# ESP Compatible Calcium Sorbent for $SO_2$ Capture at Great River Energy's Stanton Station

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## ABSTRACT

A series of dry sorbent injection (DSI) trials have been performed at Great River Energy's Stanton Station in recent years to ascertain a solution to reduce $SO_2$ emissions for future Regional Haze compliance. Various alkaline reagents have been tested at Stanton Station with DSI technology including Lhoist's enhanced hydrated lime reagent, Sorbacal® SPS. Sorbacal® SPS successfully achieved the required $SO_2$ removal efficiency to meet the 0.16 lb/MMBtu $SO_2$ Regional Haze compliance target during short term and multi-week test programs.

In addition to providing the necessary $SO_2$ removal, Sorbacal® SPS did not significantly degrade the electrostatic precipitator performance and the subsequent fly ash generated was classified as a non-hazardous waste. This paper will discuss the results of the Sorbacal® SPS DSI trials including a discussion on the balance of plant impacts including the impacts on the electrostatic precipitator, air preheater, and ash handling system.

## INTRODUCTION

Particulate resistivity is a key parameter in electrostatic precipitator (ESP) performance that provides an indication of how well the particulate conducts electricity to ground. The optimum resistivity range is generally accepted to be between 1E8 to 1E11 (Ohm·cm) where the particulates are efficiently captured and cleaned from the collection plates by normal rapping operation of the ESP[1].

If the particulate resistivity is outside of this range, being either too low or too high, ESP operational issues may occur. At low resistivity, <1E8 (Ohm·cm), the particulates easily conducts its charge to the grounded collecting plates. Therefore the particulates are easily dislodged and re-entrained as there is insufficient residual charge to hold them to the collection plates. Conversely, if resistivity is greater than 1E11 (Ohm-cm): the particulates are tightly held by the collection plates as they do not easily conduct their charge. This creates an insulating layer on the collection plates that increases the spark rates therefore lowering ESP collection efficiency.

The fly ash particulate resistivity is influenced amongst a number of parameters by its chemical composition. The relationship between fly ash composition and resistivity has been previously established empirically through testing of a large number of samples[2]. It has been reported that the presence of calcium compounds[2,3] increases resistivity due to its low conductivity and potential to capture $SO_3$. The latter being a well-established ESP conditioning agent for reducing resistivity.

Due to these findings, it has been perceived that dry sorbent injection (DSI) using calcium hydroxide is incompatible with ESP units without addition of conditioning agents. As the presence of calcium compounds, both as reagent ($Ca(OH)_2$) and reaction products (e.g $CaSO_4$), may increase the overall fly ash resistivity outside the optimal ESP operating range.

This perception has already been reported to be incorrect at the ASTM Symposium on Lime Utilization in 2012 by Lodge Cottrell[1]. The case studies based on laboratory resistivity results concluded that calcium hydroxide injection had little or no influence on ESP performance depending on the ESP design. Furthermore, any potential detrimental effects on different fly ashes could likely be managed by a series of process optimization steps.

However, ESP compatibility of calcium based sorbents had not been demonstrated on a full industrial scale unit, particularly for an $SO_2$ removal application, until now. This paper will detail the successful application of enhanced calcium sorbent (Sorbacal® SPS) for $SO_2$ compliance at Great River Energy's Stanton Station Unit 1 located in Stanton, North Dakota. A month long trial was completed at the 200 (MW) unit burning PRB coal with two cold side ESPs for particulate emission control.

The results of testing on ½ the unit (West side) will be presented that allow the other non-tested side (East side) to be used as a base line unit. The Regional Haze $SO_2$ limit was 0.16 (lb/MMBtu) as a 30 day rolling average for this plant. However, a desired target $SO_2$ emission rate of <0.14 (lb/MMBtu), which was achieved during the tests with $SO_2$ removal rates up to 85% at normal load operation and 93% at low load operation. Acceptable plant impacts were observed on the ESP and the sootblowers were operated at a higher frequency to maintain air preheater (APH) operations during normal plant load operation. A calcium based DSI solution was favorable because of its low CAPEX requirements and no adverse effects on the fly ash resale properties when used for soil stabilization which was also an important economic factor in the overall DSI performance analysis.

The full scale trial data correlated well with the laboratory resistivity measurements used in the development of the enhanced calcium sorbent for improved ESP compatibility. Laboratory results comparing the resistivity of the enhanced calcium sorbents against a standard hydrated lime will also be presented.

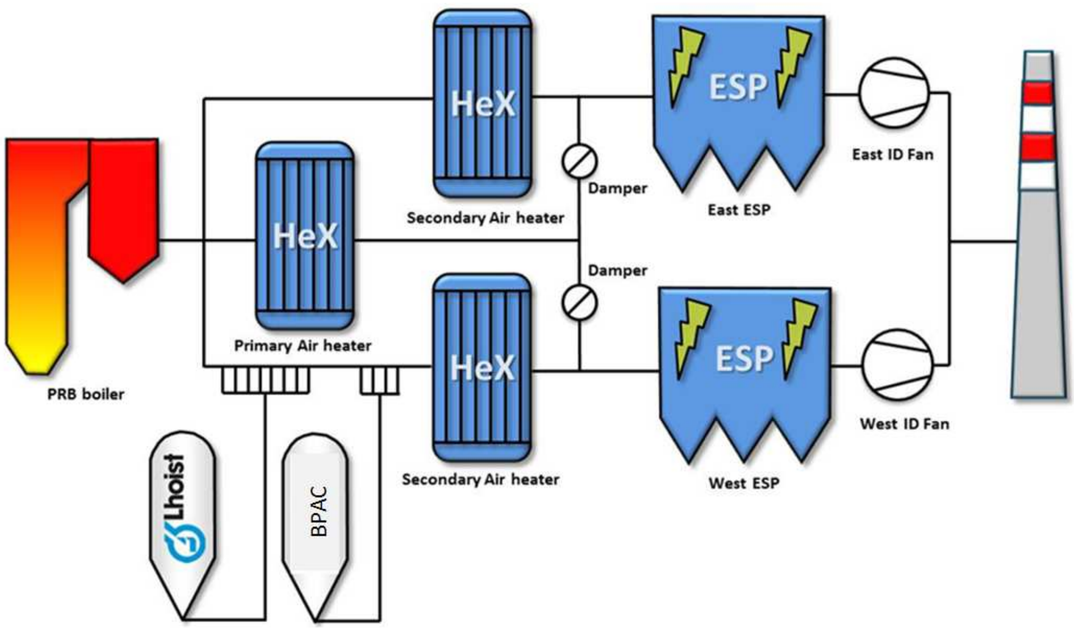
## EXPERIMENTAL METHODS AND MATERIALS

### Industrial trial at Great River Energy's Stanton Station Unit 1

Great River Energy's Stanton Unit 1 is a PRB fired coal boiler with a 200 (MW) rated capacity. Mercury Air Toxics Standard (MATS) compliance was achieved in 2015 through the use of brominated powdered activated carbon (BPAC) for mercury control. No HCl scrubbing was necessary due to low coal chlorine content and existing ESPs for filterable particulate emissions. However, a $SO_2$ control solution to meet the Regional Haze rule by 2017 was still required.

