DUST RESISTIVITY MEASUREMENTS FOR INDUSTRIAL PROCESSES

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INTRODUCTION

Electrostatic precipitators (ESPs) have been a "workhorse" of industry processes, for fly ash and dust collection for over a century. Many existing sites have operating ESPs that are in the range of 20-40 years old. These ESPs were designed to achieve particulate emissions between 30 and 200 MG/NM3, depending on age. Current legislation has become more stringent, and typically requires particulate emissions in the 10 to 50 MG/NM3 range. Each industrial process will have different dust chemistries, flue gas temperatures, and flue gas surface conditioning. In order to design ESPs, engineers must be able to predict the dust resistivity that will be encountered during ESP operation. This paper discusses past measurements on dusts for many of these processes.

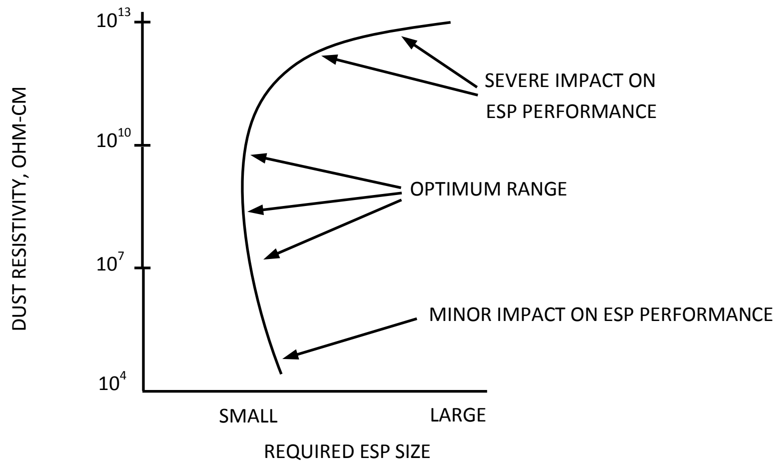
RESISTIVITY DEFINITION

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 electrostatic precipitators (ESP), resistivity levels 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. This 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. Then there is no 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 0.75-1.0 M/S range, if high carbon particles are to be collected.

These resistivity levels typically result in ESP performance impacts as shown on Figure 1, on the following page:

Figure 1

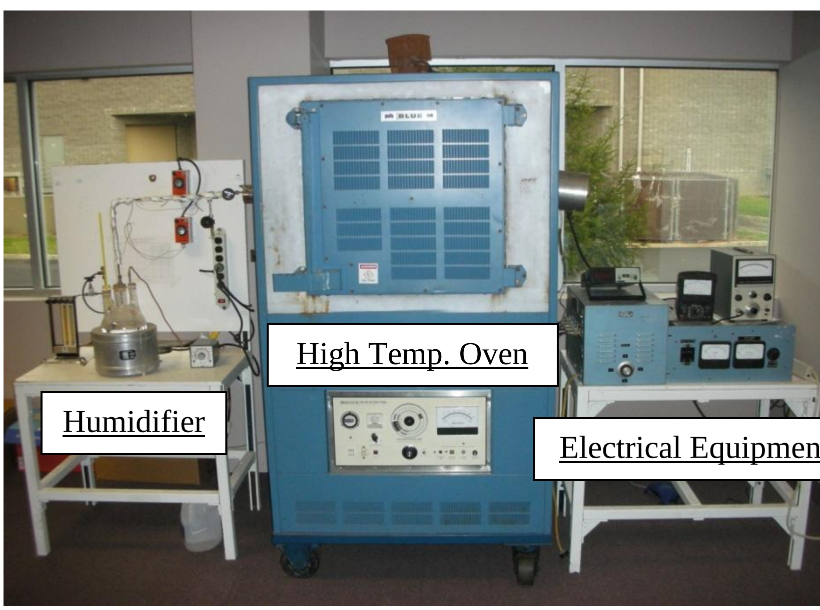


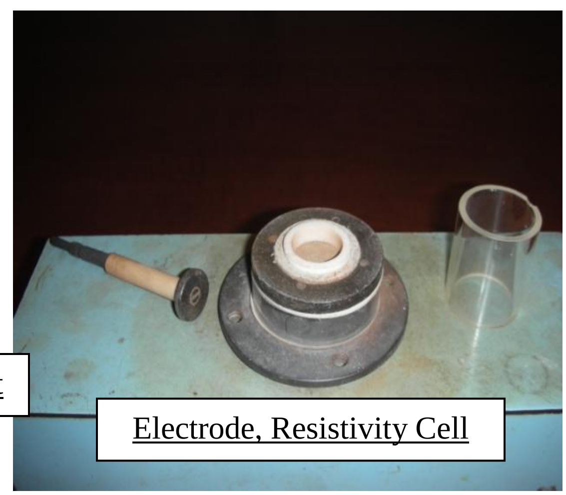
The standard test procedure for resistivity was in accordance with IEEE-548, Standard Criteria for the Laboratory Measurement of Fly Ash Resistivity. The apparatus used for the testing is a custom built arrangement utilizing a high temperature oven, a controlled temperature water bath for gas humidity adjustment, a DC power source, and an electrometer for current flow measurement (Picture shown below);

Resistivity values are calculated from

$\rho = (V/I) \times (A/L)$ where

ρ = resistivity, OHM-CM
V = applied voltage, Volts
I = measured current, Amperes
L = Ash thickness, cm
A = current measuring electrode face area, cm^2



