

## Fly ash resistivity with injected reagents and predicted impacts on electrostatic precipitators

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Electrostatic precipitators (ESPs), which are particulate collectors installed at many US coal-fired power plants, are now used as part of the flue gas scrubbing strategy by means of upstream injection of powdered sorbents or reagents. For example, dry sorbent injection (DSI) systems utilize powdered alkaline compounds such as hydrated lime or trona depending on the specific application. Pulverized activated carbon (PAC) is also utilized to capture gaseous mercury. In any of these combined systems, the particulate reagents or sorbents are injected into the flue gas upstream of the ESP. Then, the ESP must remove the fly ash from fuel combustion plus the injected sorbent or reagent/reactant. PAC injection mass rates range up to a few hundred lbs/hr, whereas DSI rates can be as high as 10,000 lbs/hr. In many instances, this addition of particulate means operating the system at or above design specification margin.

The primary parameter influencing ESP performance is the particulate resistivity (OHM-CM). This parameter is a measure of how well the particulate, when deposited on the ESP collecting electrodes, conducts electricity to ground. Variations in resistivity from optimum to extremely high can change ESP particulate emissions by significant amounts. Therefore, in the practice of injecting reagents into the flue gas and capturing these reagents in the ESP, operators are concerned with the impacts of the resultant composite particulate resistivity. This single parameter will have a greater impact on ESP performance than all others combined.

This paper describes a study of the impacts on resistivity from several different sorbent types, and varying concentrations of sorbent injection. The samples studied for resistivity were both laboratory fly ash and reagent admixtures, and full-scale site generated reagent injected fly ash samples. The reagents include alkaline based sorbents (Ca and Na) and PAC. The paper will also discuss predictions of ESP particulate emissions with sorbent injection. However, this general discussion is not a substitute for a specific study on each ESP, prior to installation of new sorbent injection systems.

### Resistivity Interpretation

Laboratory resistivity (OHM-CM) of a dust is the ratio of the applied electric potential across the dust layer to the induced current density. The value of the resistivity for a dust sample depends upon a number of variables, including dust chemistry, dust porosity, dust temperature, composition of gaseous environment (i.e. gas moisture), magnitude of applied electric field strength, and test procedure.

In working with ESPs, resistivities are encountered in the range from about 1E4 to 1E14 OHM-CM. The optimum value for resistivity is generally considered to be in the range of 1E8 to 1E11 OHM-CM. In this range, the dust is conductive enough that charge does not build-up in the collected dust layer and insulate the collecting plates. Additionally, the dust does not hold too much charge and is adequately cleaned from the collecting plates by normal rapping. If resistivity is in the range 1E12 to 1E14 OHM-CM, it is considered to be high resistivity dust. This dust is tightly held to the collecting plates because the dust particles do not easily conduct their charge to ground. Consequently, high resistivity dust insulates the collecting plates and high ESP sparking levels result (also poor ESP collection efficiencies). Conversely, if the dust is low resistivity, 1E4 to 1E7 OHM-CM, the dust easily conducts its charge to the grounded collecting plates. In this case, there is not sufficient residual charge on the dust particles to hold them on the plates. Thus, these particles are easily dislodged and re-entrain back into the gas stream. ESP gas velocities are generally designed in the 2.5-3.5 FT/S range, if high carbon particles are to be collected.

The resistivity test procedure was in accordance with IEEE-548, Standard Criteria for the Laboratory Measurement of Fly Ash Resistivity. The apparatus used for the testing is a custom built arrangement utilizing a high temperature oven, a controlled temperature water bath for gas humidity adjustment, a DC power source, and an electrometer for current flow measurement, details of which can be found elsewhere. [1] Typical fly ash resistivity measurements are conducted in a gas temperature range from 200 to 850°F. This range encloses both cold-side and hot-side ESP operation regimes. However, because the

study samples included alkaline species that may decompose at the higher temperatures, the test maximum temperature was limited to less than 500°F and only in ascending mode. Therefore, the results of this study apply to flue gas temperatures less than 500°F as is the case for cold side ESPs.

