force is sufficient to cause them to attach forming agglomerates. Plant tests have shown that BEAP also reduces fine particles by more than half on the full size installation.

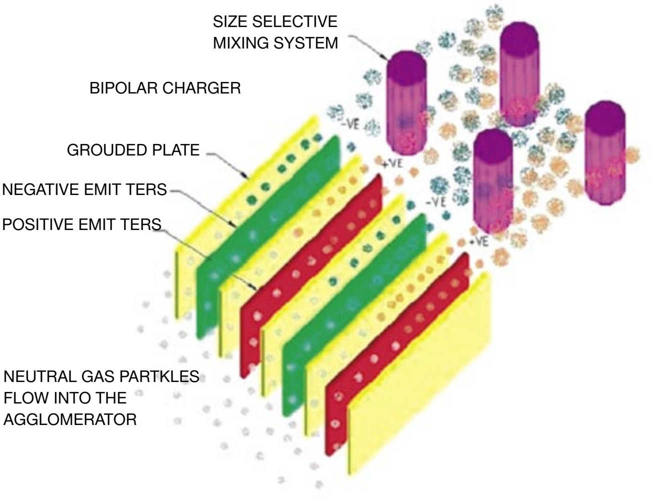


Figure 2 – Bipolar Electrostatic Agglomeration Process

The Indigo Agglomerator is installed in a five meter vertical or horizontal section of the inlet duct leading to the electrostatic precipitator and operates at a high gas velocity, generally in excess of ten meters per second. Because of this high gas velocity the Grounded Plates are kept clean without any rapping, as used in an electrostatic precipitator, thereby minimizing maintenance costs. The Indigo Agglomerator only uses about five kilowatts of electrical power per 100 MW of unit capacity and adds less than 200 Pa to the fan head. As a result the operating cost of the Indigo Agglomerator is also very low. Only five meters of straight duct, in either a horizontal or vertical orientation, is required to install both the Bipolar Charger and the SSMS, as a result Indigo Agglomerator capital cost is low relative to other electrostatic precipitator enhancement options but it is dependent upon site conditions and location. **The low capital, operating and maintenance costs make the Indigo Agglomerator very commercially attractive.**

THE PLANT AND COAL DATA

The Indigo Agglomerator installations cover a wide range of both boiler and electrostatic precipitator suppliers and configurations, as can be seen from the data in Table 1. The fact that the reduction in emissions, as a result of the Indigo Agglomerator installation, has been consistent for all of these installations indicates the Indigo Agglomerator is not plant sensitive.

These five power stations burn a wide range of coals, many of them difficult to collect in an electrostatic precipitator. Vales Point burns a range of Australian low Sulfur, high ash bituminous coals, with ash resistivities between 10^{11} ohm-cm and 10^{13} ohm-cm, that are difficult to collect in the electrostatic precipitator even using SO_3 and ammonia conditioning.

The most difficult coal is burnt at Tarong Power Station. This coal, from the Meandu Mine adjacent to the power station, contains 30% ash that is 97% Silica and Aluminum Oxide resulting in an ash resistitivity in excess of 10^{15}ohm-cm. This ash does not respond to SO3 treatment and the electrostatic precipitator operates with Intermittent Energisation using extremely long Off Times of up to two seconds in the rear zones.

The Southern Company has carried out extensive long term tests at Watson Plant burning a wide range of coals including:

- Drummond is the main Columbian low Sulfur bituminous coal burnt at Watson Plant. It has a Sulfur content of about 0.5% and an ash content of about 5% but other Columbian coals burnt at Watson Plant have up to 12% ash content. SO3 is used to condition some of these coals as the resistivity can get over 10^{12} ohm-cm.
- West Elk coal, from Colorado, is the main western US low Sulfur bituminous coal burnt at Watson. It has an ash content of about 8% and a Sulfur content of 0.6%.
- A number of eastern US medium Sulfur coals have been burnt at Watson Plant. These include American from the Appalachian Coal Basin, with about 1.3% Sulfur and 6% ash, and Emerald from the Illinois Coal Basin, with about 2.5% Sulfur and 12% ash.

