Emission Reductions at a Chinese Power Station

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Abstract: Growing attention is being placed on the adverse health effects of fine particulates, with the haze and smog through Hong Kong and Mainland China becoming a major concern for local authorities. With a large proportion of these emissions originating from the smoke stacks of power stations and other large industrial process's, a cost effective solution to this pollution is to install an Indigo Agglomerator. Through electrostatic and fluidic methods the Indigo Agglomerator has been proven to be extremely effective at reducing opacity by 50%–80% and mass emissions by up to 50%. An Indigo Agglomerator was installed at a Chinese Power Station during an outage in December 2007. The 300 MW boiler has 2 side by side Electro-Static Precipitators (ESP's) with the Indigo Agglomerator installed prior to one of the ESP's. The Indigo Agglomerator and Power Station have been operating since January the 1st with a limited number of outages for inspections of the Agglomerator and ESP.Particle size testing was performed by Indigo Technologies at the inlet and outlet of the Agglomerator as well as the inlet and outlet of the ESP's. A historical analysis of ESP emissions was also performed, comparing before and after Agglomerator emissions against each other. These tests show significant reductions in particles less than 5 micron across the Agglomerator and consequently across the ESP giving rise to large reductions in emissions and opacity.

The Indigo Agglomerator is installed directly upstream of the ESP in a rebuilt section of the existing inlet ducting. The Agglomerator can be installed in either vertical or horizontal flow configurations, with limited space and lifting access giving a flexibility of installation options and virtual zero additional footprint requirements.

Keywords: Agglomerator, PM2.5, Opacity, Indigo, Chinese pollution

1 INTRODUCTION

An Indigo Agglomerator was installed during a 45 day outage in November/December 2007 at a Chinese government owned and run power station. This Agglomerator is installed in a vertical section of the high velocity inlet duct to the ESP, in one of the two ducts feeding two separate ESP's (A&B). The Agglomerator is installed prior to the A side ESP and therefore treats one half of the 300 MW pulverised coal boilers flue gas. Existing particulate control for the unit is two 5 zone Sturtevant Gas Cleaning Ltd.–Flat plate horizontal flow ESP's with SO_3 injection. The plant burns several different Chinese and Indonesian coals individually or blended as needed.

Opacity for the two passes is measured at a single point in the chimney, that is, one measurement represents the opacity of A side and B side together. The opacity measured by the station opacity monitor is therefore the opacity emitting from the chimney and is the average of A side opacity and B side opacity.

The previously tapering duct was rebuilt to accommodate a vertical flow Agglomerator measuring 4 meters square by 6 meters long. (See Fig. 1).

By placing the Agglomerator in the high speed duct at the entrance to the ESP, the Agglomerator has a zero additional footprint at the power station making it an ideal retrofit for this space limited plant. Other features of the Agglomerator are extremely low power consumption (1 kw/h), compatibility with injection technologies, a very low pressure drop of <1″ WC, and low maintenance.

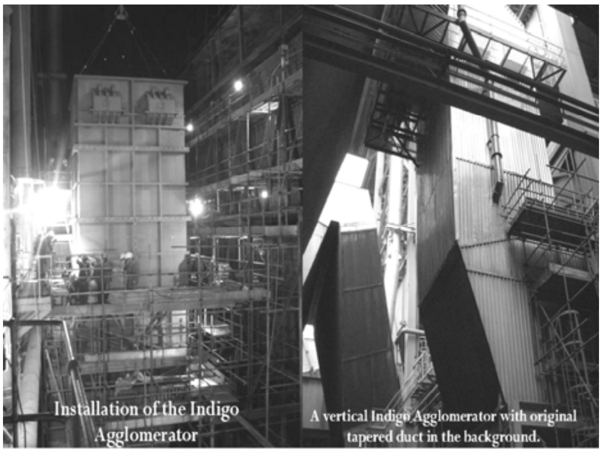

Fig. 1 Agglomerator installation

2 TESTS PERFORMED

Following commissioning of the Indigo Agglomerator in early 2008, two different methods were used to determine the Indigo Agglomerator effect on emissions. Particle size testing using a Holve PCSV probe, as well as a historical comparison of opacity trends for before and after Agglomerator installation.

Over the course of a year, this power station burns many different coals with these coals having different collection and opacity characteristics. Therefore these tests had to be performed for different coals being burned over several days. Plant staff identified 3 different coals (Coal 1, Coal 2 and Coal 3) for testing and analysis, and provided data to show what days these coals were burned at the plant.

3 PARTICLE SIZE DISTRIBUTIONS

Particle size distributions were performed by trained Indigo staff at the inlet to the Agglomerator and the inlet and outlet of both ESP's using a Holve PCSV probe. All testing was performed at the same operating conditions of 280 MW boiler load (stable), SO_3 off and no soot-blowing.

The Holve PCSV probe is an in-situ, dual forward scatter laser probe that measures and counts particles from around 0.8 μm up to 50 μm, where a smaller laser counts smaller particles and a larger laser counts larger particles. Under normal conditions these lasers do not overlap, giving a broad range of measured particles, but leaving a small gap in the region from 3 μm to 7 μm where the lasers to do not measure, and the data is interpolated to give a continuous reading. Since this is the region where the ESP performs poorly, and is the area of greatest importance for the Agglomerator, the probe was set up to concentrate on the <10 μm range by allowing the lasers to overlap, narrowing the available size range, but removing the small gap and giving better resolution at the size range of most interest.

During the testing periods in July for Coal 2, it was observed that A side ESP power was 50% lower than B side due to the rear 3 zones of A side ESP having very little current input. Even with this 50% reduction in power levels, because of the Indigo Agglomerator A side ESP emissions are comparable to B side.

Particle size tests were conducted at the same operating point (280 MW), operating conditions and time as the mass tests.