In looking at resistivity data, the resistivity “curves” generally peak out in the range of 280–360°F. On the high side of the peak, thermal conduction effects cause the resistivity to decrease as temperature increases. On the cold side of the resistivity peak, condensation of moisture on the surface of the particulate causes the resistivity to decrease.

One note on the high sulfur coal cases – the laboratory resistivity testing was done strictly with a constant humidity concentration for surface conditioning. Therefore, the resistivity measurements in this study are for the bulk material only. In an actual power plant flue gas, there will be surface conditioning from sulfuric acid, to reduce the particulate resistivity down to even lower values than shown in this report. In the field, the injected reagent may reduce the amount of sulfuric acid surface conditioning. However, the fly ash from high sulfur coal contains relatively low levels of dielectric content (i.e. silica+alumina+CaO), and higher levels of iron pyrites. So there is never a situation where we have high resistivity predicted for any of the high sulfur ash and reagent composite cases. Therefore, no matter what chemical is injected with the high sulfur coal flue gas, good to moderate resistivity levels were measured.

### Powdered Activated Carbon (PAC) Injection

The chemical formula of this reagent would be C. Of primary importance to resistivity measurements, is the fact that this material is carbon. In the ESP industry, carbon has been encountered on many applications (oil firing, coal stoker firing, woodwaste firing, etc.). In these ESP uses, the carbon has been observed to yield very low resistivity dusts. However, each of these ESP applications has carbon levels in the 20–90% wt range.

In recent years, the PAC is being injected as a reagent for mercury scrubbing purposes. But at the same time, this added particulate must be collected by the ESP. To better understand the impacts of this injection, resistivity studies were undertaken with both high resistivity fly ash and low resistivity baseline fly ash. Several hypothetical injection rates were tested for both types of fly ash. Figure 1 depicts the ascending temperature plots for high resistivity ash and for PAC.

The typical PAC injection rate for mercury removal at coal-fired plants is in the range of a 2 to 10% carbon by weight of fly ash. In the case of 2% carbon injection, the combined flyash/reagent resistivity is unchanged. In the case of 10% carbon, the resistivity drops by four orders of magnitude. This change is a significant improvement in resistivity, and

would make a large ESP, designed for high resistivity, work better in terms of particulate collection efficiency. Figure 2 shows similar tests for the low resistivity baseline fly ash;

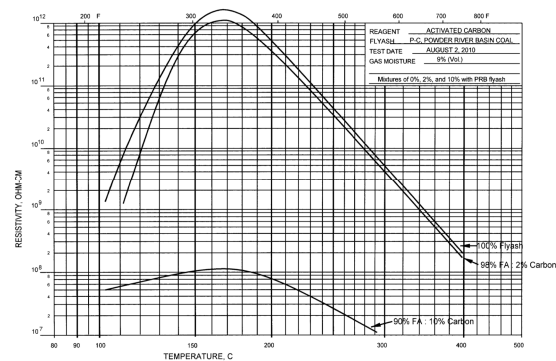


Figure 1. Results of resistivity tests for high resistivity fly ash

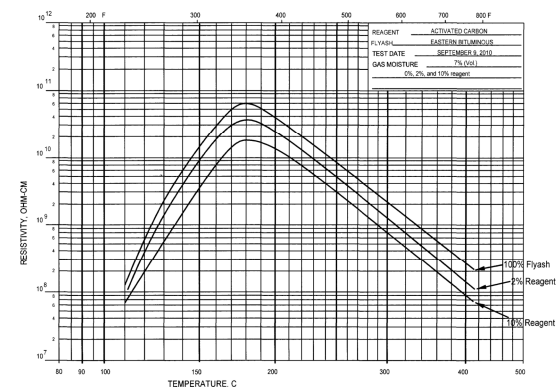


Figure 2. Results of resistivity tests for the low resistivity baseline fly ash

In the case where the baseline resistivity starts low, the change in resistivity from 2–10% PAC injection is a small reduction. Figure 3 shows a little more refinement on the percentage of PAC that is required to get significant resistivity reduction from PAC. In this case 5% PAC reduced resistivity by about one-half order of magnitude.