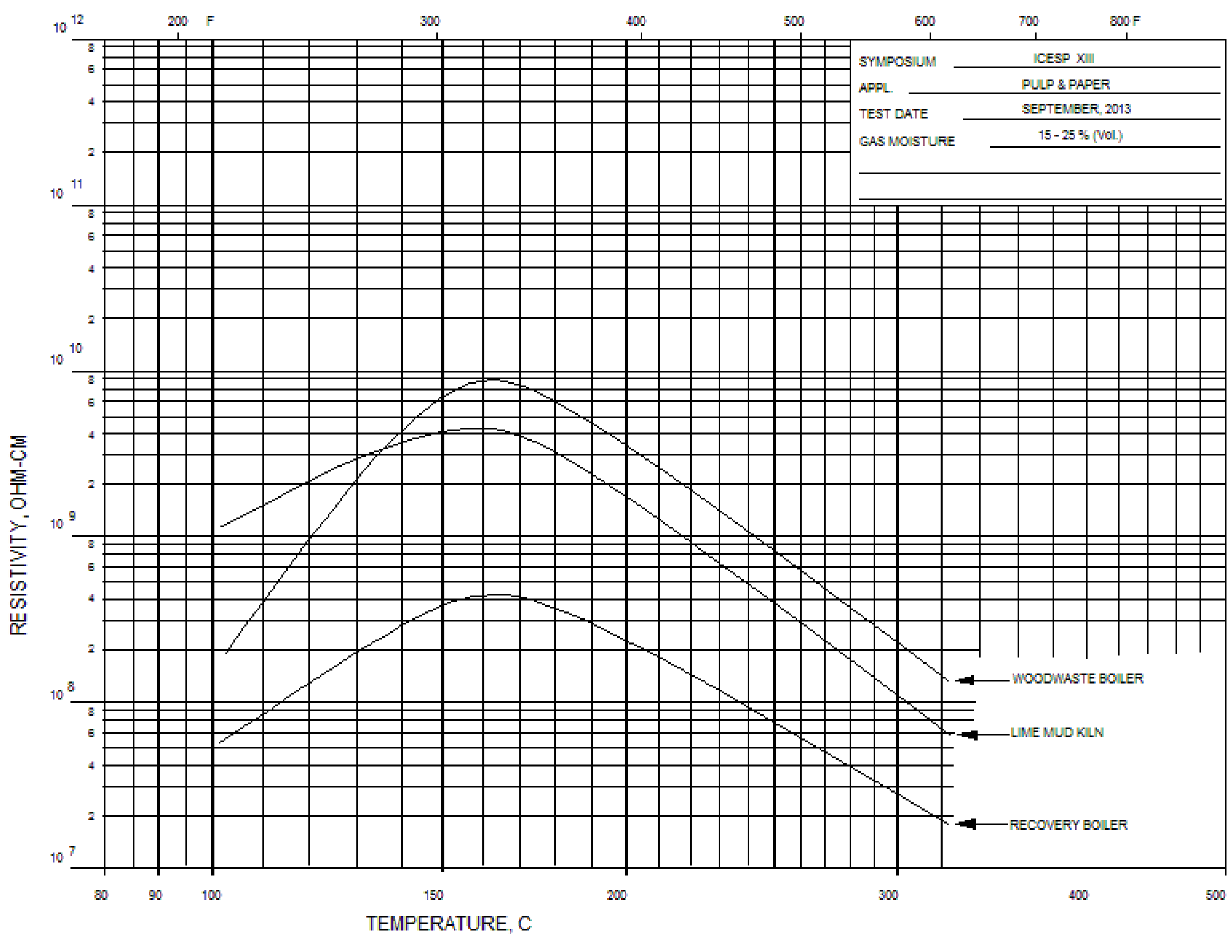


RESULTS – PULP AND PAPER

There are typically three types of ESPs encountered in the pulp & paper industry. These are on the recovery boiler, the lime mud kiln (not to be confused with cement or lime kiln, which does have a high resistivity), and the woodwaste boiler. Both the recovery boiler and lime mud kiln dust contain high levels of conductive sodium, and high levels of flue gas moisture. Therefore, recovery boilers and lime mud kilns have low resistivities.

Also shown on Figure 2 is the resistivity for a "woodwaste boiler". This shows a low resistivity, which results from high levels of carbon in the fly ash, and high flue gas moisture levels from burning high surface moisture fuel and high hydrogen containing cellulose. Care must be taken in that sometimes these boilers become "combination boilers", which can fire pulverized-coal. If low sulfur coal is P-C fired, the resultant resistivity can rise to difficult levels. As a second note, sometimes the logs are floated in salt water and contain high levels of NaCl. This has not been observed to change resistivity significantly, but does greatly impact the particle size distribution coming to the ESP (i.e. the particle size of NaCl particles is very fine and more difficult).