Hammond Plant, another Southern Company power station, burns West Virginia bituminous coal with an ash content of about 9% and a Sulfur content of 1.5%. The site of the last Indigo Agglomerator installation, the Asbury Plant, burns 85% low Sulfur Sub-bituminous western US coal from the Powder River Coal Basin mixed with 15% high Sulfur eastern US coal to reduce ash resistivity.

The Indigo Agglomerator enhancement of electrostatic precipitator performance is largely independent of coal composition and properties. In particular, ash resisitivity does not appear to affect the emission reduction resulting from the installation of an Indigo Agglomerator. The main impact on the improvement achieved is the amount of fine particulate produced in the boiler, which is dependent on both the coal properties and the combustion process. The higher the fine particle content in the fly ash, the better the improvement obtained from the Indigo Agglomerator. The reduction in Opacity can vary from 50% to over 90% as the fine particle component increases.

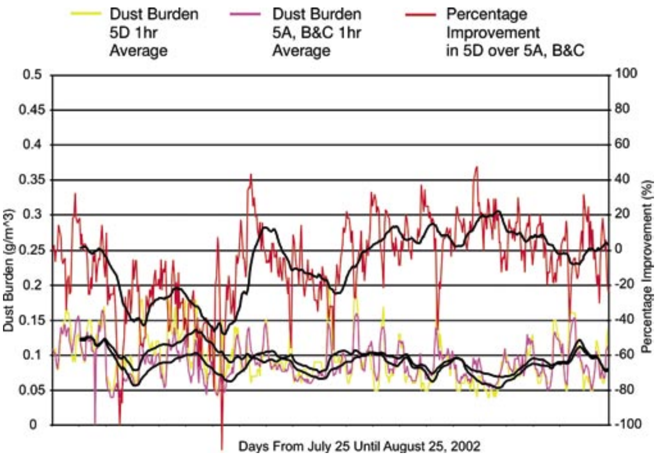
THE INDIGO AGGLOMERATOR TEST DATA

All plants have optical emission monitors installed to monitor electrostatic precipitator emissions. In the US installations record Opacity while the Australian installations record Optical Density, which has a more linear relation to Mass Emission. The average Optical Density improvement at Vales Point Plant was found to be 55% while at the Tarong Plant the average improvement for Pass 1, with the Indigo Agglomerator, was 45% compared to Pass 2, which is on the same Air Heater. The graph below show Optical Density trends at the two power stations. Graph 1 shows the Optical Density trend over a month prior to installing the Indigo Agglomerator at Vales Point and Graph 2 shows the Optical Density trend over a month following the installation. Graph 3 shows the Optical Density trend over three weeks following the Indigo Agglomerator installation on Pass 1 at Tarong. Prior to the Indigo Agglomerator installation, Pass 1 normally operated at a higher Optical Density than Pass 2.