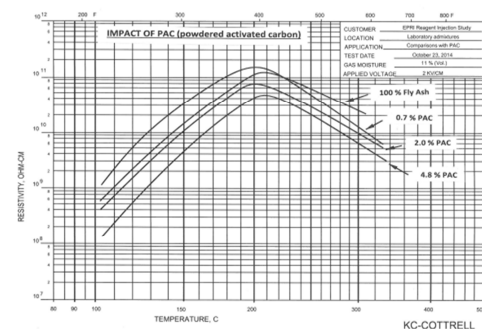


Figure 3. Percentage of PAC that is required to get significant resistivity reduction from PAC

## Trona Injection

The proper chemical name for trona, is sodium sesquicarbonate ( $\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$ ). Trona is a naturally formed ore which is mined and then milled for injection. Of primary importance to resistivity measurements is the fact that this material contains sodium. In the ESP industry, sodium compounds have been used for many years as additives to solve resistivity problems. In these ESP uses, the sodium compounds have been injected on the coal belt, dry into the flue gas, and wet into the flue gas. The purpose was to introduce sodium bearing materials into the dust layer deposited on the collecting plates of the ESP.

In recent years, the trona is being injected as a reagent for gaseous scrubbing purposes ( $\text{SO}_x$  and other acid gases). But at the same time, this added particulate must be collected by the ESP. To better understand the impacts of this injection, resistivity studies were undertaken with both high resistivity fly ash and low resistivity fly ash. Several hypothetical injection rates were tested for both types of fly ash. Figure 4 summarizes the ascending resistivity plots for composite samples with trona.

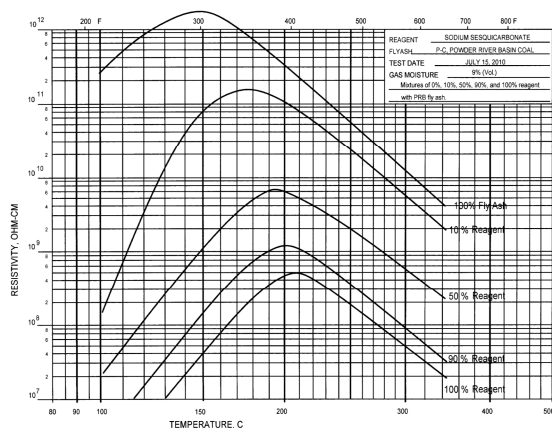


Figure 4. Results of tests for high resistivity composites

There are several things to note on Figure 4. First the resistivity of the 100% fly ash was in the high range (i.e.  $> 1\text{E}12$  OHM-CM), which on its own would cause difficulty for ESP performance. Then tests of 90 and 100% trona showed the resistivity to “peak out” at  $1\text{E}9$  OHM-CM or lower. This is a low/good value for electrostatic precipitation. So as expected, the pure or near pure sodium reagent is very low in resistivity. With any cases of very high injection rates vs. fly ash rate, there would be a huge improvement in resistivity/ESP performance.

However, the typical injection rate for trona injection is in the 10% trona to 90% fly ash by weight ratio. In this case, the combined fly ash/reagent resistivity drops by about one order of magnitude. This is a significant improvement in resistivity, and would make the ESP emit lower particulate emissions. This prediction takes into account that the inlet

loading to the ESP would be 10% higher. Inlet loading is a much less powerful impactor on ESP performance than resistivity. This is especially true in this case, when the particle size of the injected reagent is created from milling. It is typical for the particle size from pulverized-coal firing to be much finer. This is because the particle size of fly ash is created by milling and then burning off of the carbon in the coal. ESPs are known to be particle size dependent and large particles are collected much easier than fine particles.