Figure 2 – Wood Waste Fly Ash Resistivity

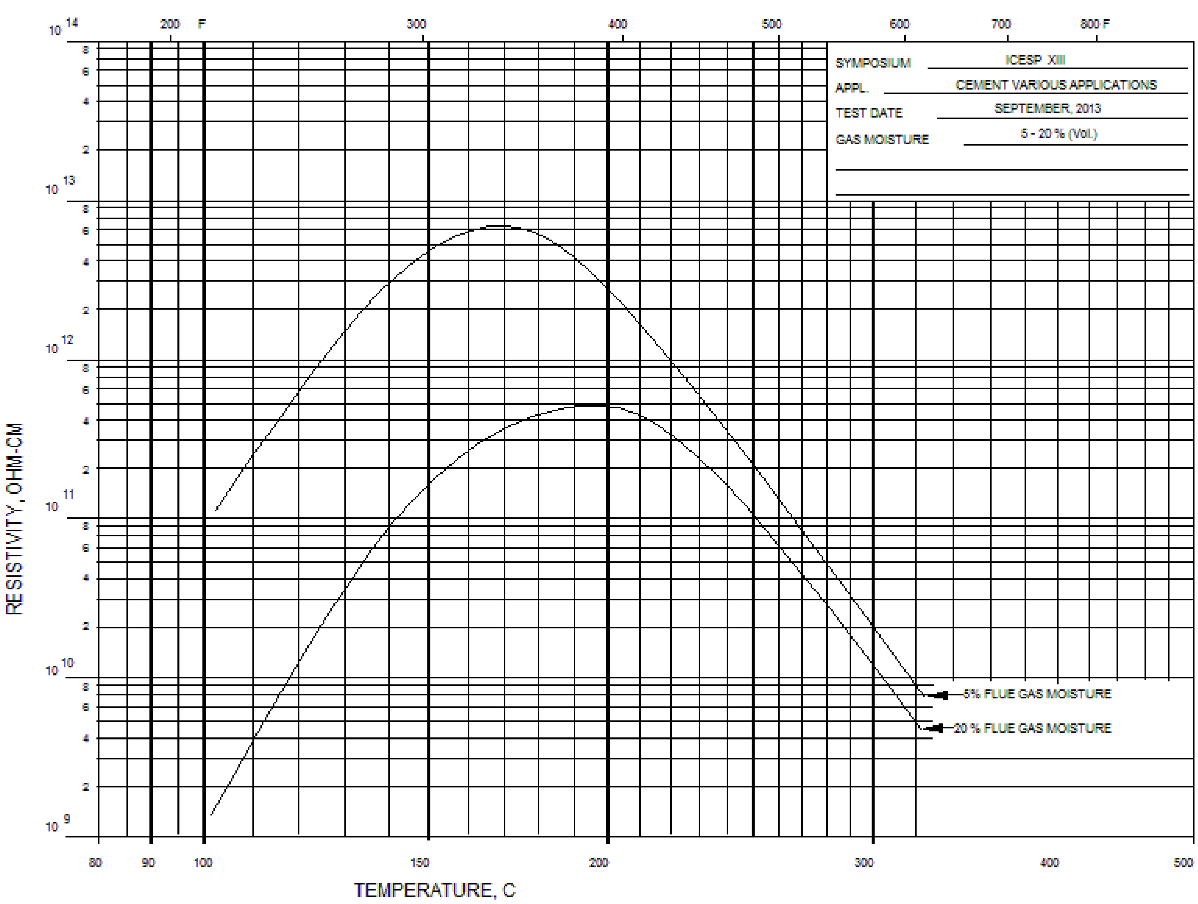


RESULTS - CEMENT

There are a number of locations where ESPs are used in the cement industry. These include grinding operations for raw material, rotary kilns, clinker cooler and finish mill. All of these applications contain calcium bearing materials, with lesser quantities of other materials (a good portion of this other content can be silica and alumina, which are both di-electrics). The most common calcium species would be limestone, $CaCO_3$, and lime CaO. In general these calcium bearing processes are all high in bulk resistivity, when in a dry atmosphere. The cement manufacturers do not like sodium oxide in the cement, as sodium is water soluble and weakens the cement. So we cannot rely on sodium as our conductive element in bulk conduction.

We must rely on temperature or flue gas moisture to control resistivity down to acceptable levels for electrostatic precipitation. Some typical values of resistivity for these calcium bearing materials are shown below on Figure 3, but certainly there is considerable variation from site to site. Values up into the 5E13 OHM-CM range have been observed in the worst cases, with low moisture contents. This will depend on cement chemistry, kiln fuel chemistry, and flue gas temperature/moisture. However, ESPs are operated either with high moisture, >15 % (Vol.), or if moisture is low at high temperature, >280 C.