The flue gas from Unit 1 is split into three streams, which are sent to three air pre heaters (APH or HeX, as shown in Figure 1); the central primary APH, and two secondary APH designated East and West. Approximately 40% of the total flue gas flow passes through each secondary APH and approximately 20% of the flue gas flows through the primary APH. After the primary APH, the flow is spit in two and is recombined with the East and West flows to go to the East and West ESP units. Refer to Figure 1 for details of this set-up.

**Figure 1: Configuration of the APH and ESP at Great River Energy's Stanton Unit 1 with trial DSI system installed on the West duct.**




Several trials since 2011 were conducted to identify technical and economically favorable solutions for $SO_2$ compliance. When DSI was selected, a number of different sorbent types and suppliers were compared for efficacy of $SO_2$ removal as well as balance of plant impacts[4]. This included the successful technical demonstration of an enhanced calcium sorbent (Sorbacal® SPS) that took place in Q3 2015.

The month long trial was split into two phases, with sorbent injection into West duct only (1/2 unit) for the first two weeks followed by complete treatment of both ducts (full unit) for the remaining two weeks. Similar results were achieved during the 1/2 and full unit trials with full $SO_2$ compliance and minimal or limited plant operational issues during normal operation, depending on process conditions. In this paper, only the 1/2 unit trial is reported to allow for a comparison between the East side (no sorbent injection) and West side (Sorbacal® SPS dosed). The plant load reduced from normal load (70% MCR) during the day to low load conditions (~35% MCR) at night. This had an influence on $SO_2$ removal performance where improvements were observed under low load conditions as expected. The continuous emissions monitor systems (CEMS) and process monitors installed at Great River Energy Stanton Unit 1 were used for data collection.

During the test work on half the unit, Sorbacal® SPS was injected in front of the West APH upstream of the BPAC injection. Injection points were approximately 40 feet upstream of the APH which is the equivalent of roughly 0.5 to 1 second of residence time. To prevent dilution of the gas flow to the ESP with untreated flue gas from the primary air heater, the primary damper in Figure 1 was closed during the test work. Because fly ash may accumulate at the closed damper due to the absence of flow, the damper was opened every 6 hours for half hour to remove any accumulated fly ash.

Sorbacal® SPS was dosed using a Nol-Tec Sorb-N-Ject mobile dosing unit that consisted of a 30 ton self-erecting silo equipped with two line dosing unit. Each dosing unit had a loss in weight dosing hopper that was capable of 5,000 (lbs/hr) sorbent injection. Sorbacal® SPS was pneumatically transported via four inch diameter rubber tube to a vertical eight way splitter. From the splitter, Sorbacal® SPS was dosed via eight separate lances into the duct work before injection to the West secondary APH.

Each of the two Research-Cottrell ESP units (East and West) consists of two boxes with three fields. The specific collection area equals SCA = 271 and the cross sectional inlet area A = 2790 ($ft^2$) leading to a face velocity of about 3 (ft/s). Both ESP units were physically inspected before and after the enhanced calcium sorbent month long trial. The Spring Creek PRB coal burnt at Great River Energy's Stanton Unit 1 has high sodium content that will be favorable for ESP operation due to its high conductivity. It is probable that the fly ash resistivity will be closer to lower end of the optimal range (1E8 to 1E11). Therefore, a wider resistivity margin may be available before entering the unfavorable high resistivity zone.

## Enhanced calcium sorbent

Commercially available Sorbacal® SPS was supplied by Lhoist North America. Sorbacal® SPS is an enhanced hydrated lime sorbent suited for $HCl/SO_3/SO_2$ removal in conjunction with ESP operations. Three key features make Sorbacal® SPS suited for this application. First, the enhanced hydrated lime has a high reactivity towards the acidic pollutants at a factor of 2-3 times higher than a standard hydrated lime. Second, the particle size of the reagent is large enough to enable efficient capture dynamics in the ESP and to prevent flow problems in the dosing system. The material particle diameter is still sufficiently small to enable high mass transport rates and good dispersive properties. Third, the material has improved particle conductivity which contributes to ESP collection efficiency by not adversely affecting the resistivity of the reagent/fly ash mixture. Table 1 below displays several of the properties of the different Sorbacal® products available.

**Table 1: Key properties of standard and enhanced hydrates available for flue gas treatment showing surface area (SA), pore volume (PV), median particle size ($d_{50}$) and maximum resistivity (R).**

| **Sorbent** | **Type of hydrated lime** | ***SA*** ($m^2/g$) | ***PV*** (ml/g) | $d_{50}$ (µ) | ***R*** ***(Ohm-cm)*** |
|---|---|---|---|---|---|
| Sorbacal® H | Premium standard hydrate | >20 | ≈0.08 | 6-12 | $10^{12}$ |
| Sorbacal® SP | Enhanced hydrate | >40 | >0.2 | 6-12 | $10^{12}$ |
| Sorbacal® SPS | Enhanced hydrate | >40 | >0.2 | 6-12 | $10^{11}$ |

## Laboratory resistivity measurements

All laboratory resistivity measurements were conducted externally at Nol-Tec – Lodge Cottrell, New Jersey. The test procedure was in accordance with IEEE-548, Standard Criteria for the laboratory measurement of fly ash resistivity[5]. The measurements were conducted in air with 10 (vol%) moisture that is typical for PRB coal firing over typical cold side ESP operating temperature ranges from 180 to 650 ($^0$F). The voltage applied was 1.667 (kV/cm).

