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ENHANCED FINE PARTICLE COLLECTION USING THE INDIGO AGGLOMERATOR

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ABSTRACT

Fine particles are a major health issue as they remain suspended in the atmosphere for extended periods, are able to penetrate deep into the human lung and contain significant concentrations of heavy metals, such as Arsenic. They are also a significant component of the smog that limits the visibility in many cities and even in some national parks plus scientists believe they have an effect on global weather patterns. The Indigo Agglomerator enhances fine particle collection by attaching the fine particles to the larger particles. These large agglomerated particles are easily collected in existing control devices, such as electrostatic precipitator, fabric filters, scrubbers and cyclones. This paper concentrated on PM2.5 particles, that is particles less than 2.5um in diameter, including data that was collected on particles down to 50nm in diameter. It was found that the reduction in fine particle emission from an electrostatic precipitator provided by installing an Indigo Agglomerator increases with reducing particle size from a factor of 5 at 2um to a factor of 10 at 100nm. Reductions of this magnitude will have a significant effect on the impact of fine particles on both visibility and health. It will also result in a reduction in heavy metal emissions.

THE FINE PARTICLE PROBLEM.

Extensive research has been carried out on the health effects of Particulate Matter and it is universally accepted that the main cause of health problems are the PM2.5 particles with a diameter less than 2.5um, by current convention known as fine particles. The EU Working Group on Particulate Matter in its Second Position Paper on Particulate Matter recommended that PM2.5 should be used "as the principal metric for assessing exposure to particulate matter". This was based on a report by the World Health Organization identifying PM2.5 as the key component of particulate that impacts on health issues.

Although small in terms of mass, the sub-micron fraction contains a very high proportion of the heavy metals, which are initially volatilized in the furnace area and then condense in the cooler region of the plant. This condensation will coat the surface of existing particles and form some fine particles. Because most of the surface area is in the fine particles, this is where most of the heavy metals condense. Also the surface area to volume is high in fine particles, so the concentration of the condensed heavy metals will be higher in the fine particles. The sub-micron particles are respirable and in passing into the lungs can be retained in the alveoli, which are small sacks through which oxygen is extracted by the blood stream and carbon dioxide released. Any heavy metals particles reaching the alveoli can eventually become absorbed by the blood stream and being accumulative can lead to various health problems.

The US EPA has carried out a number of studies that identify the following health issues, (see **www.epa.gov/ttn/oarpg/naaqsfin/pmhealth.html**):

- Premature death;
- Respiratory related hospital admissions and emergency room visits;
- Aggravated asthma;
- Acute respiratory symptoms, including aggravated coughing and difficult or painful breathing;
- Chronic bronchitis;
- Decreased lung function that can be experienced as shortness of breath;
- Work and school absences.

The EPA believes that reducing fine particle ambient air quality levels can:

- Save 15 000 lives per year;
- Reduce hospital admissions by thousands each year due to reduced heart and lung diseases;
- Improved visibility.

There are two factors that cause the greatly increased contribution of fine particles to the plume visibility, which is what is measured by Opacity:

- 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 modeling program. 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 plume visibility or Opacity are the 0.5um to 1 um size particles. It is these fine particles that also contribute most to the reduced visibility in our cities and nature reserves.