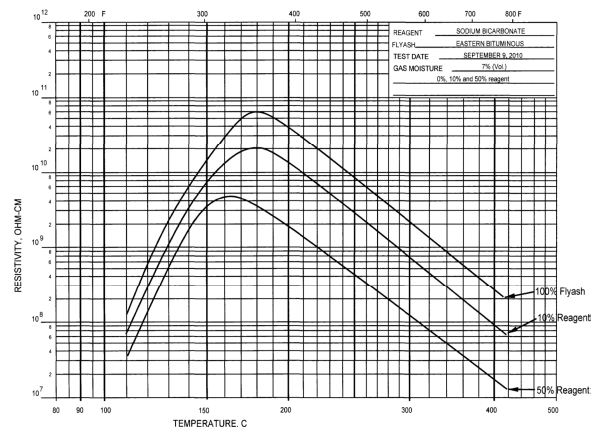


Figure 5. Results of tests for the low baseline resistivity fly ash

On Figure 5, the bulk resistivity of 100% fly ash falls within the good resistivity on its own. The addition of the typical injection quantity of 10% Trona does serve to reduce resistivity, although resistivity is good in both cases. Thus, there is not really an improvement in resistivity here. In this case, the ESP must be studied specifically to see if the increase in inlet dust loading would cause a “bogging down” of the inlet fields of the ESP. This will be dependent on ESP size, inlet field electrode geometry, and ESP rapping density. There is the potential that injection could cause higher particulate emissions, if the ESP is marginal in size or design.

## Calcium Hydroxide Injection

The chemical formula of calcium hydroxide is  $\text{Ca}(\text{OH})_2$ . Of primary importance to resistivity measurements is that this material contains calcium. In the ESP industry, calcium compounds ( $\text{CaO}$ ,  $\text{CaSO}_4$ ,  $\text{CaCO}_3$ ) have been observed for many years as highly resistive. In these ESP uses, the resistivity of the calcium bearing compounds has been controlled by injecting moisture and operating on the cold side of the resistivity peak.

In recent years, the  $\text{Ca}(\text{OH})_2$  is being injected as a reagent for acid gas scrubbing purposes that is also collected by the ESP. Note that at the ESP, some of the calcium may exist as reactant,  $\text{Ca}(\text{OH})_2$ , and some as product in sulfate form,  $\text{CaSO}_4$ . To better understand the impacts of this injection, resistivity

studies were undertaken with varying concentrations of  $\text{Ca}(\text{OH})_2$  and  $\text{CaSO}_4$ .

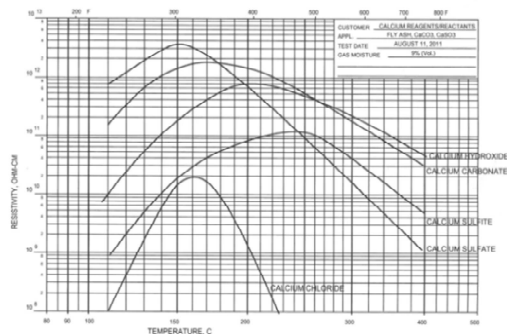


Figure 6. Resistivity of common calcium species that may be generated with injection of  $\text{Ca}(\text{OH})_2$