# RESULTS AND DISCUSSIONS

The results of the industrial trial at GRE Stanton Station Unit 1 will be presented first, followed by details on Lhoist's development of the enhanced calcium hydroxide sorbent for ESP compatibility. The baseline without sorbent injection was established prior to start of Sorbacal® SPS trials that showed comparable results between East and West ducts. This allows the East duct to be used as a comparator for determining the impact of Sorbacal® SPS injection in the West duct with respect to $SO_2$ emissions, ESP performance and APH operation. Key flue gas emission and flowrates without sorbent injection for both East and West ducts are summarized in Table 2.

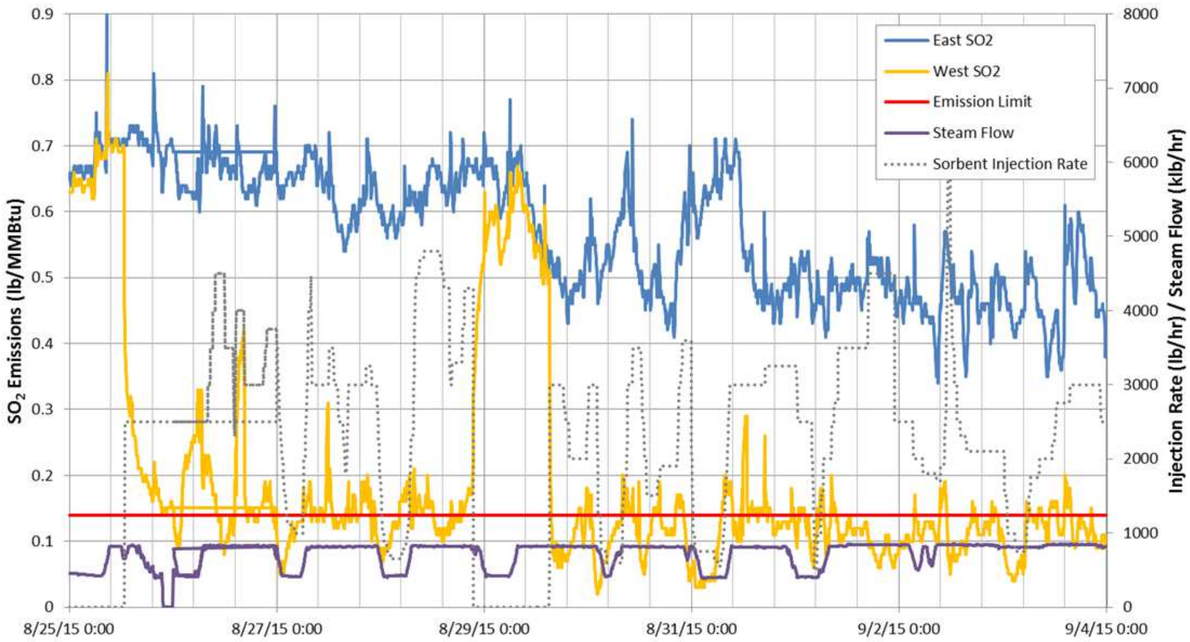
**Table 2: Baseline flue gas emission and flowrates without sorbent injection.**

| **Parameter** | **Normal load** | **Low load** | **Unit** |
|---|---|---|---|
| Gas flowrate West | 9,300,000 | 5,400,000 | (SCFH) |
| Gas flowrate East | 11,000,000 | 6,200,000 | (SCFH) |
| Total flue gas flow rate | 20,300,000 | 11,600,000 | (SCFH) |
| Steam flowrate | 800 | 420 | (KPPH) |
| $SO_2$ emission West | 0.54 | 0.51 | (lbs/MMBtu) |
| $SO_2$ emission East | 0.53 | 0.50 | (lbs/MMBtu) |
| Opacity West | 6.50 | 4.2 | (%) |
| Opacity East | 3.2 | 1.1 | (%) |

## $SO_2$ compliance with enhanced hydrated lime sorbent

Referring to Table 2, an average inlet $SO_2$ emission of 0.54 (lbs $SO_2$/MMBtu) was recorded on the West side, which generally shows good agreement with the SO2 emission rate from 'uncontrolled' East side. The target outlet $SO_2$ emission was 0.14 (lbs $SO_2$/MMBtu) therefore a $SO_2$ reduction of 74% was necessary. Sorbacal® SPS was dosed over a 10-day period at different injection rates to investigate $SO_2$ removal performance. See Figure 2.

**Figure 2: Overview of 10 day sorbent injection rates in West secondary APH showing the $SO_2$ inlet and outlet concentrations with steam load of both units.**




It can be clearly seen that $SO_2$ compliance below 0.14 (lb $SO_2$/MMBtu) was achieved during Sorbacal® SPS injection with $SO_2$ conversion up to 93% (Target = 74% at 0.55 lb $SO_2$/MMBtu). Excluding the period where injection was shut off on 8/29/15, the average $SO_2$ emission once $SO_2$ stabilized was 0.13 (lb $SO_2$/MMBtu). Average injection rates of 2,525 (lb/hr) were utilized, ranging from 600 to 4,500 (lb/hr) depending on the inlet $SO_2$ concentration and boiler load. In comparison, standard hydrates may not be able to potentially achieve the required $SO_2$ conversion or only at very high dosing rates that could be as much as twice that of Sorbacal® SPS[6].