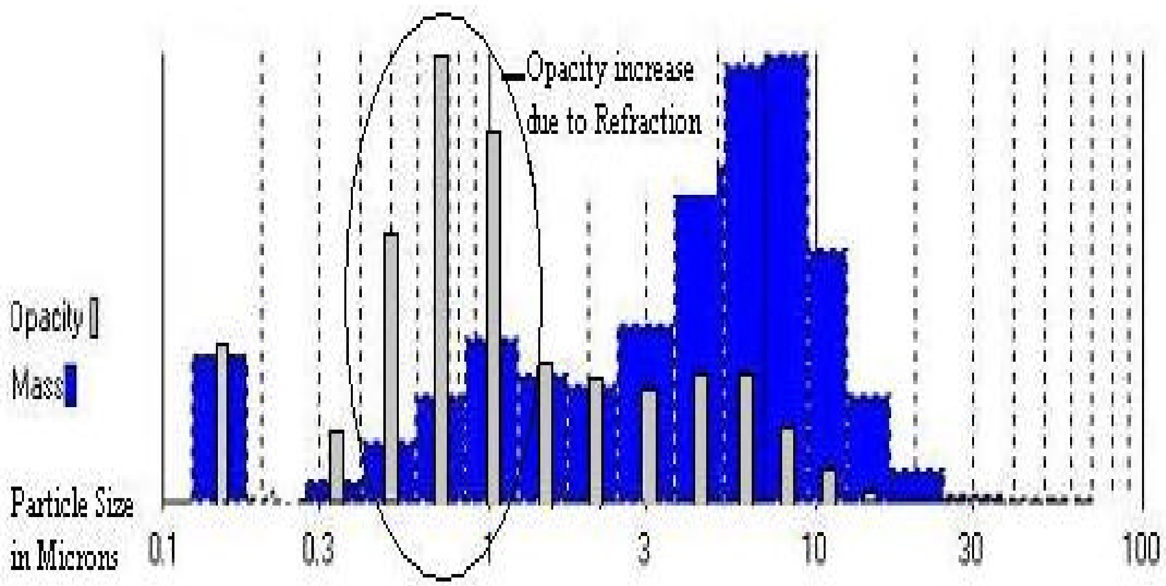


Figure 1. - EPSM Model estimates of Opacity and Mass Emissions

Finally there is increasing evidence that fine particles are a major contributor to global warming, generally referred to as the Greenhouse Effect. Scientists carrying out research in this area suggest that up to 30% of global warming may be due to fine black particles carried into the upper atmosphere.

THE ELECTROSTATIC PRECIPITATOR PROBLEM.

The electrostatic precipitator is very efficient (>99.9%) at collecting large particles, those greater than 10um, but as the particle size falls below 2um the electrostatic precipitator efficiency falls off dramatically. In extreme cases the collection efficiency can drop below 50% but will generally be less than 90% for particles between 0.5um and 2um. This is greater than two orders of magnitude (that is over 100 times) increase in the emission of this particle size range.

A typical electrostatic precipitator dust emission for particle sizes from 0.05um to 10um is given in Figure 2. This data was collected using two particle size measurement instruments, namely:

- The Process Metrix, Model PCSV-P, dual beam forward scatter laser particle size analyzer was used to measure particle size distribution from 0.5um to 50um. This analyzer has a water cooled probe that is inserted into the gas flow to measure the particles suspended in the gas. The particle size was adjusted slightly, a factor of 0.7 was applied, on the data collected by the PCSV analyzer so that the data coincided with the SMPS analyzer data, see Figure 2.

- Sub-micron particle tests were carried out at Plant Watson by the Southern Research Institute using a TSI Model 371A SMPS Analyzer, which uses electrostatic mobility to measure particle distribution from 0.03um to 0.85um. The TSI Model 371A SMPS Analyzer uses an extraction system that removes the larger particles followed by an electrostatic mobility based particle size selector that is used to scan and count the sub-micron particles.