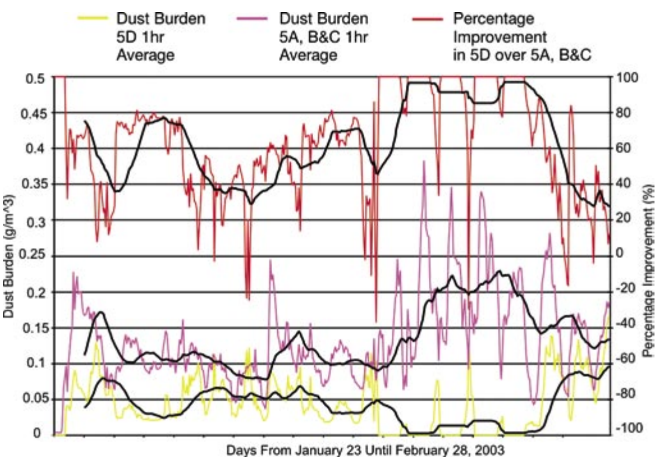
Table 1

Plant Data for Current Indigo Agglomerator Installations

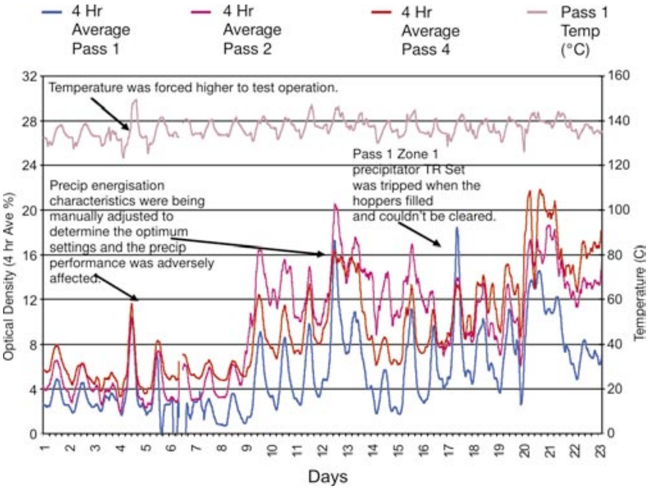
Indigo Agglomerator Installation	Date and Location Installed Month-Year	Unit Size MW	Boiler Type	ESP Size Sec/m (Sq Ft/1000ACFM)	ESP Type	Gas Conditioning Systems
Vales Point Power Station Delta Electricity New South Wales, Australia	Nov-02 ESP 5A	660	*Combustion Engineering* Corner Fired Tangential	100 (500) 4 Casings each with 5 Sections	*Flakt (Alstrom)* European Design Bottom Rap Tumbling Hammer	SO_3 and Ammonia
Watson Plant Mississippi Power Mississippi, USA	Mar-03 ESP 4B	250	*Riley* Opposed Wall Fired	47 (234) 2 Casings each with 3 Mechanical and 6 Electrical Sections	*Environmental Elements Corporation* US Design Top Rap MIGI Rappers	SO_3
Hammond Plant Georgia Power Georgia, USA	Nov-04 FULL	115	*Riley* Single Wall Fired	33 (168) Single Casing with 2x3 Sections	*Research Cottrell* US Design Top Rap MIGI Rappers	SO_3
Tarong Power Station Tarong Energy Queensland, Australia	Dec-04 ESP PASS 1	350	*Hitachi Babcock* Opposed Wall Fired	236 (1230) 4 Casings each with 6 Sections	*Lurgi* European Design Bottom Rap Tumbling Hammer	No Conditioning
Asbury Plant Empire Electric Missouri, USA	May-05 FULL	225	*B & W* Cyclone Fired	33 (164) 2 Casings each with 2 Mechanical and 2x4 Electrical Sections	*Lodge Cottrell* Top Rapp MIGI Rappers	No Conditioning



Graph 1 – Vales Point Optical Density prior to Indigo Agglomerator installation



Graph 2 – Vales Point Optical Density after the Indigo Agglomerator installation on 5D



Graph 3 – Tarong Optical Density after the Indigo Agglomerator installation on Pass 1

The Watson Plant Indigo Agglomerator installation, on electrostatic precipitator 4B, has had the Opacity monitored for over two years, during which time a range of coals were burnt.

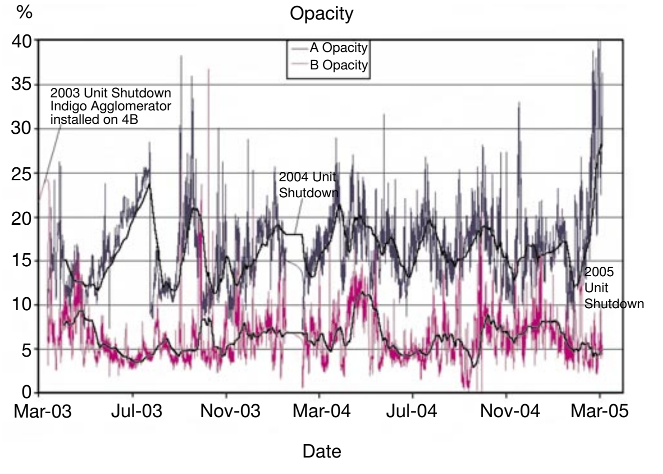
Table 1 details the Opacity improvement, averaged over weeks of operation, for 4B electrostatic precipitator, with an Indigo Agglomerator, compared to the identical 4A electrostatic precipitator. A 50% improvement indicates that 4B Opacity is half that of 4A. Watson Plant monitors the coal being burnt, so it was possible to determine the improvement for a number of different coals at both high and low loads. A time averaged analysis over three months prior to the Indigo Agglomerator installation showed less than 5% bias in favor of 4B, an equivalent of 19% Opacity on 4B compared to 20% on 4A.