Tests were conducted in 5 positions.

- Both Air Pre-Heater (APH) Outlets (2 positions);
- The Indigo Agglomerator Outlet (1 position);
- Both ESP Outlets, (2 positions).

From these tests the following analysis could be performed:

- A side APH outlet and B side APH outlet – confirmation that there are similar particle concentrations and distributions exiting the boiler.
- A side APH outlet and A side ESP inlet – evaluation of the Indigo Agglomerator efficiency (η= 1-(ESP $\text{inlet}_{\text{numbers}}$ / APH $\text{outlet}_{\text{numbers}}$).
- A side ESP outlet and B side ESP outlet – evaluation of the impact of agglomeration on ESP outlet emission
- Efficiency of A side ESP versus the efficiency of B side ESP (η= 1-(ESP $\text{outlet}_{\text{numbers}}$ / APH $\text{outlet}_{\text{numbers}}$)×100).

3.1 Test Results

Data for Coal 1 (February and April) Coal 2 (July) and Coal 2/Coal 3 blend (July) are presented in the following graphs, (Figs. 2 to 5). The data is presented in terms of particle numbers per size band on the A side at the Agglomerator inlet (blue), the Agglomerator outlet (red with triangles) and the ESP outlet (pink) and on the B side at the ESP inlet (black) and the ESP outlet (Black with boxes).

No Coal 2/Coal 3 blend data is collected for B side. Cooling water failure lead to the Holve PCSV probe overheating and tests being postponed for a time while the instrument recovered. Plant availability, wet weather and cooling water availability meant that only A side data could be collected before time ran out for the Coal 2/Coal 3 tests.

Comparing the uppermost lines (Figs. 2 to 5, log/log scale), i.e. the blue line and the black lines, shows that in all cases, the APH outlets on A side (i.e. the Agglomerator inlet) and on B side are equivalent. Therefore the particle distribution across the boiler is even and the tests are comparable.

Particle reduction between the Agglomerator inlet and Agglomerator outlet, i.e. the upper blue and red with triangles lines, is not the same for all tests but is always present. Analysis shows that particle reduction varies between 34% and 67% depending on coal type and particle size.

In all cases ESP performance is measured to be superior on A side with the Agglomerator than on B side without the Agglomerator (comparison of the pink and bottom black lines). In the case of the Coal 2 tests of July (Fig. 4) it can be seen that the margin of improvement is slight, even though the tests across the Agglomerator show generally the same improvement as all of the other tests.

During all test periods, VI curves were taken and showed for all other tests, power levels in both ESPs were the same ±2%. The VI curves taken during the coal 2 tests in July however (Fig. 6) shows that the due to unidentified ESP problems, the rear two zones of the A side ESP get virtually no power, with A side ESP having 50% less total power. Since the resulting emissions from both ESPs are nearly the same, this shows that the improved inlet loading due to the Agglomerator, makes up for the loss of the two rear zones of the ESP.

Fig. 7 presents Agglomerator efficiency (change in numbers between the inlet and the outlet of the Agglomerator), and shows how the Agglomerator efficiency varies with particle size. This shows that on average, the efficiency for the Agglomerator of PM 1 is around 47%, PM2.5 is 40% and PM10 is 46%.

The ESP inlet and outlet tests also allow calculation of ESP efficiency ($\eta_{\text{esp},}$ % collected) and ESP slip (% emitted) where, η_{esp} = 1-(ESP $\text{out}_{\text{numbers}}$ /APH $\text{out}_{\text{numbers}}$)×100

ESP Slip = 1 - η_{esp}.

Fig. 8 shows the reduction in ESP slip, realised due to the Agglomerator. Although the Agglomeration efficiency is higher in the >5 μm range (Fig. 7), the majority of the Agglomerators impact on ESP efficiency occurs at sizes lower than 5 μm, as this is where the ESP has the greatest slip (Fig. 8). That is, the Agglomerator also reduces the number of larger particles, but the impact of this is not seen as the ESP is nearly 100% efficient >5 μm.