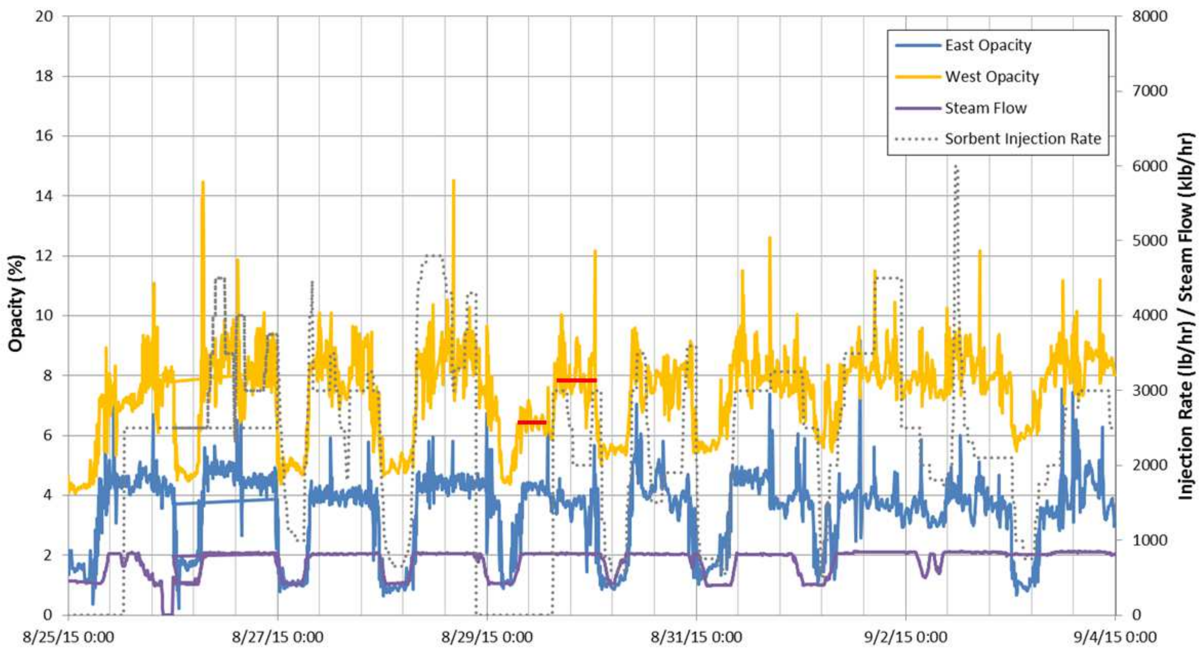
DSI performance will be affected by process parameters such as flue gas temperatures, flue gas moisture content, residence time, dust loading, sorbent dispersion, and sorbent reactivity that will be unique to each plant. The high sorbent reactivity performance associated with enhanced calcium sorbents make DSI an attractive possibility for $SO_2$ control with low CAPEX, low auxiliary requirements and no leachability issues associated with the final fly ash that enables reuse in various applications.

## Impact of enhanced hydrated lime injection on ESP performance

Both the West and East ESP inlet fields were cleaned and inspected before the month long Sorbacal® SPS test campaign. After completion of the DSI tests, the ESPs were inspected by a third party. It was concluded that there were minimal effects on the ESP during the low and normal load injection from the enhanced calcium hydroxide sorbent. This is supported by the process results collected during the low and normal load portions of the trial looking at opacity, spark rates, and voltages of the ESPs. The voltage-current (V-I) curves were also inspected (not provided for brevity) that showed an increase in coronal onset voltage indicative of higher dust loading accompanying DSI sorbent injection. Increased loading was observed primarily on the 1st and 2nd fields as expected with the 3rd field remaining relatively unchanged.

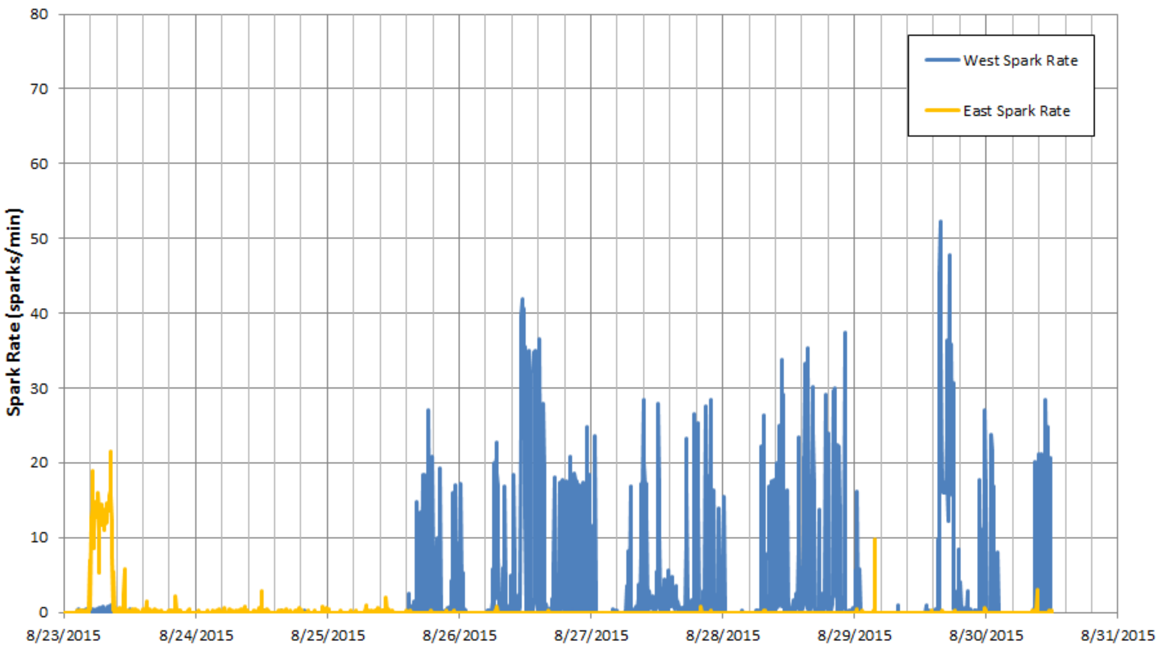
The baseline opacity of the West and East ESPs were 6.5% and 3.2% respectively with DSI sorbent injection in the West duct. Stanton Station has a permitted opacity of 20%. The impact of sorbent injection on opacity can be seen in Figure 3 where injection of Sorbacal® SPS has increased opacity up to a stable average value of 8.3% over the 10 day period shown. This effect is highlighted in the red bars when no Sorbacal® SPS was injected for 18 (hrs) and the opacity dropped back to the original baseline of 6.5%. When sorbent injection is re-started, opacity again increases to 8%.

**Figure 3: Opacity of West and East ESPs over 10 days of West side sorbent injection.**




It is expected that an increased load of fine materials results in higher opacity if ESP operational settings remain unchanged. Increased resistivity due to the injection of calcium based sorbents and the subsequent reaction products could also have contributed to the increased opacity by reducing ESP efficiency. The latter is supported by the increase in spark rate and voltage on the West ESP with sorbent injection as shown in Figure 4 and Figure 5.