Table 2

Opacity improvement with Indigo Agglomerator

Coal	Average Load (MW)	Average improvement (%)
West Elk Coal High Load (>230 MW) Low Load (<200 MW)	 245.2 169.6	 51.2 51.2
American Coal High Load (>230 MW) Low Load (<200 MW)	 245.3 137.6	 50.7 64.9
Emerald Coal High Load (>230 MW) Low Load (<200 MW)	 245.7 139.9	 78.3 88.4
Drummond Coal High Load (>230 MW) Low Load (<200 MW)	 245.6 142.5	 60.2 68.7

Watson Plant is a base load generator, so it operates at close to full load for all but a few hours each day. By removing data at loads below 245 MW the Opacity trend at full load for the full two years of operation can be trended. This trend is given in Graph 4, which shows clearly that 4B electrostatic precipitator emission is consistently less than half that of 4A.



Graph 4 – Watson Plant two Year Opacity Trend at Full Load

A number of Mass Emission tests using the US Method 17 have been performed at Watson and Hammond Plants. Table 2 contains the data for the three tests carried out at Watson Plant including two sets of tests burning West Elk Coal performed one year apart.

This shows a consistent improvement in Mass Emissions on electrostatic precipitator 4B, with the Indigo Agglomerator, compared to the unmodified 4A. Table 3 contains similar data for Hammond Plant. Because the Indigo Agglomerator was installed on both electrostatic precipitator inlets, it was necessary to compare the performance of Unit 3, with the Indigo Agglomerator installed, to an identical unit, Unit 2. Both of these units share a common Stack where the Method 17 tests were performed on Saturday and Sunday. On Saturday Unit 2 was operated at full load for the test, with Unit 3 shut down, and on Sunday Unit 3 was operated at full load with Unit 2 shut down. The willingness to accept the significant cost of taking generating units off-line to allow testing of the Indigo Agglomerator is an indication of the importance that the Southern Company places on the potential application of the Indigo Agglomerator technology on their coal fired power plants.

Particle size tests were also performed at both Watson and Hammond using a unique laser particle size analyzer by Process Metrix, Model PCSV-P. This device measures particle count concentration, rather than particle mass, and operates most effectively in the range of 0.3 to 50 um. The 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, which is inserted into the gas stream to eliminate extraction problems encountered with other particle size analyzers. Sub-micron particle tests were also carried out by the Southern Research Institute using a TSI Model 371A SMPS Analyzer, which uses electrostatic mobility to measure particle distribution from 0.02 um to 0.9 um. This unit uses an extraction system that removes the larger particles. Although there is only a small overlap in the size of particles analyzed by the two very different processes, there was a good correlation in this region.

Graph 5 shows a typical West Elk Coal size distribution using the Process Metrix Analyzer and Graph 6 shows this data in terms of Slip, the percentage of particles that are not collected, and outlet emission reduction compared to 4B electrostatic precipitator, which does not have an Indigo Agglomerator. Graphs 7 and 8 show similar data for the Emerald Coal and Graphs 9 and 10 show the same information for the sub-micron data obtained using the TSI Analyzer while burning Drummond Coal.

Points of note include:

- The particle size distribution at 4A and 4B Air Heater Outlet are almost identical, validating the electrostatic precipitator Opacity and Mass Emission comparsion.
- Emission reduction, due to the Indigo Agglomerator installation, increases with reducing particle size from about 60% at 10 um to over 90% below 0.1um.
- The emission reduction in the particle size range that is most visible and has most impact on Opacity is about 80%.