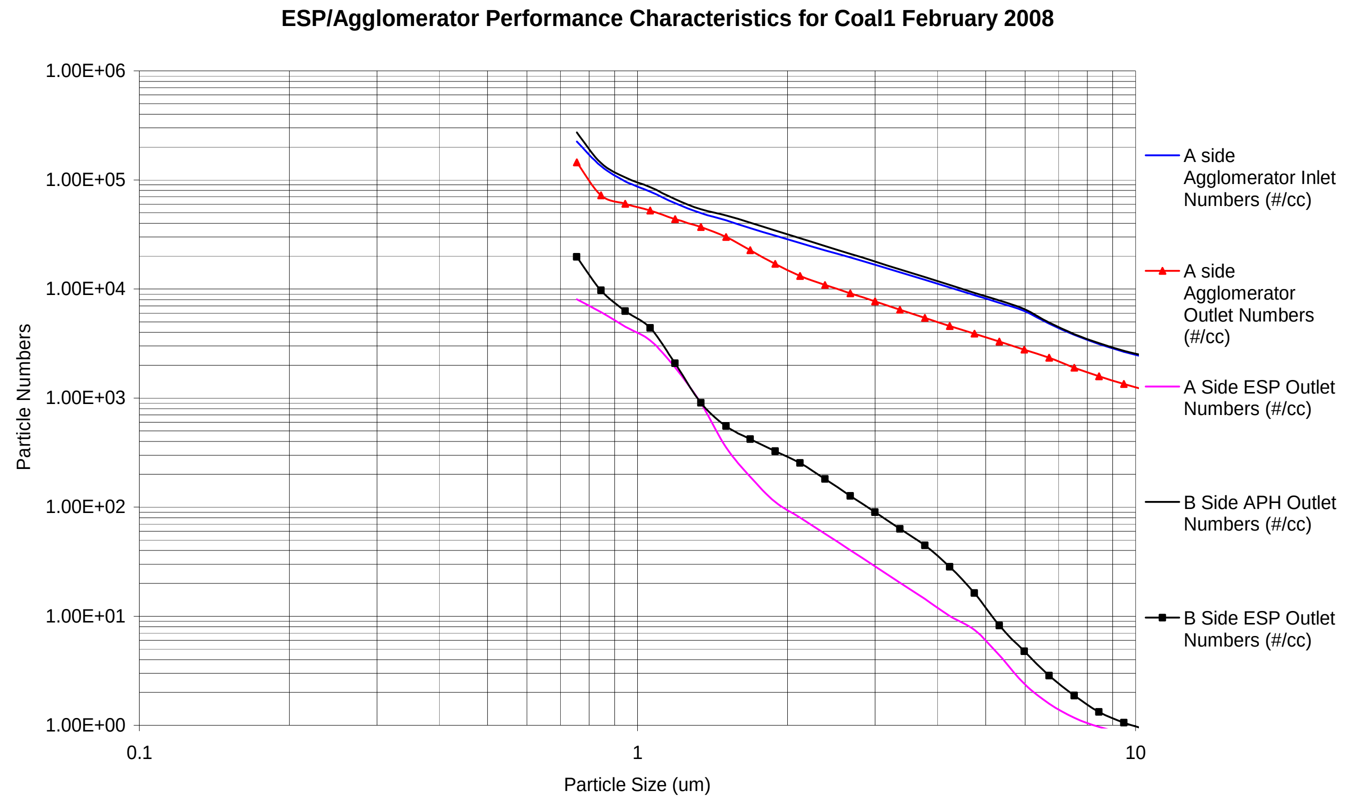

Fig. 2 Particle size distribution for Coal 1 in February 2008

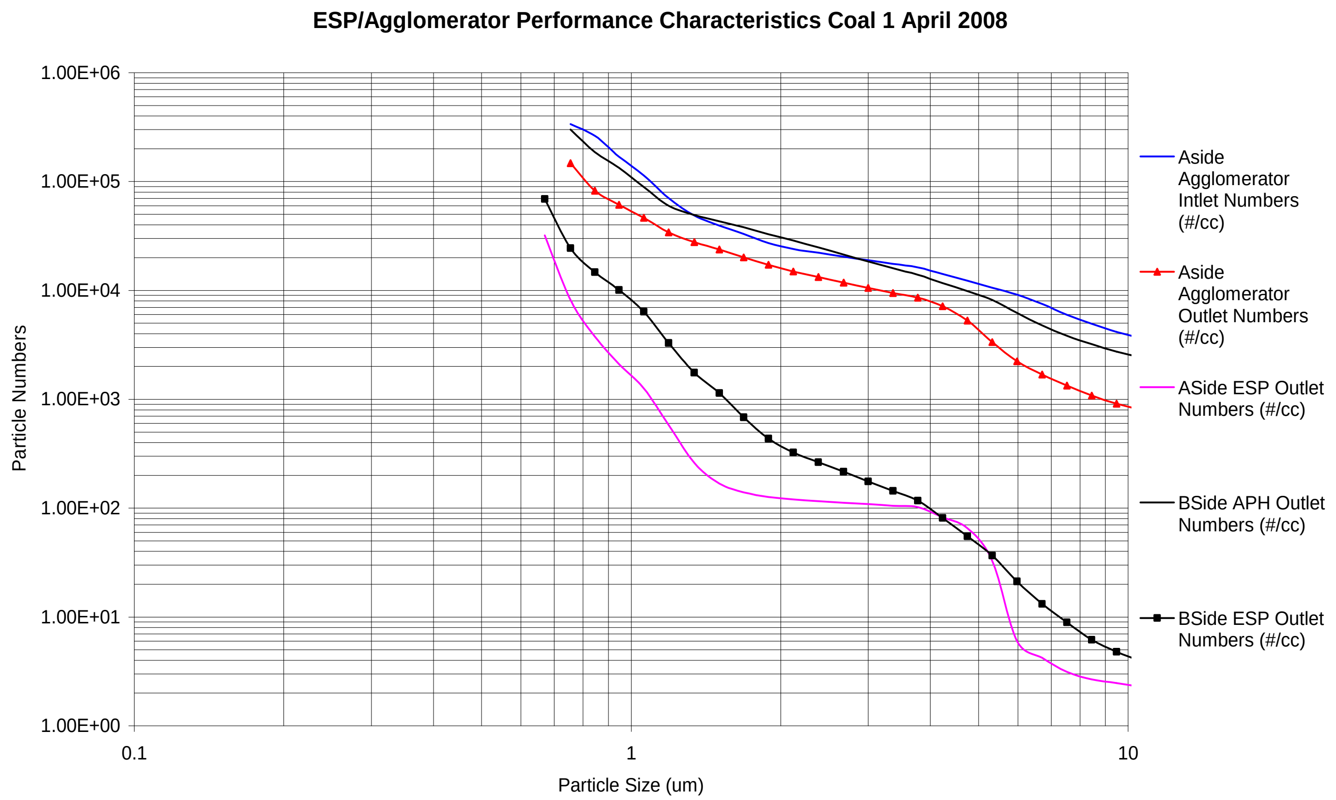

Fig. 3 Particle size distribution for Coal 1 in April 2008

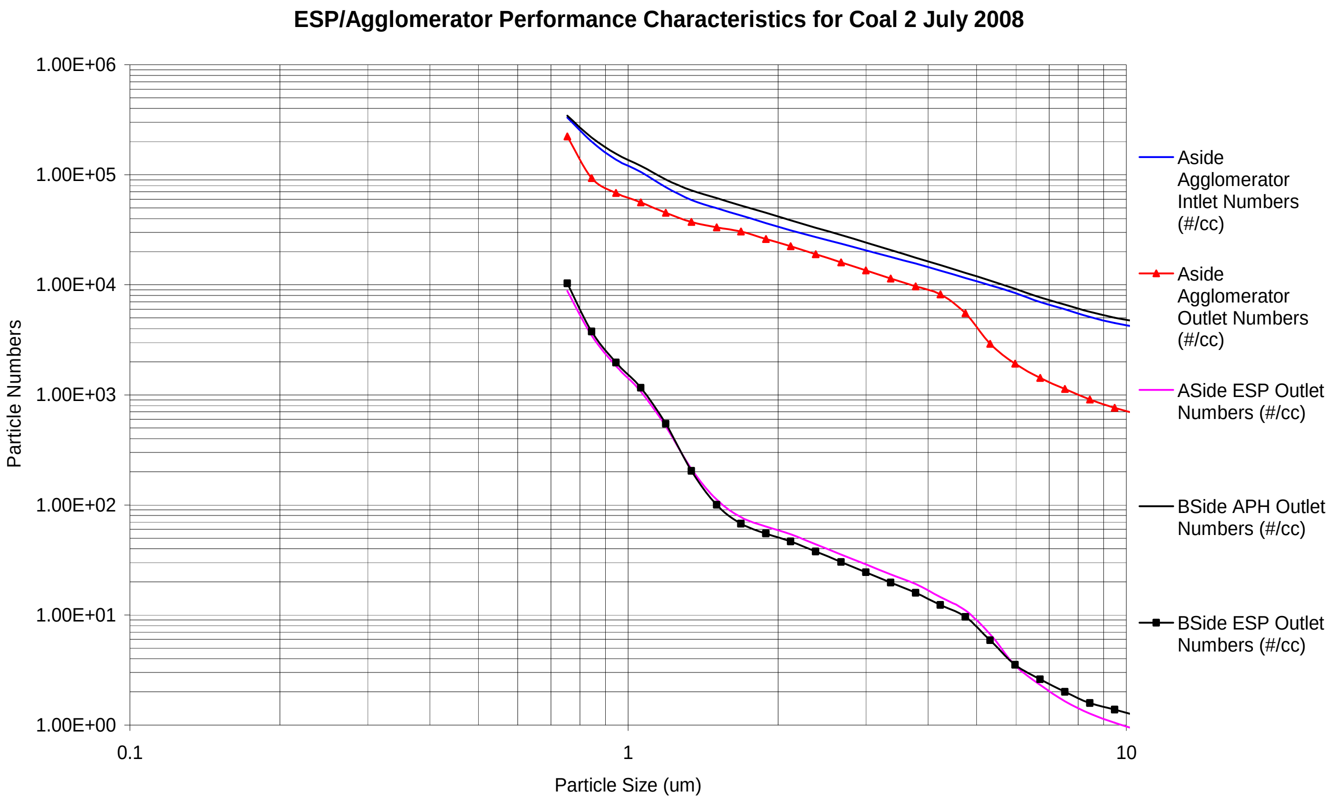

Fig. 4 Particle size distribution for Coal 2 in July 2008

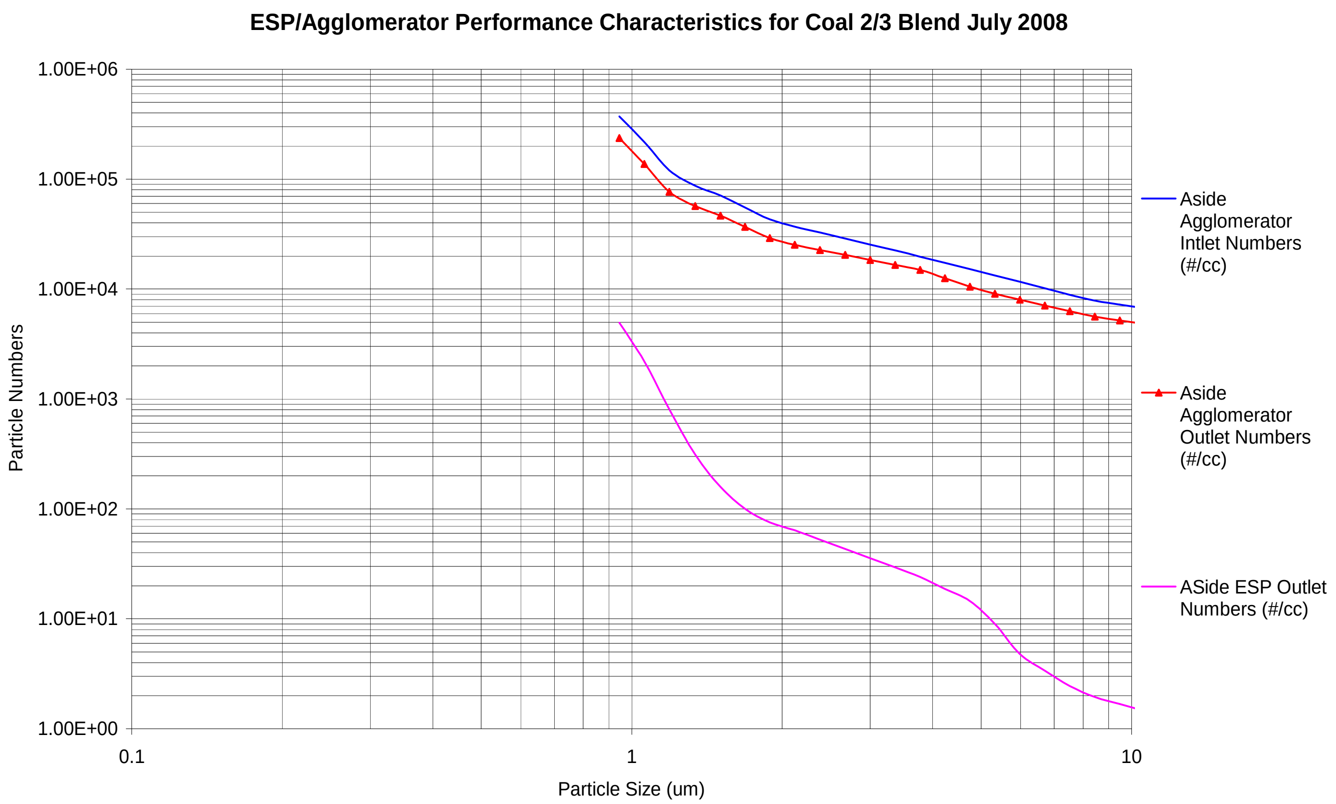

Fig. 5 Particle size distribution for Coal 2/3 blend in July 2008