**Figure 4: Spark rate of West and East ESPs over 8 days of West side sorbent injection.**




An increase in the spark rate shown in Figure 4 reaches an average around twenty sparks per minute from a baseline without sorbent injection of below five sparks per minute. This is a manageable value and in fact below the reported optimum spark rate of 50 to 100 sparks per minute[7] for ESP operation. This range is where the gain in efficiency associated with higher voltage compensates for the decreased gas ionization due to collapse of the electric field. However, the optimum spark rate will be dependent on each individual ESP design.

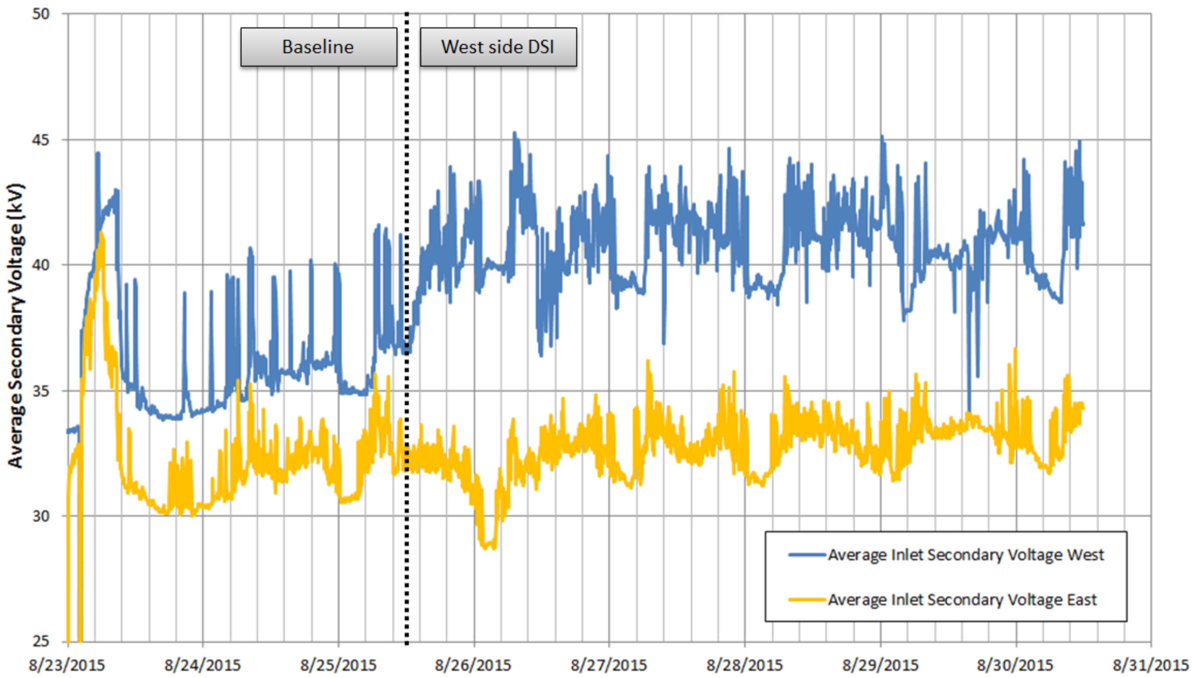
The average secondary current and voltages across the inlet, center and outlet fields of the West ESP were examined to evaluate the impact of sorbent injection. A comparison can be made between the baseline data without sorbent injection (23rd Aug 00:00 to 25th Aug 12:50) and with DSI applied (25th Aug 12:50 to 30th Aug 12:00) that is given in Table 3.

**Table 3: Average Inlet, Center and Outlet secondary current and voltage of West ESP**

| West ESP | Average Secondary Current (mA) | | | Average Secondary Voltage (kV) | | |
|---|---|---|---|---|---|---|
| | Baseline | DSI | % change | Baseline | DSI | % change |
| Inlet | 377 | 374 | -1% | 36 | 41 | 13% |
| Centre | 355 | 368 | 4% | 34 | 36 | 5% |
| Outlet | 411 | 404 | -2% | 33 | 33 | 0% |

It is clear that enhanced calcium hydroxide sorbent injection on the West ESP has had a measurable effect on the inlet field with a small and no effect on the center and outlet fields as expected. The secondary current was unaffected but there was a clear shift in the secondary voltage from an average of 36kV to 41kV. This change in secondary voltage baselines can be seen in Figure 5 that includes the East ESP as a reference. The delta between West and East secondary voltage widens when comparing the baseline and DSI periods. A minor increase in secondary voltage fluctuation in the West ESP represented by the width of the curve could also be inferred. This would be consistent with the increase in spark rates as shown previously in Figure 4.

**Figure 5: Average inlet secondary voltage of West and East ESPs over 8 days of West side sorbent injection.**




During the test program, there was a short term condition with Unit 1 operating at 100% MCR. This represents an operational scenario where Great River Energy's other boiler (Unit 10 at ~50MW) is off line. It requires Unit 1 to handle more flue gas. During this short term 100% MCR test condition, operational issues were observed such as air heater dP increased, which required constant sootblowing, and there were elevated opacity readings in conjunction with increased sparking rate on the ESP, requiring a reduction in sorbent injection.