Table 4

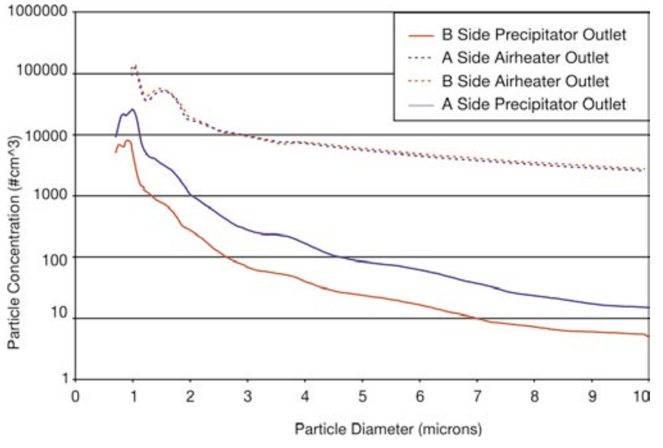
Hammond Plant Method 17 Mass Emission Tests

Measurement	Unit 2 11/20/04	Unit 3 11/21/04	Unit 3 Reduction Compared to Unit 2
Mass Emission			
Grains/Act Cubic Ft.	0.0038	0.0015	60.5%
Milligrams/Cubic Metre	8.7	3.4	60.5%
Pounds/Million BTU	0.0124	0.0049	60.5%
Gas Flow			
Actual Cubic Ft/Min	540,064	489,363	9.4%
Actual Cubic M/Min	15,295	13,859	9.4%
Gas Temperature			
Degrees F.	264.8	253.8	4.1%
Degrees C.	129.3	123.2	4.7%

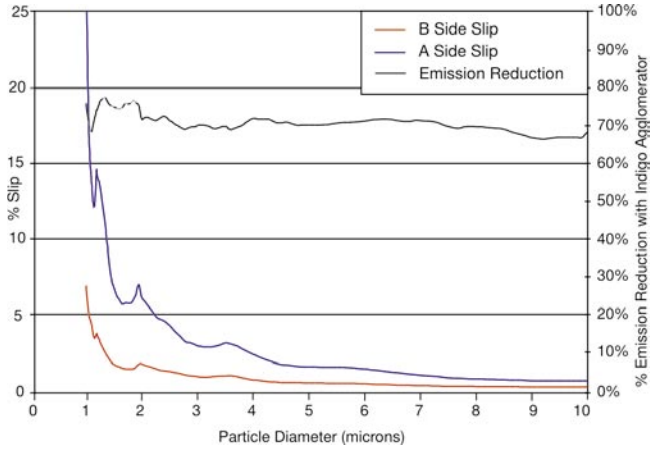
Table 3

Watson Plant Method 17 Mass Emission Test Data

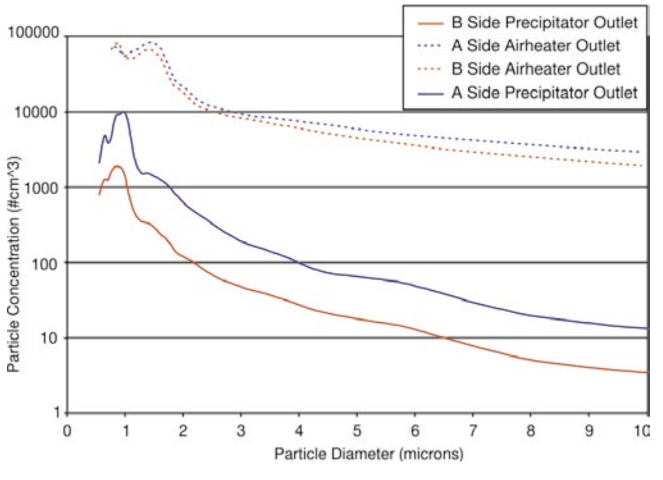
Measurement	West Elk Coal Test Date 4/17/03			West Elk Coal Test date 4/1/04			Emerald Coal Test date 4/13/04		
	A Pass	B Pass	B Pass Reduction Compared to A Pass	A Pass	B Pass	B Pass Reduction Compared to A Pass	A Pass	B Pass	B Pass Reduction Compared to A Pass
Opacity %	15	4	73.3%	20.2	7.25	64.1%	13.25	2.3	82.6%
Mass Emission									
Grains/Act Cubic Ft.	0.012	0.0066	45.0%	0.02369	0.0159	32.9%	0.0137	0.0082	40.1%
Milligrams/Cubic Meter	27.5	15.1	45.1%	54.3	36.3	33.1%	31.3	18.8	39.9%
Pounds/Million BTU	0.0382	0.0231	39.5%	0.0735	0.0475	35.4%	0.045	0.026	42.2%
Gas Flow									
Actual Cubic Ft/Min	408,718	450,700	-10.3%	433,093	395,412	8.7%	443,609	406,455	8.4%
Actual Cubic M/Min	11,575	12,764	-10.3%	12,265	11,198	8.7%	12,563	11,511	8.4%
Gas Temperature									
Degrees F.	276	273	1.1%	280	264	5.7%	269	260.5	3.2%
Degrees C.	135	134	0.7%	138	129	6.5%	132	127	3.8%