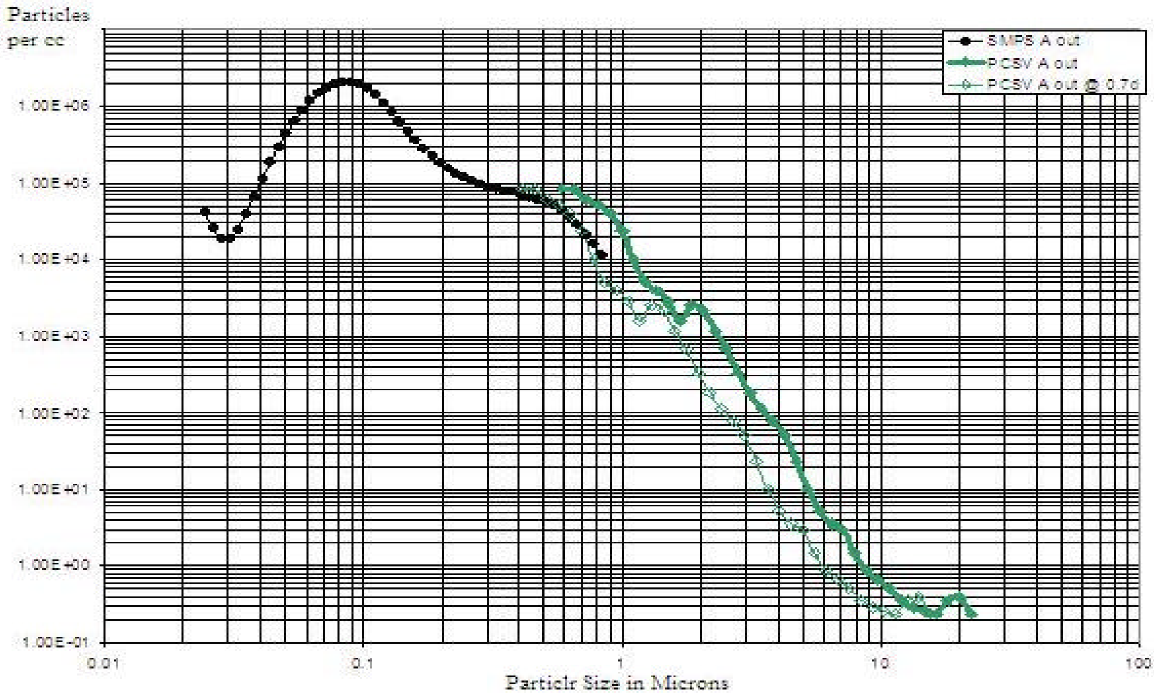


Figure 2. - Electrostatic Precipitator Emissions.

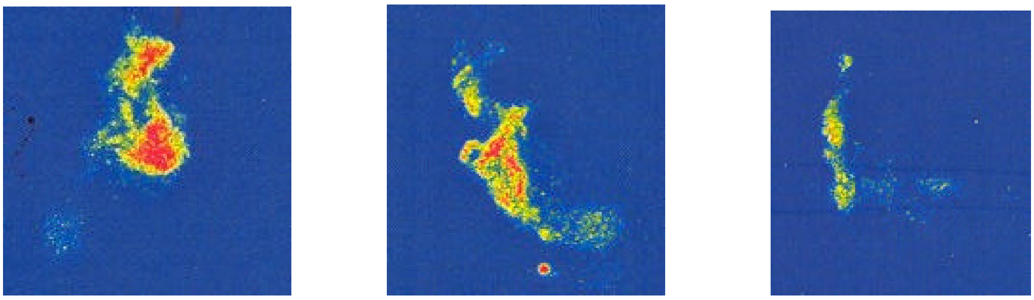
The above graph shows the number of particles per cubic centimeter that the electrostatic precipitator emissions are worst in the particle size range where the particles are most visible and most dangerous for human health, namely from 0.2um to 2um. Because of their small size, these particles will have a very low mass but a very high visibility. Electrostatic precipitator mass emissions of less than 10mg have been measured using the US Method 17 at Hammond Power Station while still measuring Opacity levels approaching 20%. Opacity levels below about 8% are normally invisible to the human eye. This shows that very visible plumes can result from high fine particle emissions even with extremely low mass emissions.

THE INDIGO AGGLOMERATOR SOLUTION

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 Indigo 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 Indigo Agglomerator.

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 spatial 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.



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

Figure 3. - Color Coded LIF Analysis of Fine Particle Mass Density
Color Code - Blue - no 1um droplets
Red – maximum concentration of 1um droplets

Figure 3a, the color coded distribution (Blue - no 1um droplets through to Red - maximum concentration of 1um droplets) of fine droplets without any large droplets or FAP, is the base condition for fine droplet mass comparison. Figure 3b, 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 3c, 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.

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 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 mixing system also causes the fine negatively charged particles to mix with the large positive particles, as shown in Figure 4. Because electrostatic force decreases rapidly with distance, the mixing system 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.