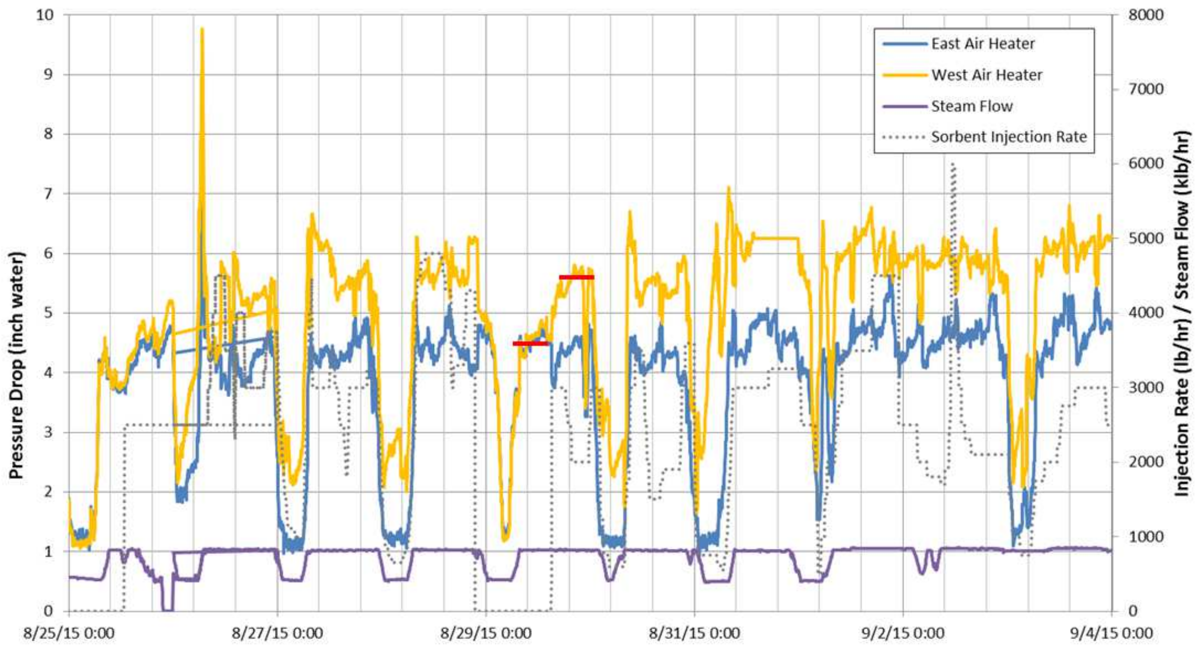
The ESP upset was likely a function of combination of factors including increased gas velocities, reduced particle residence time, and an increase in fly ash resistivity due to increased ESP inlet flue gas temperatures and high Sorbacal® SPS dosing rates in order to sustain $SO_2$ compliance. Additional testing and performance optimization is expected in order to find an ideal DSI solution with Sorbacal® SPS at this 100% MCR condition.

Overall, it can be concluded that although an increase in these key ESP indicators (opacity, spark rate, and secondary voltage) were observed, they were stable and manageable within safe operating conditions during normal operating loads. Further, through better injection system design and optimization, as well as through ESP improvements, it is likely that more performance benefits can be achieved.

## Impact of enhanced hydrated lime injection on APH performance

APH pressure drop is another important plant process parameter to consider when using DSI for $SO_2$ control. High sorbent injection rates raise the solid particulate loading (solid hold up) and therefore increase the pressure drop according to hydrodynamic theory[8]. As expected, an increase in the pressure drop (1 in w.c) over the West APH due to Sorbacal® SPS injection was observed, see Figure 6. The East APH can be used as a baseline comparator where similar differential pressure was recorded in West APH without sorbent injection (8/25/2015).

**Figure 6: Pressure drop of APH over 10 days of sorbent injection (West side).**



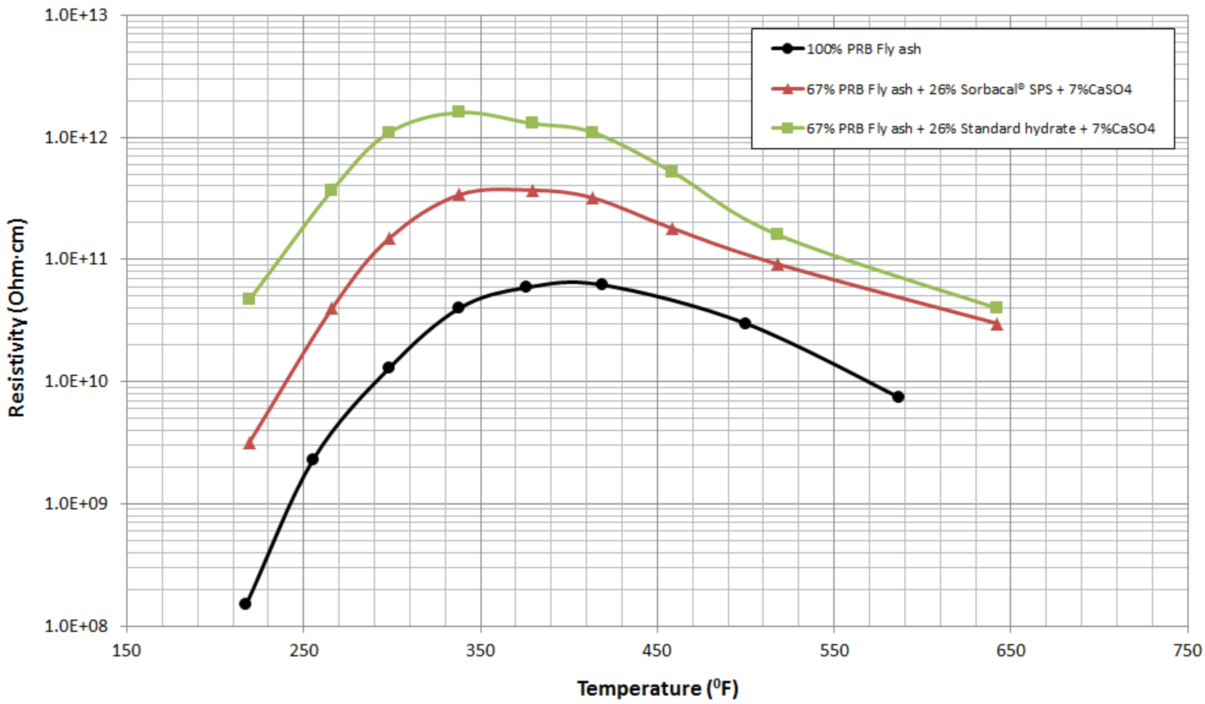

On average, the pressure drop over the West APH increased to stable values that are 1 to 1.5 inch water column (in w.c.) higher than East APH due to Sorbacal® SPS loading. This effect can be clearly seen when sorbent injection was stopped briefly that are highlighted by the red lines in Figure 6. The West APH pressure drop reduces to match the East APH at 4.5 in w.c. and again increases to 5.7 in w.c. when sorbent injection restarts.

Overall, it can be concluded that the pressure drop over the West secondary APH remains stable which indicates there are no signs of plugging. This was true over the full range of Sorbacal® SPS injection rates tested that was up to 4,500 (lb/hr). The increase in pressure drop measured is normal behavior due to increased solids loading. While the plant was able to maintain a steady delta P, it was necessary to increase APH sootblowing at normal load conditions from 1/day to an average of 4/day over the 10 day period shown in Figure 6.