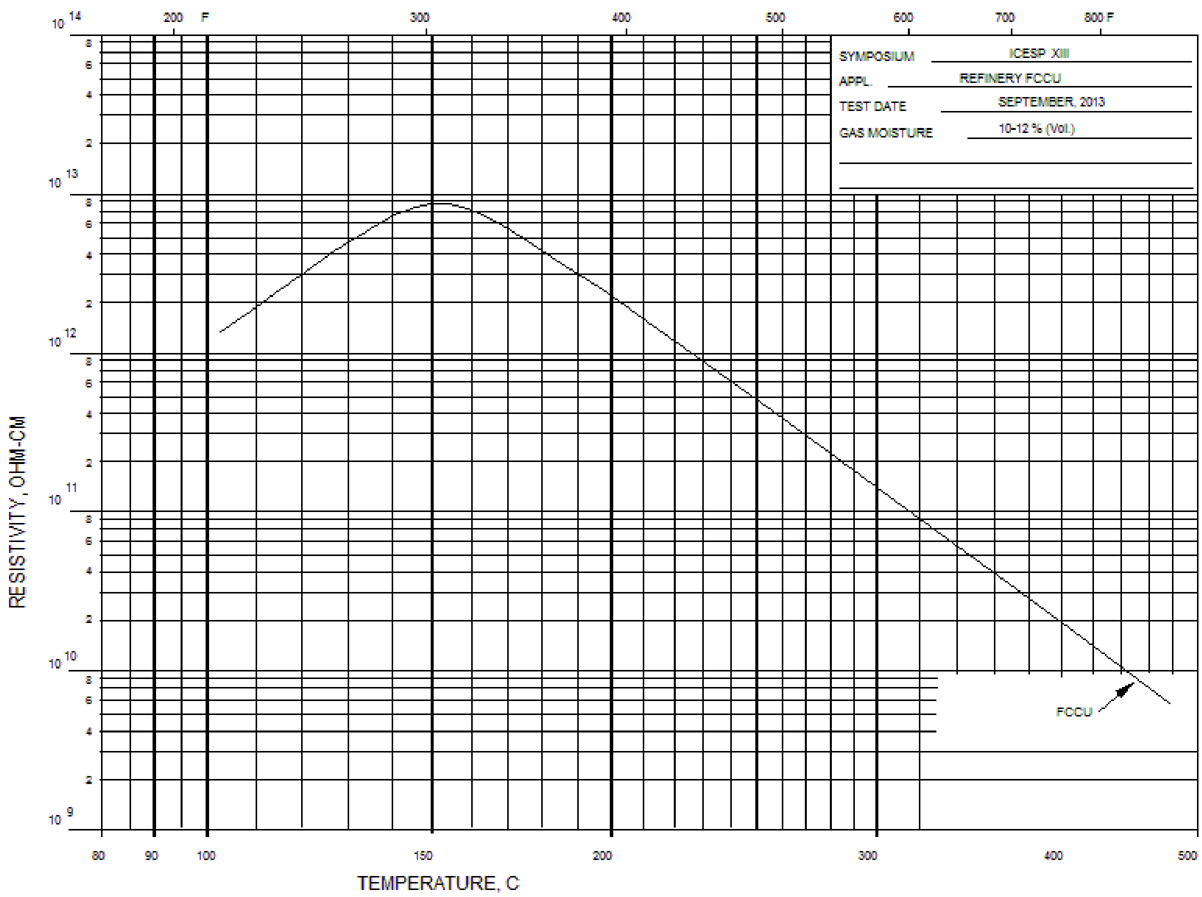
Figure 3 – Cement Dust Resistivity



RESULTS - FCCU

In the petroleum refining industry, there is often an ESP placed on the exhaust from the catalytic cracking unit regenerator. This ESP must collect dust that is 99% silica plus alumina. Depending on the flue gas temperature and unburned carbon left on the catalyst fines, the resistivity can be quite high (note that there is approximately 10-12% moisture in the flue gas, coming from the combustion of oil). A typical resistivity plot for this application is shown below on Figure 4;

Figure 4 – FCCU Dust Resistivity

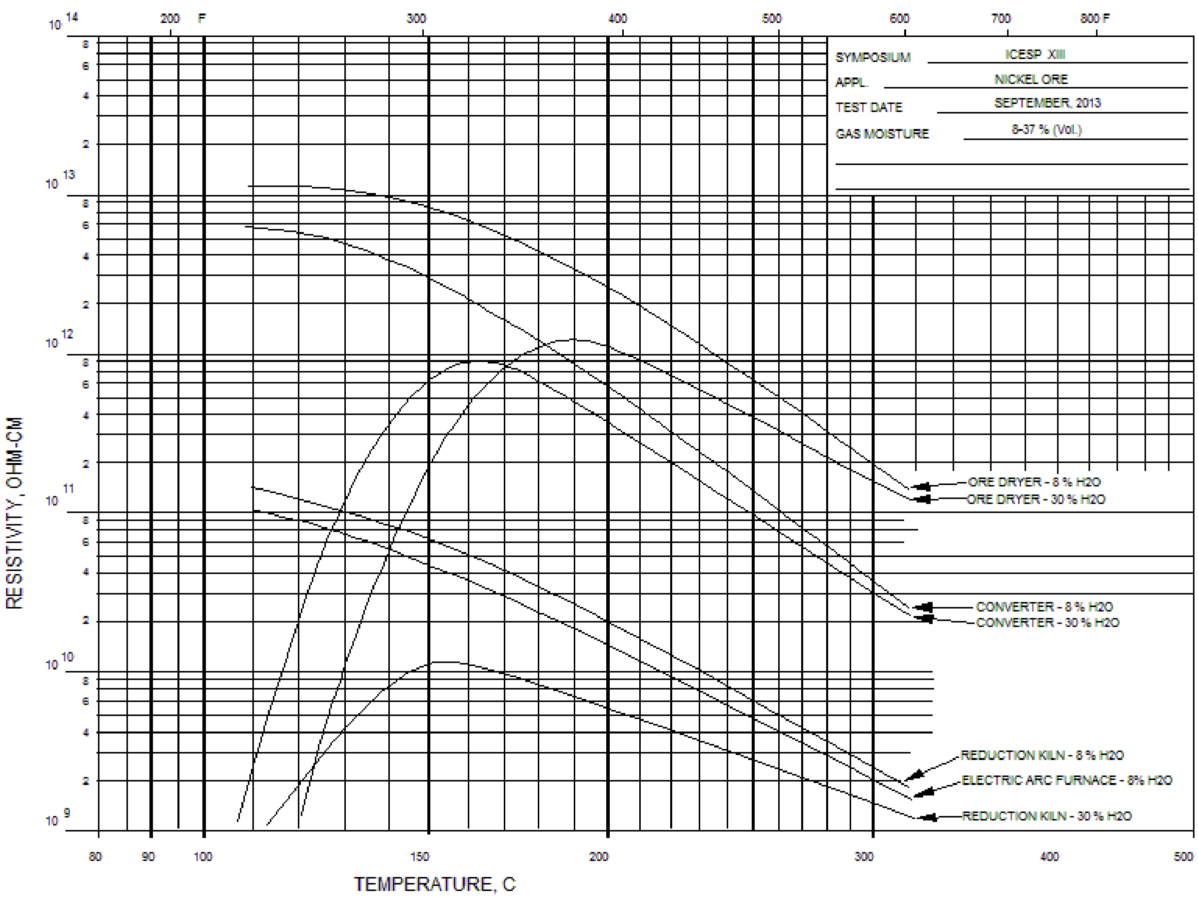


For many years, ESP suppliers were able to take advantage of temperature impacts on resistivity. ESPs were operated in the 300-400 C range, and dust resistivity was in the 1E10 range. However, in recent years the refineries have been driving down on back end temperatures to save energy. ESP performance sometimes suffers severely from high resistivity, in these cases. The standard remedy for high resistivity problems on FCCU is to install ammonia injection, which is quite effective in correcting a resistivity problem. It is recommended that if new ESPs are to be installed in the range of 200-250 C, that ammonia injection ports or probes be installed, to be conservative.