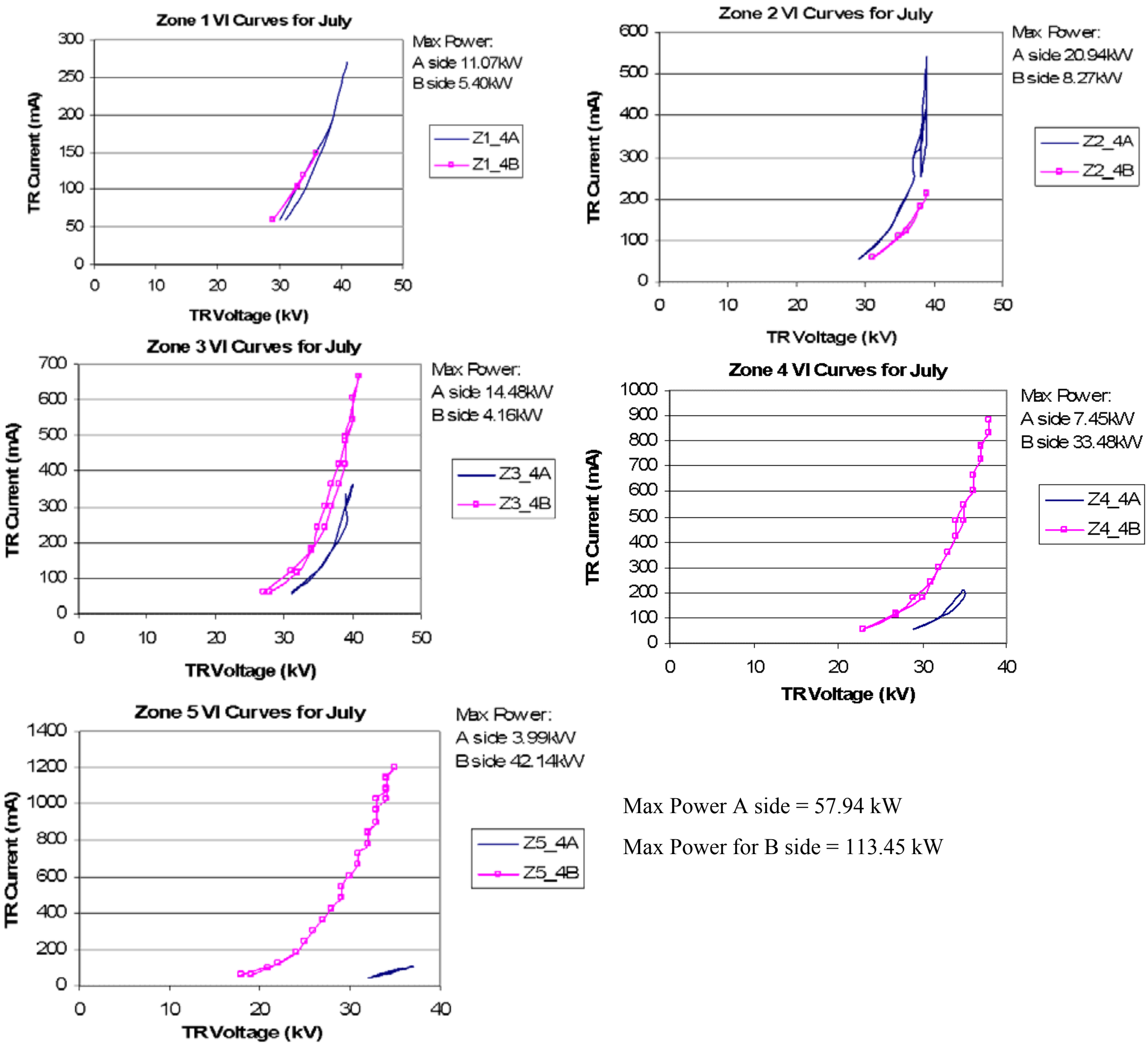

Fig. 6 VI curves for A and B ESPs during the July tests

3.2 Agglomerator Tests Conclusions

Agglomerator inlet versus outlet tests show that, regardless of type of coal or type of test, an average particle reduction of 45% for all particles less than 10 μm is achieved by the Indigo Agglomerator. In arriving at this result 3 different coals were tested at 4 test periods spanning 6 months operation.

Results from the four tests can be summarised as follows:

- Strong Similarity between Coal 1 and Coal 2 agglomeration efficiencies,
- Peak Submicron Agglomerator Efficiency at 0.75 μm,
- Minimum Agglomeration Efficiency at 1.3 μm–2.0 μm,

Peak PM10 Agglomeration at 6 μm

- Distribution form is consistent between February, April and July Tests.