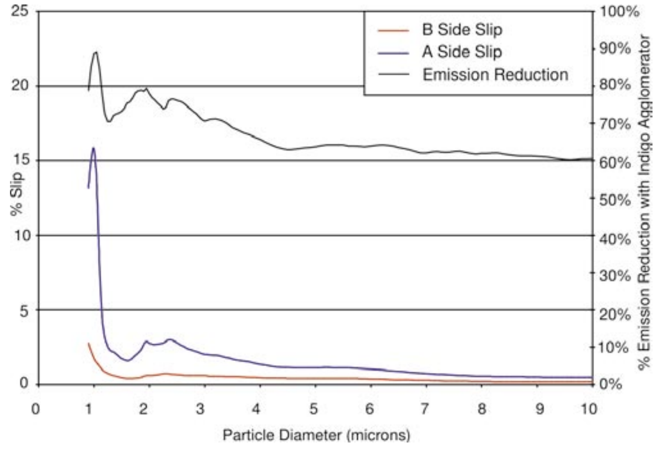
Graph 5 – West Elk Coal Particle Size Distribution using Process Metrix Analyzer



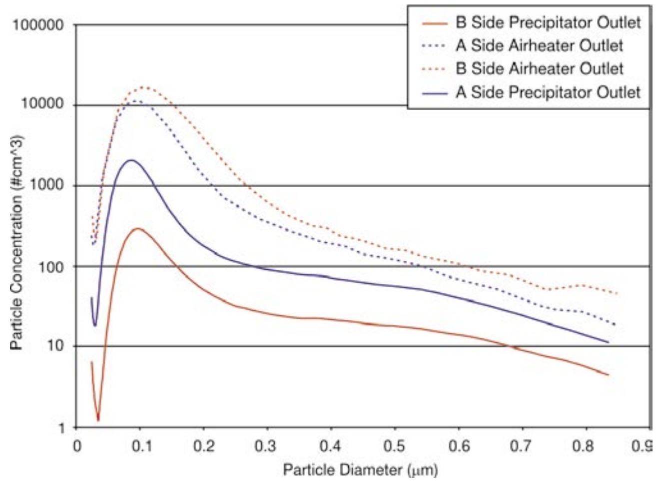
Graph 6 - West Elk Coal Slip and Emission Reduction vrs Particle Size



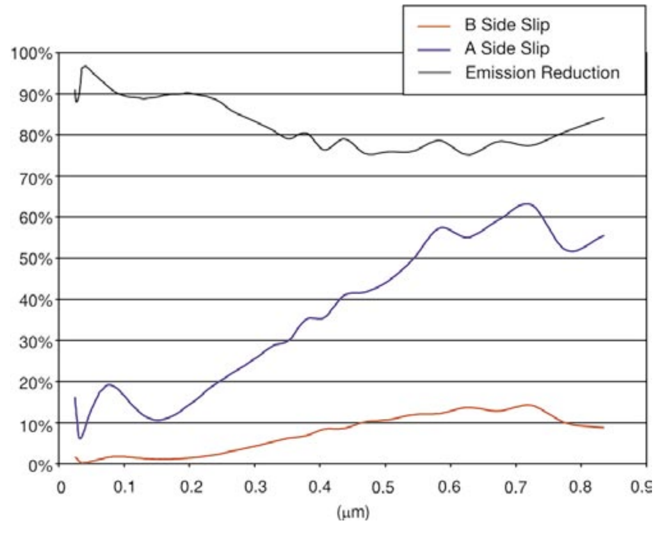
Graph 7 – Emerald Coal Particle Size Distribution using Process Metrix Analyzer



Graph 8 – Emerald Coal Slip and Emission Reduction vrs Particle Size



Graph 9 – Drummond Coal Sub-micron Particle Size Distribution using TSI Analyzer



Graph 10 – Drummond Coal Sub-micron Slip and Emission Reduction vrs Particle Size

CONCLUSION

The broad range of data presented in this paper used a variety of test equipment and processes to prove the installation of an Indigo Agglomerator significantly reduces emissions from a variety of electrostatic precipitators at a number of different power stations burning a wide range of coals. All of these Indigo Agglomerator installations are full size commercial units on large boilers with a range of design configurations and electrostatic precipitator sizes.