RESULTS - NICKEL ORE

Although nickel ore refining sites are less common than some other processes, they rely heavily on ESPs for dust collection. Within a nickel refining facility, the ore (which typically only contains 2-3 % nickel), is refined to higher and higher purities. As shown on Figure 5 below, the ore itself with low moisture content exhibits a high resistivity, 1E13 OHM-CM. Thus we must rely on high flue gas moisture levels to condition the dust for ESP collection. At the end of the process is the electric arc furnace, which typically is very difficult for an ESP due to low flue gas moisture content. However, in this case the dust itself was high enough in metal purity to be somewhat conductive, 1E11 OHM-CM.

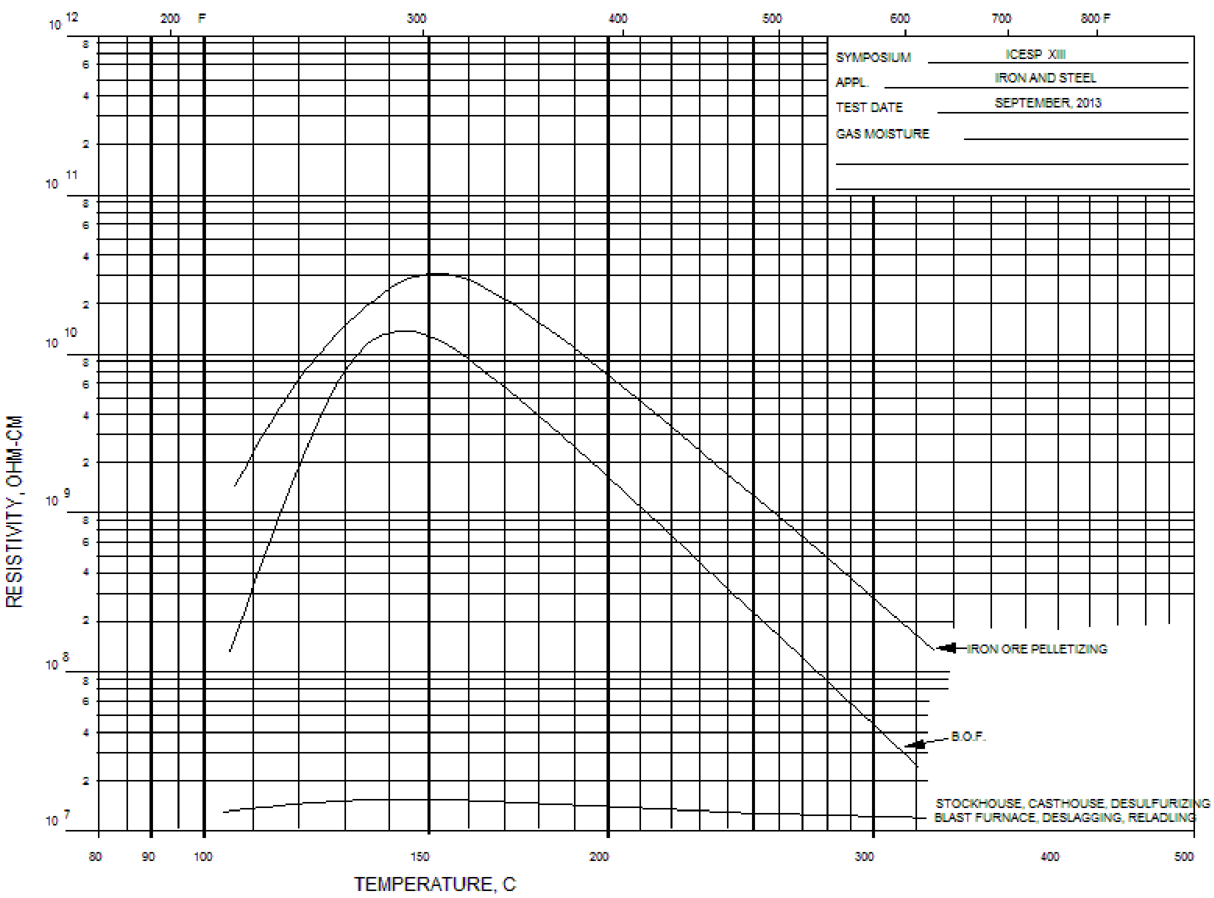
Figure 5 – Nickel Dust Resistivity



RESULTS - STEEL

There are many types of processes in the manufacture of steel that use ESPs. These start with iron ore pelletizers at the mines and end with steel making processes. Generally speaking, iron oxide is not high in resistivity. Only in processes such as sinter, where we add limestone, do we get into severe resistivity situations. The graph below, Figure 6, shows many of the processes which we have tested in the past. These show good resistivities in all cases where we are dealing with iron oxide. Note that there are about six processes that were lumped together at the bottom of the graph, as having resistivities in the range less than 1E7 OHM-CM.