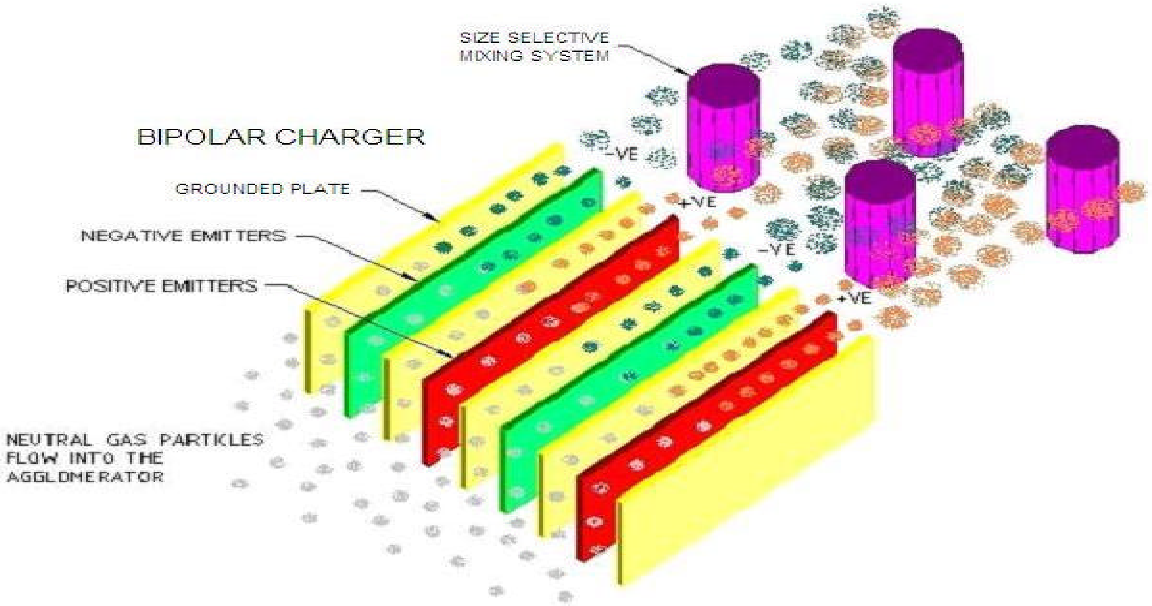


Figure 4. - The Bipolar Electrostatic Agglomeration Process (BEAP)

Test results from Watson Power Station

Tests performed at the Indigo Agglomerator trial installation at Watson Power Station show a huge reduction in fine particle emissions when an Indigo Agglomerator was installed in front of an existing electrostatic precipitator. Watson Power Station is a 250MW wall fired pulverized coal boiler with two air-heaters connected to two separate electrostatic precipitators. An Indigo Agglomerator was installed in front of the "B" electrostatic precipitators and particle size tests were performed on both "A" and "B" electrostatic precipitators. Figure 5 shows a comparison of the Slip, the percentage of the dust entering the electrostatic precipitator that is emitted to the atmosphere, from both "A" and "B" electrostatic precipitators, for particle sizes from 0.05um to 10um. These tests were performed using the two probes described above.

The collection efficiency of "A" electrostatic precipitator decreases rapidly below 2um particle size, as indicated by the increasing slip (Slip%=100-Efficency%). Over 50% of the particles in the key 0.6um to 1um size range are not captured by "A" electrostatic precipitator. The "B" electrostatic precipitator captures 90% of those particles, resulting in a greatly reduced visible emission as measured by Opacity.

It can be seen that the reduction in fine particle emissions provided by the Indigo Agglomerator increases with reducing particle size, as indicated by the improvement trend line in Figure 5. This shows a 60% improvement at 10um increasing to 75% at 1um and 90% at 0.1um. Thus, the fine particle emission reduction provided by the Indigo Agglomerator increases from a factor of 2 at 10um to a factor of 10 at 0.1um. The average reduction in PM2.5 emissions is about a factor of 5 or 80%.