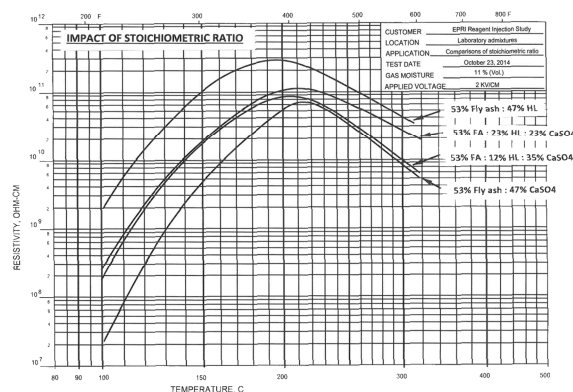


Figure 7. Results of hypothetical injection rate tests

There are several things to note on Figure 7. First the addition of  $\text{Ca}(\text{OH})_2$  and  $\text{CaSO}_4$  serves to increase the combined fly ash resistivity. Second, the ratio of  $\text{Ca}(\text{OH})_2$  to  $\text{CaSO}_4$  appears to significantly impact the resistivity. In similar fly ash to combined  $\text{Ca}(\text{OH})_2$  and  $\text{CaSO}_4$  admixtures (i.e. 53% fly ash to 47%  $\text{Ca}(\text{OH})_2$  and  $\text{CaSO}_4$ ), the combined fly ash resistivity increased as the ratio of  $\text{Ca}(\text{OH})_2$  to  $\text{CaSO}_4$  increased. This means that anything we can do to decrease the stoichiometric ratio of injection will have a dual impact on resistivity (i.e. lower stoichiometries will lower reagent addition and lower  $\text{Ca}(\text{OH})_2$  to  $\text{CaSO}_4$  ratio).

The above discussion is especially important in light of the changes that have occurred in the chemistry and material handling aspects of reagent injection. Comparisons of technologies ten years ago calculated that dry sorbent injection followed by a fabric filter was the best approach to the problem. This decision was based upon 1) reagent savings from better stoichiometric ratios, and 2) anticipated problems with the size of the ESP with higher resistivity  $\text{Ca}(\text{OH})_2$  to  $\text{CaSO}_4$  combined fly ash. However, since that time, a number of improvements have been made that challenge that thinking. First, the  $\text{Ca}(\text{OH})_2$  suppliers have increased the surface area of

their products. This reduced the  $\text{Ca}(\text{OH})_2$  required to get a given acid gas collection efficiency by about 30%. This change would impact reagent usage for both an ESP and a fabric filter. Second, injection technologies have now been developed that use high pressure air to fire the reagent into the flue gas stream. This greatly improves the dispersion of the reagent and has been shown to decrease the required reagent to get a given acid gas collection efficiency by an additional 20% [2] (working from the original reagent requirement). This change only impacts the stoichiometry of using an ESP as the final dust collector. This is because the fabric filter already had intimate contact with the reagent as the gases passed through the filter cake. Now the added dispersion is causing more disperse contact with the gases ahead of the ESP. Thus, depending on the acid gas removal target, reductions of up to 50% less reagent than were hypothesized some years ago may be attainable. [3] So overall reagent usage is going down, and the difference in stoichiometric ratio between ESP and fabric filter is getting closer.

A third development in the industry has been the surface treatment of  $\text{Ca}(\text{OH})_2$  to improve the resistivity of the combined fly ash.

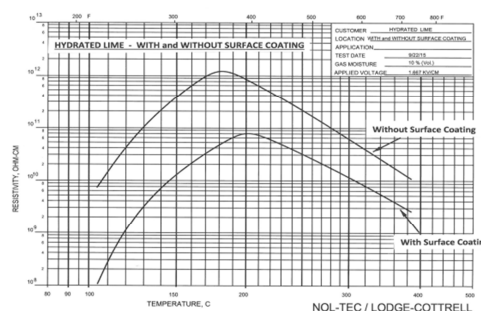


Figure 8. Results of resistivity tests for combined fly ash with surface treated  $\text{Ca}(\text{OH})_2$

The surface coated  $\text{Ca}(\text{OH})_2$  has a resistivity about one order of magnitude lower than “standard”  $\text{Ca}(\text{OH})_2$ . This same effect is shown on Figure 9 with fly ash admixtures;

As can be seen on Figure 9, in the case of high resistivity the surface treated  $\text{Ca}(\text{OH})_2$  will actually pull down the resistivity of the combined fly ash. Figure 10 shows the impact if the starting point is a low resistivity fly ash;

In this case, the reagent had almost no impact to increase combined fly ash resistivity, even in concentrations up to 30%.