Utilizing a DSI solution may also have the attractive co-benefit of enabling higher energy recovery as the APH outlet temperature can be lower without the risk of corrosion from $SO_3$ species, the latter will have been effectively removed prior to achieving $SO_2$ compliance. This was modelled and quantified by Duke Energy[9] where a 30 ($^0$F) reduction on the APH exit temperature leads to an approximate 1% savings in unit heat rate. This represents significant savings not only in coal costs but also ancillary benefits with reduced fuel, ash, and waste handling. Lower overall emissions can also positively impact ESP performance.

ESP performance may also benefit from lower APH outlet temperatures in two ways. First, the lower temperature reduces the overall resistivity of fly ash, as seen in Figure 7, where surface conductivity effects dominate. Second, the residence time may be increased as the gas velocity is lower with cooler, denser gas flows. Longer residence times can also improve $SO_2$ removal performance which further reduces required feed rates and by extension particulate loading at the ESP which improves performance.

**Figure 7: Laboratory resistivity measurements on fly ash mixtures showing: 100% PRB Fly ash (●), Fly ash + Sorbacal® SPS + $CaSO_4$ mixture (▲) and Fly ash + Standard hydrate + $CaSO_4$ (■).**




## Dedicated enhanced hydrated lime sorbent for ESP compatibility

This section discusses the development work conducted to improve ESP compatibility of enhanced hydrated lime sorbents based on typical PRB fly ash that was not supplied by Great River Energy's Stanton Unit 1. There are three key properties which are important in the compatibility of enhanced calcium hydroxide sorbent in ESP applications

1. High $SO_2$ / acid gas removal efficiency
2. Resistivity within the optimal range: 1E8 to 1E11 (Ohm·cm)
3. Particle size that is suitable for efficient ESP capture

The first key property is generally applicable to DSI sorbents resulting in lower sorbent consumption and residual generation but also reduced particulate loading for ESP applications. Particulate loading is an important parameter as the ESP performance may be negatively impacted in particular if approaching or exceeding the ESP design capacity. This enhanced performance was achieved by starting with a high porosity and high surface area, see Table 1, calcium hydroxide sorbent that has been proven to be significantly more effective than standard hydrates[6].

Generally, the enhanced hydrated lime has a reactivity of about a factor of 2 compared to a standard hydrated lime. This may result in a consumption reduction of approximately 30 – 50% compared to a standard hydrated lime. In addition, Sorbacal® SPS has an improved reactivity compared to Sorbacal® SP due to the use of additives designed to boost the capture of acidic gaseous pollutants.

The second key property is the resistivity of the sorbent. Figure 7 shows the resistivity of a typical PRB fly ash (not sourced from Great River Energy) along with ash mixtures of 26% of calcium sorbents and 7% calcium sulphate shown as a function of temperature. In this figure the total resistivity is a combination of surface conductivity (dominating at low temperatures) and bulk conductivity (dominating at high temperatures) resulting in a curve with a maximum value in resistivity. Laboratory grade $CaSO_4$ was used in preparation of the mixture to simulate typical fly ash residue that includes DSI reaction products such as $CaSO_4$ which have been previously reported to have higher resistivity than $Ca(OH)_2$[1].

In Figure 7, three curves are shown; typical 100% PRB coal fly ash, 67:26:7 mixture of fly ash, Sorbacal® SPS and $CaSO_4$ and a second 67:26:7 mixture with standard hydrate. The PRB fly ash alone has a good resistivity that is within the optimal range of 1E8 to 1E11 (Ohm-cm). The data indicates that the addition of hydrated lime and calcium sulphate increases the overall residue resistivity, which is in line with expectations based on literature reports[1].

However, significant differences can be seen between Sorbacal® SPS and standard hydrate. The use of standard hydrate has clearly shifted the peak resistivity by one order of magnitude from 1E11 to 1E12 (Ohm-cm) which places the ash firmly in the undesirable high resistivity range. In contrast, Sorbacal® SPS had approximately half the resistivity increase, where the peak resistivity has shifted to within the marginal zone between 1E11 and 1E12 (Ohm-cm).

This means that Sorbacal® SPS will have much less impact than a standard hydrate on the ESP performance due to smaller resistivity increases. This benefit is further compounded by the lower sorbent injection rates required with Sorbacal® SPS, therefore lowering the overall ESP particulate matter loading. This analysis demonstrates that a net increase in resistivity takes place with use of Sorbacal® SPS.

However, due to the smaller increase in resistivity with Sorbacal® SPS, the ash resistivity is shifted to the marginal zone instead of the high resistivity zone in this example. This enables the opportunity for process optimization to balance the increased resistivity. Stronger measures are likely to be necessary within the high resistivity zone such as the addition of conditioning agents or substantial upgrades to the ESPs.

The resistivity analysis agrees with the full scale results from the trial at Great River Energy's Stanton Station Unit 1 where a small impact on the ESP performance was observed (Figures 3, 4, and 5) at low and normal loads. Overall, the results shows that Sorbacal® SPS is compatible for $SO_2$ control with ESP equipped power plants but assessment of specific plant ESP(s) should be conducted due to the diversity in designs and operational parameters.

As the third key property, particle size is an important consideration as it has an impact on ESP efficiency. This can be determined from the fundamental ESP design equations associated with the collection efficiency and particle migration velocity. ESP collection efficiency is typically described by the Deutsch-Anderson equation[7,10] or modifications of the equation that is given below.

$$\eta = 1 - e^{-w(\frac{A}{Q})} \tag{1}$$

| | | |
|---|---|---|
| Where: | η = collection efficiency of the precipitator | |
| | w = particle migration velocity | cm/s (ft/s) |
| | A = the effective collecting plate area of the precipitator | $m^2$ ($ft^2$) |
| | Q = gas flow through the precipitator | $m^3/s$ ($ft^3/s$) |

The particle migration velocity ($w$) is a parameter influencing collection efficiency which in turn is affected by the particle size as described by equation 2[7,10]

$$w = \frac{d_p E_0 E_p}{4\pi\mu} \tag{2}$$

| | | |
|---|---|---|
| Where: | $w$ = migration velocity | cm/s (ft/s) |
| | $d_p$ = diameter of the particle | µm |
| | $E_0$ = strength of field in which particles are charged | V/m (V/ft) |
| | $E_p$ = strength of field in which particles are collected | V/m (V/ft) |
| | $\mu$ = gas viscosity | Pa.s (cp) |
| | π = pi | |

From equations (1) and (2), particle migration velocity can be seen to increase with particle size. Furthermore, the ESP collection efficiency increases with the particle size. These fundamental equations demonstrate that larger particles are easier to capture in ESPs. While, in practice, there is an upper limit to the particle size, (>50 µm), where ESP collection efficiency may start to decrease. The typical fly ash particle size ranges from 5 to 20 (µm)[5] with Sorbacal® products having a range from 6 to 12 (µm).