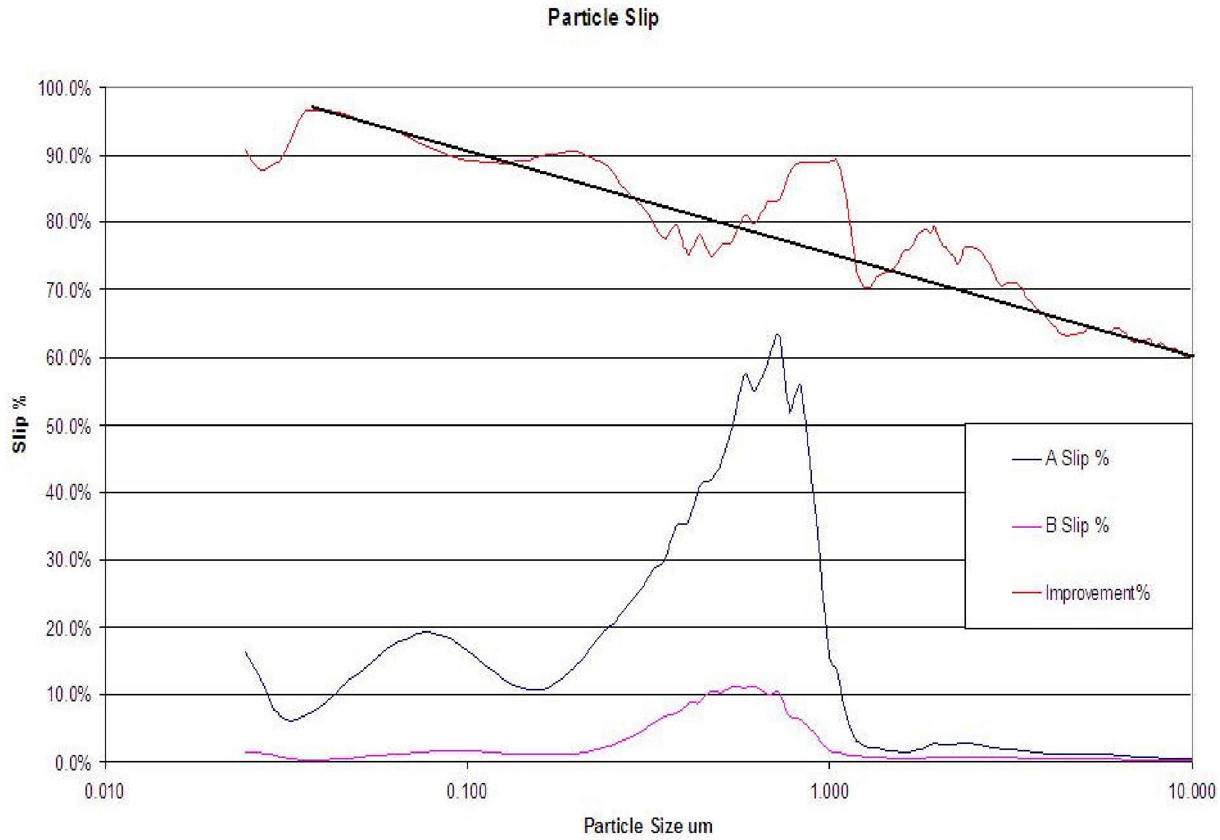


Figure 5 - Comparison of dust emitted to the atmosphere with and without the Indigo Agglomerator

Test results from Tarong Power Station

Tests performed at Tarong Power Station show an increase in fine particles collected in the electrostatic precipitator hoppers and an increase in Arsenic concentration in the collected dust on Pass 1, with an Indigo Agglomerator installed before the electrostatic precipitator, compared to Pass 2, without an Indigo Agglomerator. Both Pass 1 and Pass 2 treat gas from Air-heater A while Pass 3 and Pass 4 treat gas from Air-heater B. Each electrostatic precipitator pass at Tarong Power Station has six Zones or Sections with a separate hopper for each. Ash was taken from hoppers 1, 2, 4 and 6 for particle size and/or Arsenic concentration measurement are representative of the dust collected in the 1, 2, 4 and 6 electrostatic precipitator zones.

Figure 6 shows the particle size distributions for Hoppers 1, 4 and 6. The larger particles are mainly captured in the in the front of the electrostatic precipitator. Most of the larger particles are found in the front hopper, Hopper1, however there are more fine particles captured in this hopper on Pass 1. The fine particles are captured in the in the rear of the electrostatic precipitator, as is evident from the rear hopper particle size distribution. There are less large particles in the rear hoppers of Pass 1 but there are more fine particles. The agglomeration of the fine particles to the larger particles will result in the larger agglomerates being captured in the front of the Pass 1 electrostatic precipitator with the Indigo Agglomerator, hence the reduced number of larger particles in the rear hoppers. The agglomeration of fine particles to slightly larger particles will increase the number of fine particles collected in the rear of the electrostatic precipitator, hence the increased number of fine PM2.5 particles in the rear hoppers.