Inconsistencies:

- Magnitude of Submicron Agglomeration varies between coals particularly between the Coal 2 /Coal 3 blend and the other two coals,
- Agglomeration of large particles is reduced for the Coal 2/Coal 3 blend.

Explanations:

- Different coals agglomerate to different degrees,
- February tests are collected over 4 days at different operating conditions,
- July and April tests are collected from a dedicated test run on one day,
- Results presented for February are selected from >30 test runs by matching similar Boiler operating conditions.

3.3 ESP Outlet Test Conclusions

The ESP outlet data shows that;

- As expected, for all ESPs and all coals the submicron particles have the greatest slip,

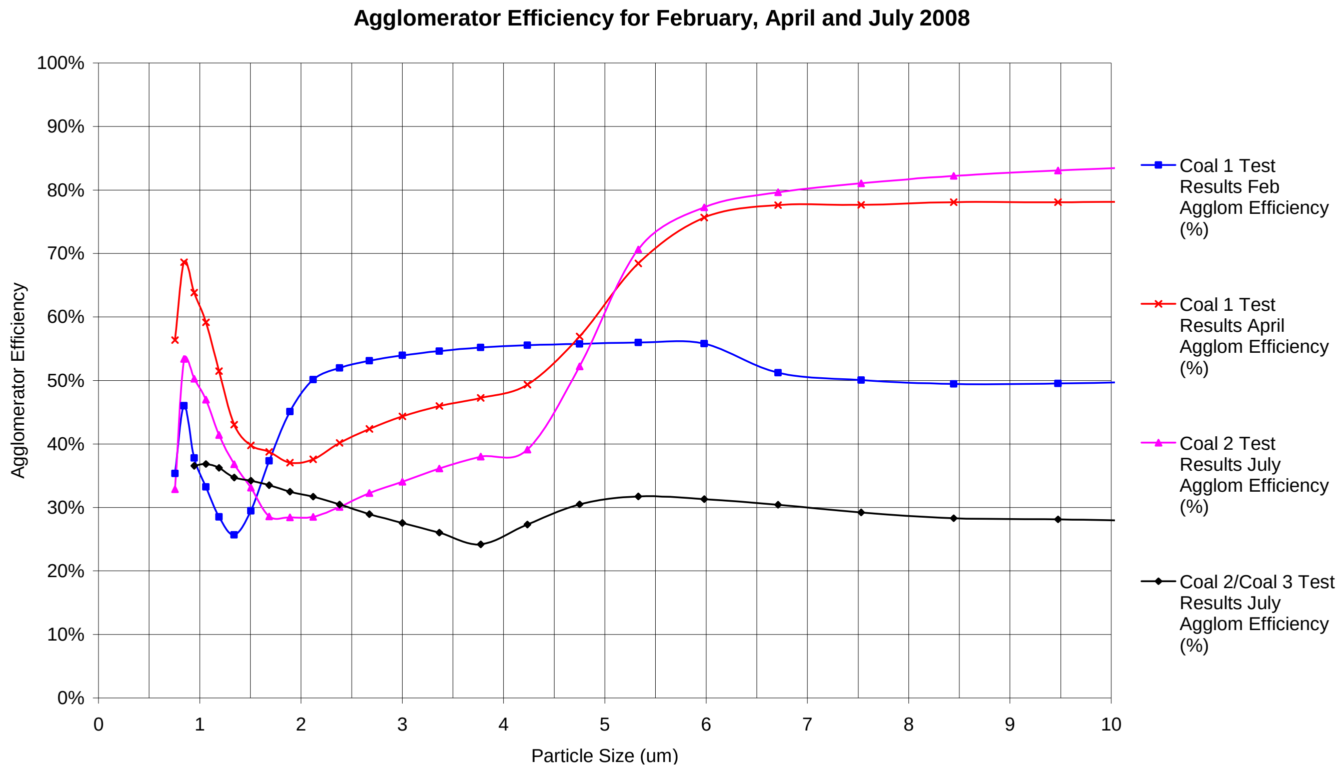

Fig. 7 Agglomerator efficiency curves

- By 5 μm Coal 2 and Coal 1 (February) are collected with (essentially) 100% efficiency,
- By 10 μm all ESP's are 100% efficient for all coals.

Coal 2 is collected more efficiently than Coal 1:

- The greatest improvement to the emission of both ESPs will be achieved by reducing or treating the particles smaller than 5 μm,
- Even with 50% less power than B side, A side has an average reduction of 30%–40% for particles <5 μm.

4 HISTORICAL ANALYSIS

Since this station has only one opacity monitor at the stack, opacity reductions achieved by the Agglomerator can not be measured on a pass by pass basis, as what is measured at the stack is an average of both passes opacities.

To determine the opacity reduction achieved by installing an Indigo Agglomerator, a historical analysis of plant operation was performed. Plant operating data, boiler load (MW), opacity (%) and coal usage (type and rate), was collected and compared for 6 months in 2007 (Pre-Agglomerator) and 6 months in 2008 (Pos-Agglomerator). The data was then analysed to determine the days on which each of the selected coals were burned, with days on which two or more coals were burned together discarded. Only days when just one of the target coals was burned for the whole day were selected.

In general, as with most other plants with ESPs, opacity emissions of the plant increase over time, due to build-up, misalignment etc. Therefore, to be correct, a historical analysis of the plants opacity emissions must account for this deteriorating ESP performance. The plant was shutdown with the ESPs washed and adjusted in January 2007 at the scheduled unit maintenance outage. Similarly, the ESP's were also washed and adjusted before returning to service in January 2008, after the Indigo Agglomerator was installed. Therefore, comparisons are only made between similar months in both 2007 and 2008.

Comparisons were made using the 60 minute opacity trend for clarity.

Although supplied, the 15 minute opacity trend was not used because it is a noisier signal that makes trends difficult to isolate and compare.