To summarize our three impacts on ESP performance, we now in 2016 have the following;

Lower injection rates of  $\text{Ca}(\text{OH})_2$

- More reactive reagent
- Better dispersion injectors

Lower ratio of  $\text{Ca}(\text{OH})_2$  to  $\text{CaSO}_4$

Lower resistivity surface treated reagent

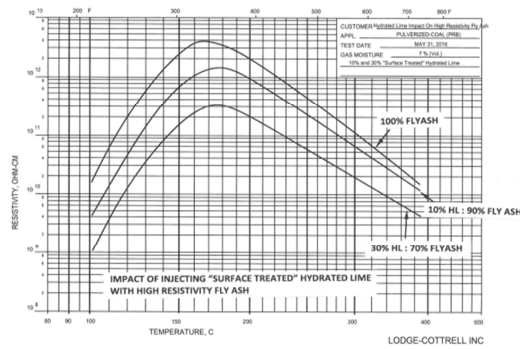


Figure 9. Results of resistivity tests for fly ash admixtures with surface treated  $\text{Ca}(\text{OH})_2$

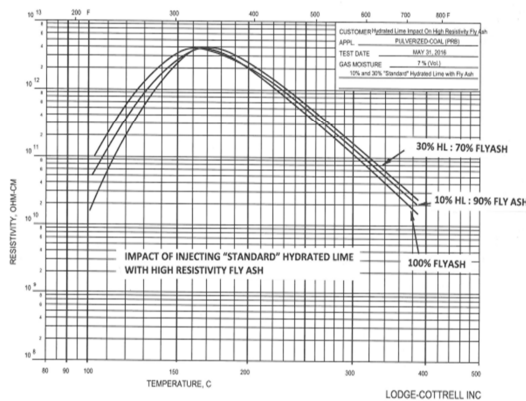


Figure 10. Results of resistivity tests for low resistivity fly ash with surface treated  $\text{Ca}(\text{OH})_2$

These three factors may combine to change the decision of whether to remove an existing ESP and replace with a fabric filter.

## Conclusions

- Adding activated carbon reduces the resistivity of the combined fly ash. Low levels of injection ( $< 2\%$ ) have only a minor impact, but by 4% the resistivity reduction is one half order of magnitude.
- Adding trona reduces the resistivity of the combined fly ash. Injection rates of 10% cause a reduction of one full order of magnitude in the combined fly ash.
- Adding hydrated lime has a more complicated effect on combined fly ash resistivity. This will depend on the overall concentration of  $\text{Ca}(\text{OH})_2$  added, the split of  $\text{Ca}(\text{OH})_2$  to  $\text{CaSO}_4$ , and the type of surface treatment that has been performed on the  $\text{Ca}(\text{OH})_2$  to reduce its resistivity.
- Trends observed for the fly ash mixtures of hydrated lime and the PRB ash showed slight differences at the low hydrated lime to fly ash ratios. In some instances, the trends tend to show a lower resistivity than the baseline fly ash.
- Trends at the higher sorbent to ash ratio did show an order of magnitude increase in resistivity trends between the ESP operating temperature window. This was irrespective of the fraction of reacted vs. unreacted hydrated lime. The differences observed between the various sensitivity compositions did not show a clear trend. This may be caused by a number of reasons beyond experimental control. Some of these include, the mixing effectiveness of the  $\text{CaSO}_4$ , hydrated lime and fly ash. There may also be other contributing factors such as the  $\text{CaSO}_4$  quality and particle size distribution which were not accounted for in this experiment.
- For the PAC admixtures, minor differences between the samples were observed which tends to indicate that PAC usage at these levels does not affect resistivity significantly.

## References

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- [3] Fitzgerald, Howard, *Hydrated Lime DSI – Solution for Acid Gas Control*, MARAMA/ICAC  $\text{SO}_2/\text{HCL}$  Control Technologies Webinar 2012.