Figure 6 – Iron and Steel Dust Resistivity

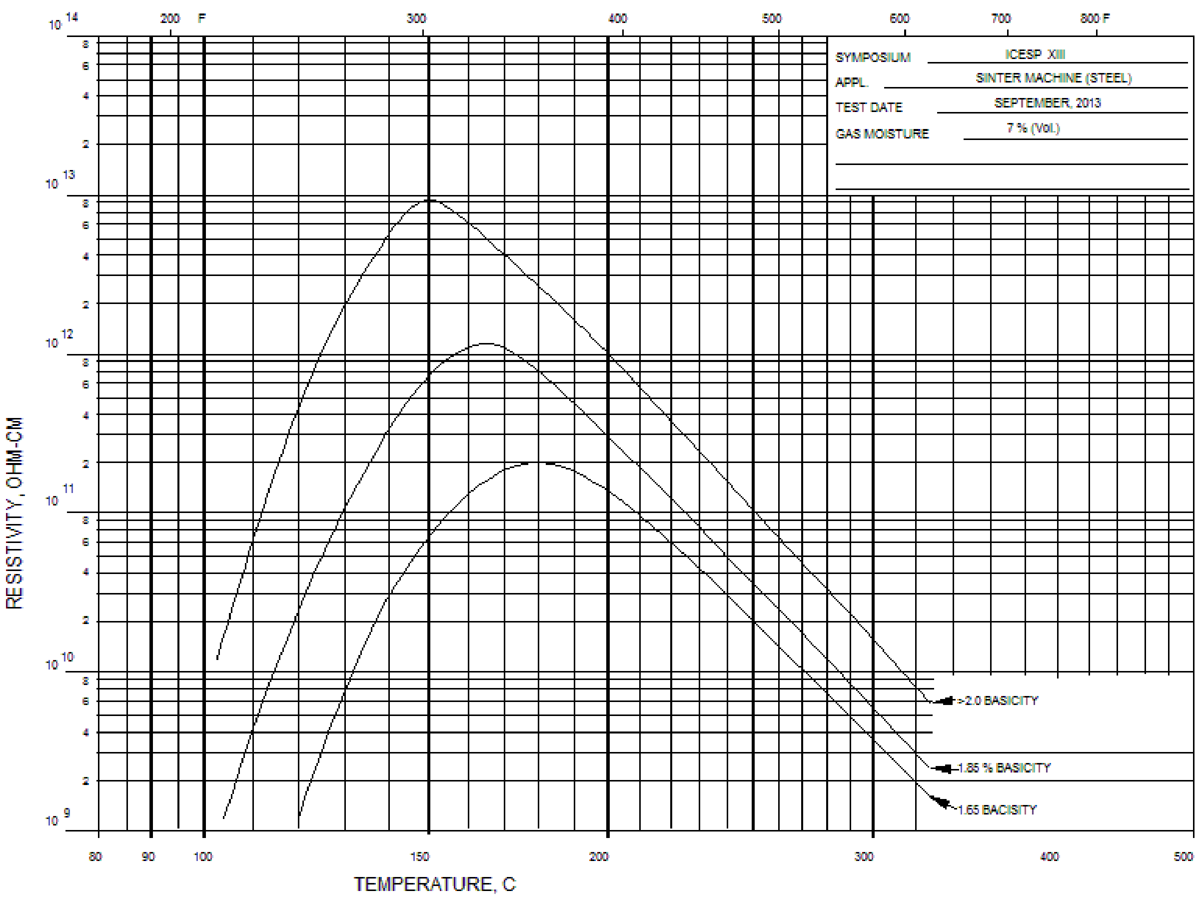


ESP problems with high resistivity dusts from sinter machines, is a completely different story. In the sinter machine, the iron ore is combined with limestone, $CaCO_3$. As was discussed in the cement section of this report, limestone is a high resistivity material. Compounding the problem is the very low flue gas moisture content of sinter machines. These combine to create a difficult resistivity for ESP. The exact extent of the difficulty is often related to the mix of the iron ore to limestone. The operators of these machines use a parameter called basicity, which is a measure of the ratio of limestone to iron ore;

$$\text{Basicity} = (CaO + MgO) / (SiO_2 + Al_2O_3)$$

If the basicity value is higher, it means that there is a greater ratio of limestone to iron ore in the mix. The range of basicity has been observed in the past to vary from about 1.6 to 2.2 (this is a unit-less number). Very good basicity (from a resistivity perspective) is in the range of 1.6 to 1.7 and very poor basicity is in the range of 2.0 to 2.2. Resistivities have been as shown on Figure 7;