Opacity and boiler load for each day on which one of the target coals was burned were extracted from the data sets supplied by plant staff, and the opacity and boiler load data was arranged by coal and by month (2007 before Agglomerator and 2008 after Agglomerator). The averages of opacity Vs load for each coal before Agglomerator installation was compared to the averages of opacity Vs load after Agglomerator installation, and was graphed for each coal.

4.1 Coal 1

While this data represents treatment of half the gas flow only, from Fig. 9 it can be seen that.

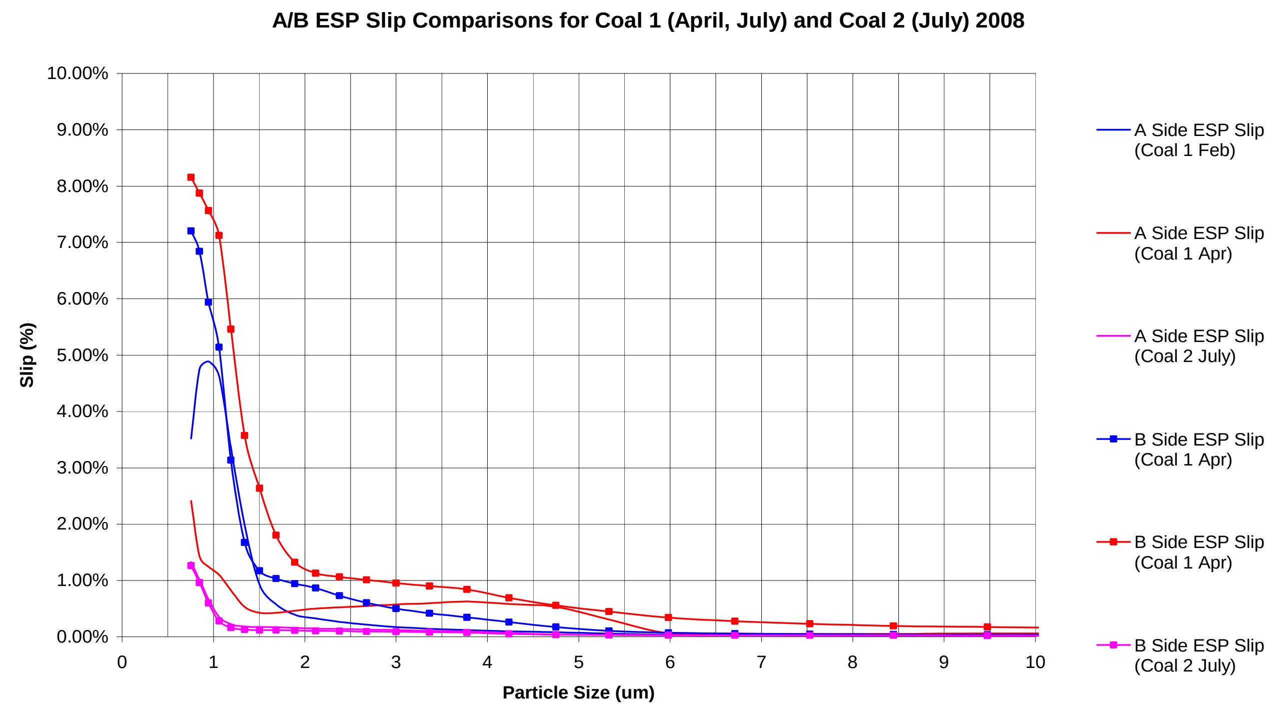

Fig. 8 ESP slip comparisons for Coal 1 (February, April) and Coal 2 (July)