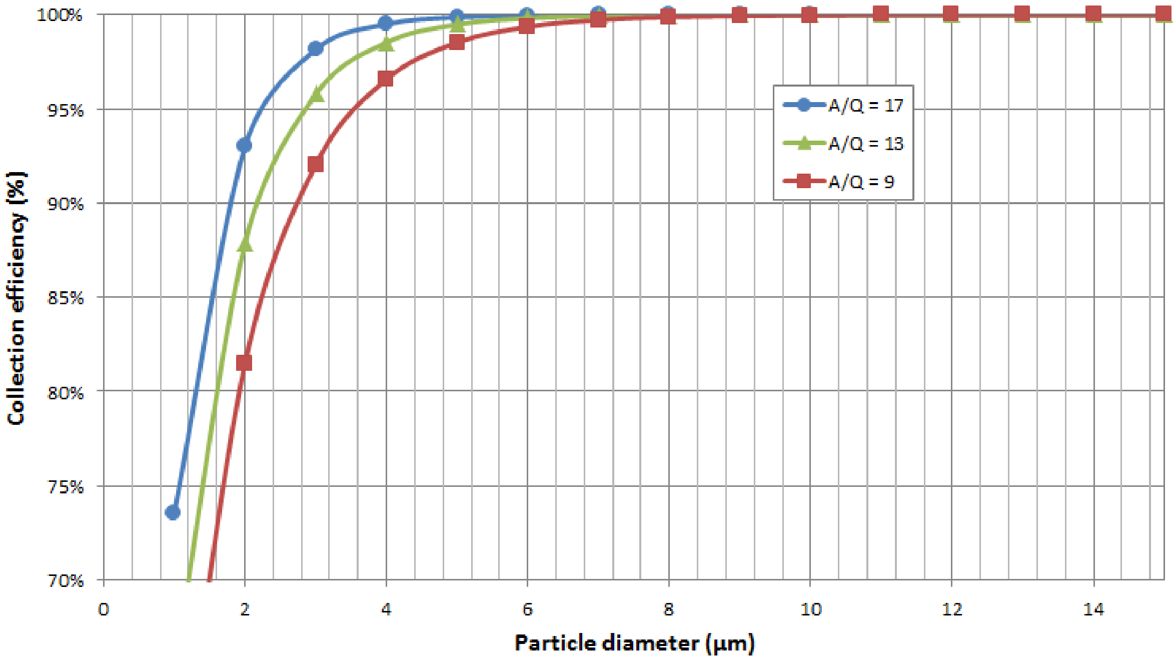
The Sorbacal® SPS material used for this trial had a $d_{50}$ of 10 (µm) making it very well suited for ESP applications. During the development of Lhoist's Sorbacal® SPS, adverse consequences of $d_{50}$ < 10 (µm) were identified such as problems with handling of the sorbent material, difficulties in the dosing silos and injection equipment, and higher potentials for clogging and caking in the duct work combined with increased ESP particulate emissions.

For the lower range of particle sizes, the efficiency of an ESP is a function of the design and operation of the unit. However, in general, the ESP particle collection efficiency starts to be impacted by particle size below 8 - 9 (µm)[7,11]. The $d_{50}$ of the enhanced calcium sorbent is designed at a range 6 < $d_{50}$ < 12 (µm) which is a good balance between high $SO_2$ removal performance, dispersibility and mass transport, powder flow behavior, and ESP compatibility. In the Sorbacal® manufacturing process the particle size can be tuned.

The effect of particle size on ESP collection efficiency can be modelled using equations (1) and (2) which are illustrated in Figure 8. Three different effective collection area to gas flow ratios (A/Q) are modeled against increasing particle diameter. This figure demonstrates how ESP collection efficiency decreases as the particle size are reduced when the effects are more pronounced at lower A/Q ratios.

The modeled results are in agreement with those reported in the literature where the detrimental effect of smaller particle sizes, in the range of 1 to 5 (µm), is widely reported[12,13]. Note that the shape of the curve based on idealized equations will differ slightly from those based on more complex modified Deutsch-Anderson equations; however this does not alter the fundamental relationship between particle size and ESP collection efficiency.

**Figure 8: Effect of particle size (µm) on ESP collection efficiency (%), modelled using equations (1) and (2) for different area to gas flow ratios (A/Q) of 17 (●), 13 (▲) and 9 (■).**




In the above example, the average $d_{50}$ of Sorbacal® SPS is 10 (µm) which corresponds to high ESP collection efficiency approaching 100%. In contrast, if the average $d_{50}$ is reduced to 3 (µm), for example, then ESP collection efficiency drops to values between 92 to 98% depending on the A/Q ratios. This falls within the reported typical range of ESP collection efficiency of 80 to 99% associated with particulates with $d_{50}$ *of* 3 (µm)[14,15].

The three key parameters discussed above are important for long term DSI applications, both in reliability and efficiency. These parameters are strongly influenced by sorbent particle size as well as $SO_2$ removal efficiency and resulting ash resistivity. Therefore, it is important to have a sorbent that is optimized not only for $SO_2$ removal performance but balance of potential plant impacts.

## SUMMARY

DSI for $SO_2$ control to meet future Regional Haze compliance at a 200 MW PRB coal fired facility at Great River Energy's Stanton Unit 1 was successfully demonstrated as described in this report with the use of Lhoist's enhanced hydrated lime, Sorbacal® SPS. Most notably, Sorbacal® SPS injection had acceptable impact on balance of plant and fly ash properties during normal operation that presents an attractive $SO_2$ compliance solution for plants with ESPs.

The enhanced hydrated lime sorbent has been specially developed for ESP compatibility to maintain the combined fly ash mixture resistivity within the optimal range. This was proven in both East and West ESPs at Great River Energy's Stanton Unit 1. This clearly demonstrates that enhanced calcium hydroxide sorbents can be used compatibly with ESPs but, as with any plant operational changes, system optimization and review of balance of plant will be required.

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## KEYWORDS

Dry sorbent injection, Calcium hydroxide, Sulphur dioxide, Electrostatic precipitator, Resistivity