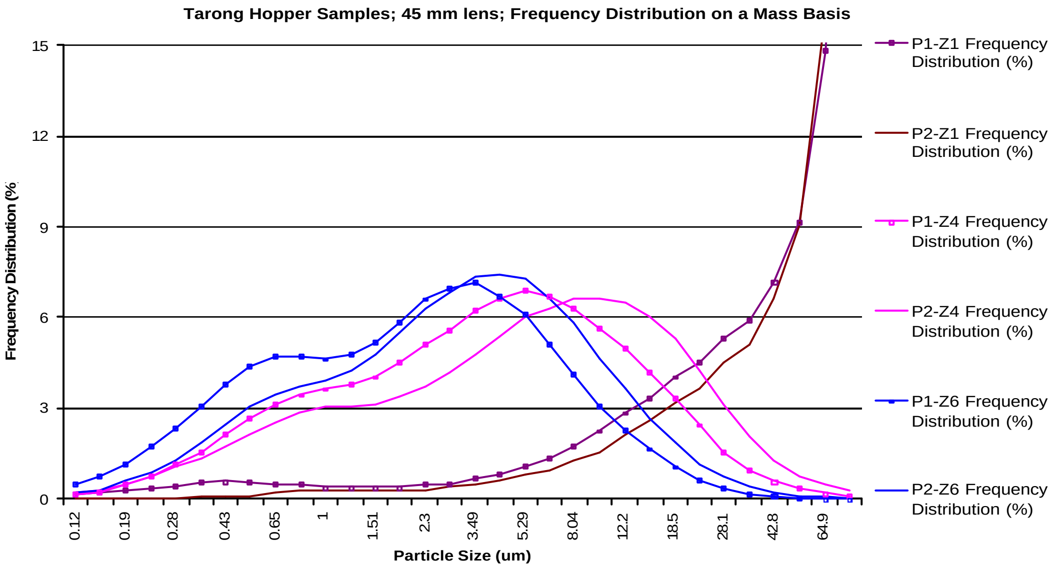


Figure 6 – Hopper Particle Size Distribution

Arsenic vaporizes in the combustion process but condenses in the colder rear section of the boiler. The condensation will preferentially form on the surface of existing particles on the basis of surface area. Some may also condense to form ultra-fine particles. Because the vast majority of the surface area is in the fine particles, most of the condensed Arsenic ends up in the fine particles. The concentration of Arsenic will also be higher in the fine particles because the ratio of surface area to volume is inversely proportional to particle size.

Table 1 shows the Arsenic concentration in the ash samples from Hoppers 1, 2, 3 and 4. The Arsenic concentration is consistently higher on the Pass 1 electrostatic precipitator, with the Indigo Agglomerator, as this electrostatic precipitator consistently collects more fine particles, as shown in Figure 6. As the fine particles are preferentially collected in the rear of the electrostatic precipitator, the concentration of Arsenic is largest in the rear hoppers. The increase in the fine particle collection on Pass 1 provided by the Indigo Agglomerator has less of an impact on the Arsenic concentration because there is already a high concentration of fine particles and Arsenic. The electrostatic precipitator preferentially collects large particles in the front section, where most of the dust is collected (up to 90%), hence the concentration of Arsenic is lower, due to the dilution of the large particles, and the improvement is lower, due to the large mass of dust collected.

The improvement is greatest in Hopper 2, which represents the dust collected in Zone 2 of the electrostatic precipitator. The amount of dust collected in electrostatic precipitator Zone 2 is a lot less, up to an order of magnitude, than that collected in Zone 1 and therefore there is a lot less dust in Hopper 2 than Hopper 1. The increase in fine particles and, hence Arsenic concentration, is therefore more significant.

	Hopper 1	**Hopper 2**	**Hopper 4**	**Hopper 6**
ESP Pass 1	**2.98 mg/kg**	**7.94 mg/kg**	**20.3 mg/kg**	**24.7 mg/kg**
ESP Pass 2	**1.7 mg/kg**	**2.78 mg/kg**	**14.1 mg/kg**	**20.2 mg/kg**
Pass 1 Increase	**75%**	**186%**	**45%**	**22%**

Table 1 – Arsenic Concentration in the Ash

CONCLUSION

Fine particles, in particular PM2.5, are an acknowledged health hazard and government environmental protection organizations around the world are now focusing on controlling the emission of these fine particles. Electrostatic precipitators are poor collectors of fine particles, particularly between 0.5um and 2um. The electrostatic precipitator collection efficiency, normally around 99.9% for larger particles, is generally less than 90% in this particle size range and can fall below 50% in worst case conditions. This results in the emission of large numbers of very fine but very visible particles. Although these emissions may have a very low mass emission, in some cases less than 10mg/m3, the Opacity, the measurement of visibility will be very high.

The Indigo Agglomerator provides a significant reduction in fine particle emissions by attaching the fine particles to the large particles, which are easily collected in the electrostatic precipitator. The reduction in fine particles provided by the Indigo Agglomerator technology increases from 60%, about a factor of 2, at 10um to 90%, about a factor of 10, at 0.1um. PM2.5 emissions may be reduced by up to 80% with the installation of an Indigo Agglomerator in front of an electrostatic precipitator. This will provide a significant reduction in visible emissions, as measured by Opacity.

The hopper ash tests carried out at Tarong Power Station show increased fine particle collection and a significantly increased Arsenic concentration in the ash. This supports both the relationship between fine particles and heavy metal concentration plus the enhanced fine particle removal provided by the Indigo Agglomerator. Thus the Indigo Agglomerator also will significantly reduce heavy metal emissions by reducing fine particle emissions.