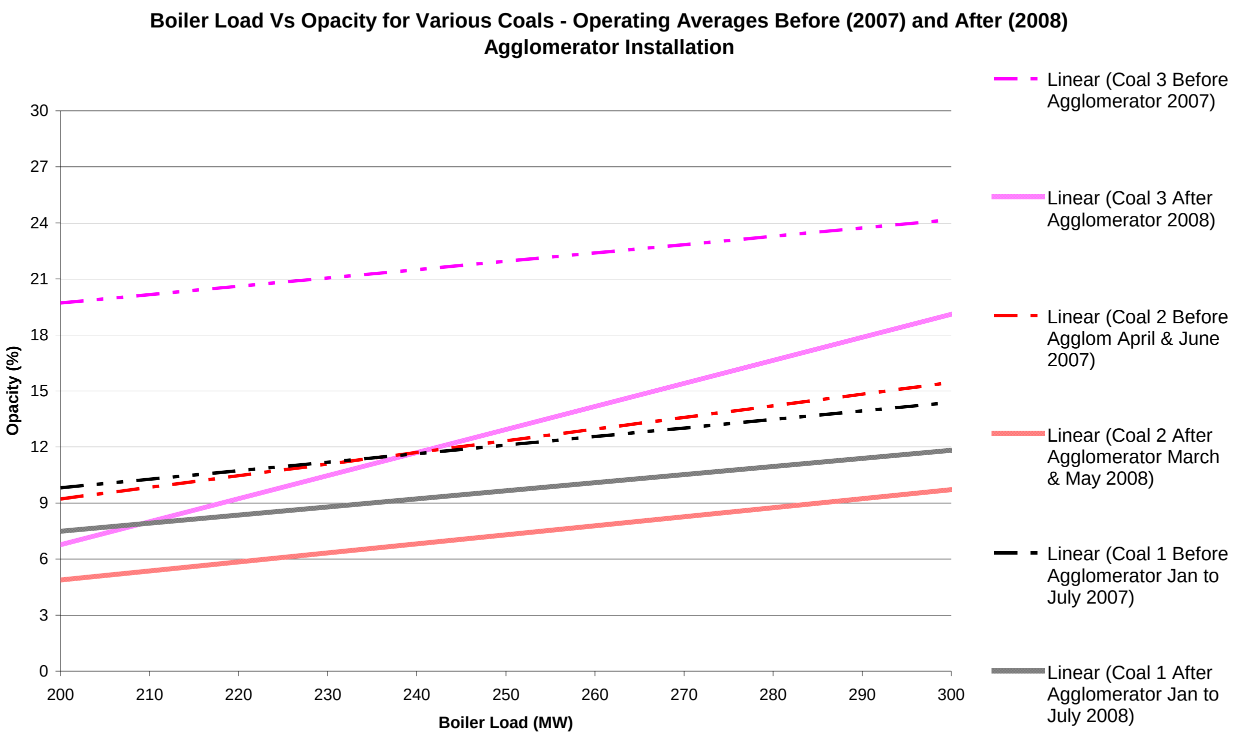

Fig. 9 Six monthly linear averages of opacity versus load trends for Coals 1, 2 and 3 in 2007 before Agglomerator installation and 2008 after Agglomerator installation

At 300 MW opacity emissions are lower in 2008 (12.1%) than opacity emissions at 290 MW (13.8%) in 2007, this represents a 12.5% reduction in opacity at 10 MW more generation.

The linear best fit line shows an improvement that is consistent for all loads from 200 MW to 300 MW.

Average improvement between 2007 and 2008 is 20.0% approximately for Coal 1 while treating only half the flue gas.

4.2 Coal 2

While this data represents treatment of half the gas flow only, from Fig. 9 it can be seen that.

The linear best fit line shows an improvement that is consistent for all loads from 200 MW to 300 MW.

Average improvement between 2007 and 2008 is 33.0 % approximately for Coal 2.

4.3 Coal 3

Coal 3 is typically a difficult to collect coal, its ash has a high resistivity and its ash content is very much higher than either of the other two coals investigated (eg. Coal 3 ash=6¼%, Coal 2 ash =2½%, Coal 1 ash=¾%). Consequently Coal 3 is not burned often by the plant and when it is burned it is usually blended with other coals to improve its collect-ability. The data set for Coal 3 is therefore very small, being only 5 days before Agglomerator installation and 1 day after Agglomerator installation. Even though the data set is small and confidence in it can not be as high as for the other coals, it is presented here for reference.

There is no data for Coal 3 from the first half of 2007 because Coal 3 was only burned by itself at the end of that year, hence for Coal 3, September and October of 2007 is compared with July 2008.

While this data represents treatment of half the gas flow only, from Fig. 9 it can be seen that the average improvement between 2007 and 2008 is approximately 20.0% (for loads >280 MW) when burning for Coal 3 coal.

4.4 Historical Opacity Conclusions

On average after analysis and comparison of 82 days operation burning Coal 1 in the first half of 2007 and 2008, Unit 4 opacity emissions are 20 % lower in 2008 than they were for the same period in 2007

Based on analysis of 36 days operation the average improvement between 2007 and 2008 is 33.0% approximately for Coal 2.

Based on analysis of 6 days operation the average improvement between 2007 and 2008 is approximately 20.0% when burning Coal 3.

Coal 1 and Coal 3 display the same level of improvement after an Agglomerator is installed, although Coal 3 is a more difficult ash to collect so the absolute emission levels for Coal 1 is lower than Coal 3. Coal 1 and Coal 2 emission levels are at the same level on average before the Agglomerator was installed in 2007 but Coal 2 emissions levels are 15% lower than Coal 1 emissions after Agglomerator installation in 2008.

Different coals respond differently to Agglomeration and subsequent collection in an ESP, but this analysis show that a 20% emission reduction can be expected for each Agglomerator at maximum load, a minimum of 40% reduction at this plant.

5 CONCLUSIONS

The Indigo Agglomerator has now been installed in 8 stations across 3 different countries as well as many different coals, boilers and particulate collection devices (Cold and Hot side ESP’s as well as Wet scrubbers), all yielding strong opacity reductions. The installation at this Chinese power station, burning both Chinese and Indonesian coals have also produced extremely good results across the diverse selection of coals and operating conditions.

From the particle size tests of 3 different coals tested at 4 test periods spanning 6 months operation, regardless of type of coal or type of test, Agglomerator inlet versus outlet tests show that an average particle reduction of 45% for all particles less than 10 μm is achieved by the Indigo Agglomerator. This translates to a 30%-40% increase in average collection efficiency at the ESP outlet.

Due to unidentified ESP problems during the coal 2 July tests, the rear two zones of the A side ESP achieved virtually no power, resulting in 50% less total power. Since the emissions from both ESPs for these tests are nearly the same, this shows that the improved inlet loading due to the Agglomerator, makes up for the loss of the two rear zones of a 5 zone ESP.

From the historical analysis, on average after analysis and comparison of 82 days operation burning coal 1 in the first half of 2007 and 2008, the plants opacity emissions are 20% lower in 2008 than they were for the same period in 2007. Based on analysis of 36 days operation the average improvement between 2007 and 2008 is 33.0% approximately for coal 2. Based on analysis of 6 days operation the average improvement between 2007 and 2008 is approximately 20.0 % when burning coal 3.

The particle size testing performed has shown that the Agglomerator can reduce PM5 by 40% across different coals. Since the opacity comparisons presented here result from the impact of one Agglomerator in a 2 pass system, it is reasonable to assume that a second Agglomerator installed in the same system will result in a larger emission reduction than this analysis identifies. A total opacity emission reduction of 40% (with Indigo Agglomerators installed on both ducts) is a reasonable, conservative prediction based on the historical emissions analysis.

These results show that the Indigo Agglomerator increases choice of coal and reduces the number of opacity excursions, as well as baseline opacity. At this power station, the Indigo Agglomerator could yield a minimum of a 40% opacity reduction across several different coals.