Figure 7 – Sinter Dust Resistivity

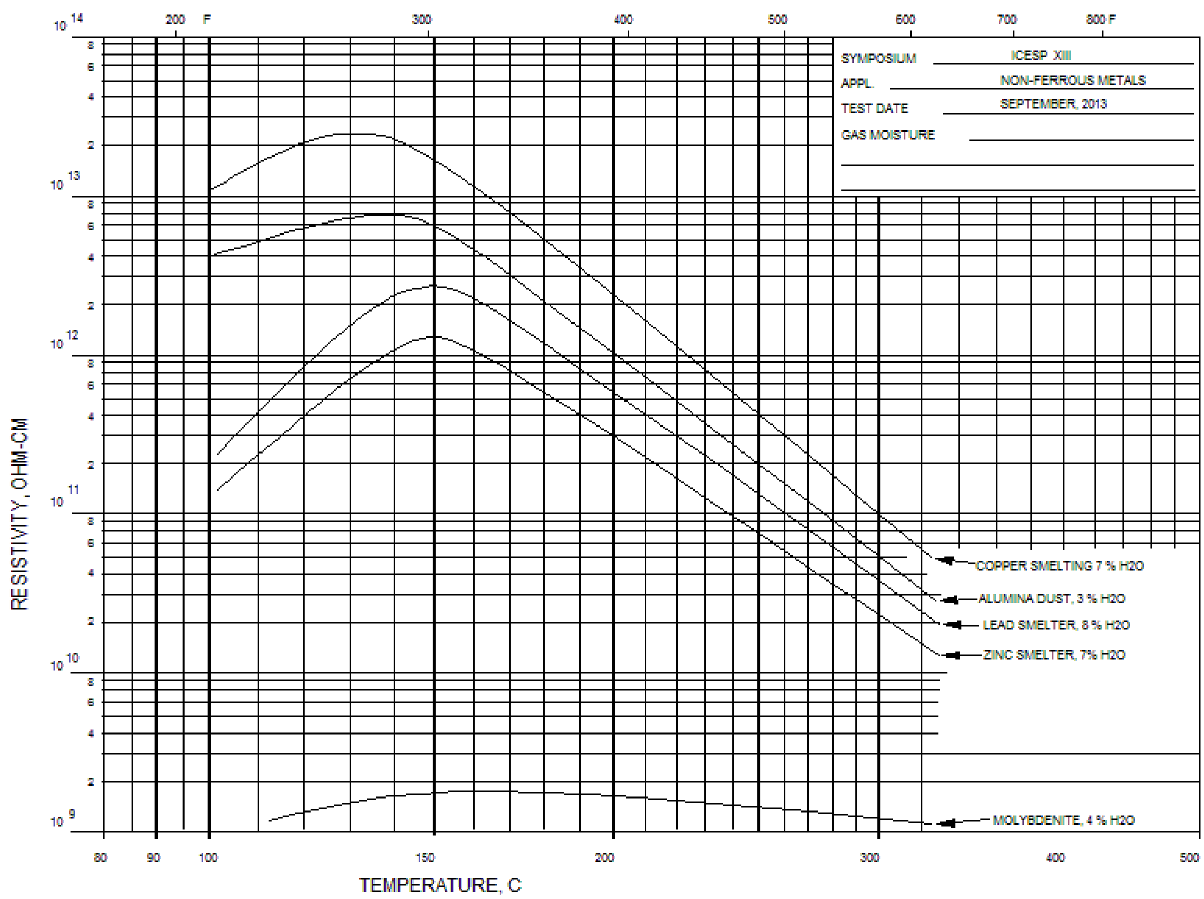


In the case of sinter machines, there is one other problem that can occur with these ESPs. If the process raw material has an incoming stream of NaCl, and no bleed of NaCl from the system, then the ESP stack can become the NaCl process bleed from the system. This will occur as the NaCl builds up in a recycle from sinter machine to ESP hoppers and back to the sinter machine. To prevent this problem, the steel process must have a NaCl bleed equal to the NaCl incoming stream. This typically can occur by dumping part of the ESP hopper catch, rather than returning it all to the process.

RESULTS - MISCELLANEOUS AND NON-FERROUS METALS

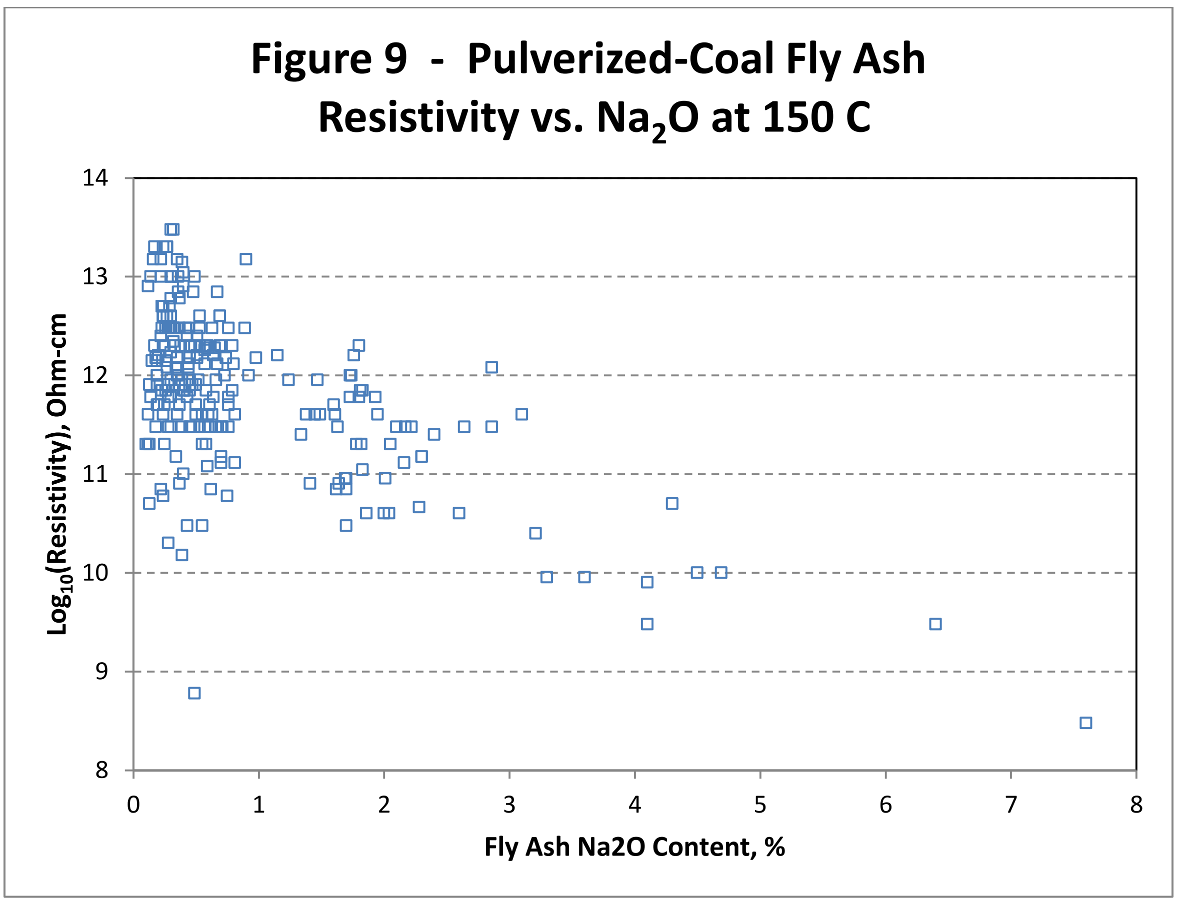
There is a wide range of less common processes that use ESPs. Many of these are metals smelting processes. It is interesting to note that even though the pure metals themselves might be quite conductive, when they are in an oxidized or sulfate condition they can be quite high in resistivity. The curves below have all been shown with low flue gas moisture contents. Almost all these oxides (other than molybdenite) exhibit a high bulk resistivity. It is standard practice in installing ESPs on these applications, that either the flue gas moisture must be high or the temperature must be high. There is a second issue with many of these applications that causes the use of high temperature ESPs. Many of these ores contain high levels of sulfate. In those cases, low temperature operation would have extreme corrosion problems. Therefore, these high sulfate ores are processed with ESPs up in the 350 C range.