The key factor that proves the Indigo Agglomerator technology is that this data is consistent over:

- **Time** with testing carried out over periods in excess of two years.
- **Plant** with a range of boiler and electrostatic precipitator designs and sizes.
- **Coal** with a board range of coals from a number of regions being tested.
- **Testing process** with a variety of tests carried out by independent testers using proven methodology and equipment.

The data shows that the installation of an Indigo Agglomerator will reduce:

- **Mass Emission** reductions of 30% to over 60%.
- **Opacity** reductions of 50% to over 80%.
- **PM2.5 Emission** reductions of 70% to over 90%.

It is the fine particles, which impact the most on visibility and contribute to smog and respiratory health problems, where the installation of an Indigo Agglomerator is most effective in reducing emissions from electrostatic precipitators. **The Indigo Agglomerator is a commercially proven technology that greatly reduces hazardous fine particle emissions from large process plants without a large capital or operating cost.**

Other papers containing more information on the extensive Watson Plant tests, electrostatic precipitator energisation improvement and performance modeling are available at the Indigo Technologies internet site www.indigotechnologies.com.au

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Technologia redukcji emisji drobnych pyłów w elektrofiltrach za pomocą aglomeratora *Indigo*

Eksploatowane od dłuższego już czasu aglomeratory firmy *Indigo* znacząco poprawiają skuteczność odpylania elektrofiltrów w pięciu elektrowniach, gdzie wspomagają oczyszczanie spalin pochodzących ze spalania bardzo różnych gatunków węgli. Istniejące w tych elektrowniach elektrofiltry mają różne konstrukcje (zarówno europejskie, jak i amerykańskie), a także bardzo zróżnicowane są rozwiązania i wielkości kotłów.

W kotłach spalane są węgle australijskie, kolumbijskie a także wschodnio- i zachodnioamerykańskie. W czasie ponad dwuletniej eksploatacji aglomeratorów osiągnięto trwałe średnie obniżenie masowej emisji pyłu za elektrofiltrami w zakresie 30-60% oraz redukcję zaczernienia spalin (opacity) w zakresie 50-80%, co pozwala na uznanie tej nowej technologii jako już sprawdzoną i przydatną w celu podwyższenia skuteczności odpylania elektrofiltrów w warunkach przemysłowych.

Budowę oraz pierwsze próby prototypu aglomeratora *Indigo* w pełnej skali rozpoczęto w 1999 r. i trwały one, dla różnych wersji aglomeratora, do końca 2002 r.

W połowie 2002 r. powstała pierwsza komercyjna wersja aglomeratora *Indigo*, będąca wynikiem szeroko prowadzonych prób i badań przez okres poprzednich trzech lat. Instalacja została uruchomiona w listopadzie 2002 w elektrowni *Vales Point PS* w Australii, gdzie wcześniej prowadzono badania prototypu aglomeratora. Korzystając z zaproszenia firmy *Southern Company,* USA, drugi aglomerator zabudowano w elektrowni *Watson*, Mississippi, USA, w marcu 2003 r.

Dwuletnie badania aglomeratora, przy spalaniu w kotle energetycznym różnych węgli, wykazały uzyskiwanie trwałej i znaczącej poprawy skuteczności odpylania testowanego elektrofiltru. W związku z powyższym, firma *Southern Company* złożyła zamówienie na dostawę i zabudowę kolejnego aglomeratora *Indigo* w elektrowni *Hammond*, USA. Został on uruchomiony w październiku 2004 r. Był to pierwszy aglomerator zabudowany na pionowym odcinku kanału spalin. Dwa poprzednie, w elektrowniach *Vales Point i Watson*, zabudowano na poziomych odcinkach kanałów spalin przed elektrofiltrami.