Figure 8 – Non-Ferrous Metals Dust Resistivity



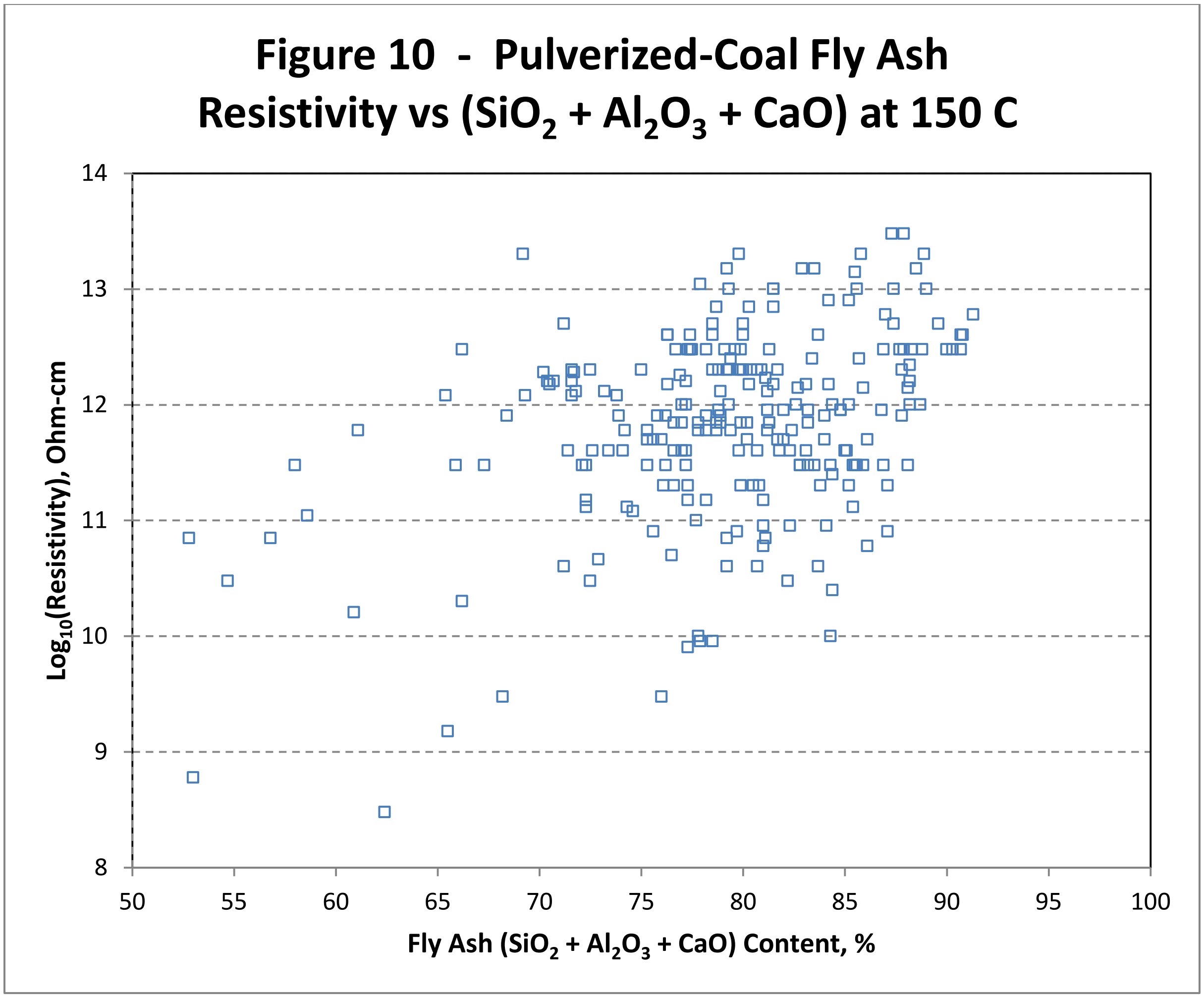
RESULTS - PULVERIZED COAL

Fly ash resistivity for pulverized-coal fired boilers is such a broad subject, that a comprehensive discussion is impossible in this short paper. Some high carbon containing fly ashes exhibit bulk resistivities in the 1E5 OHM-CM range. Some severe low sulfur coals exhibit resistivities in the 5E13 OHM-CM range. However, the following two figures show what we have found to be the primary two factors in predicting the resistivity of coal fly ash (excluding the presence of high carbon in the ash). Figure 9 shows the impact of sodium oxide content on fly ash resistivity;



This graph shows that primary conductive species is sodium oxide. The data shows a general trend toward higher resistivity as sodium oxide gets lower. Care must be taken here so that, what constitutes a severe low level of sodium oxide, changes, depending on the geography of the coal source.

Additionally Figure 10 below shows that as the di-electric content (silica plus alumina plus CaO) gets higher, the fly ash resistivity gets higher. In our studies, looking at silica, alumina, and CaO separately has not shown as high a significance as looking at the sum of their contents.



The prediction of coal fly ash resistivity has been found to be so complicated, that in modern times it is performed using computer programs. These computer programs are held proprietary by the ESP specialists, and are used to size ESPs for new installations.

SUMMARY

ESPs have been used in industry for such a long time that dust resistivity data is available for almost every application. This historical data can be used to reliably size ESPs for new sites. However, resistivity laboratories continue to gather data on dust resistivity, as changes in process technology move the design points for the ESPs.