



FUELS AND FUEL SWITCHING

Although natural gas and oil are used for steam generation and power production, this section focuses on solid fuels, primarily coal.

Various Solid Fuels

Solid fuels of widely varying characteristics and ranks have been used for electric power generation and steam production worldwide. Fuel ranging from refuse derived fuel (RDF) through bagasse, wood waste and wood to peat and various types of coal have been used. Coals are classified by rank into:

- mine waste (culm);
- lignite;
- sub-bituminous and bituminous;
- anthracite; and
- petroleum coke.

This immense variety of fuels can have heating values ranging from under 3,000 Btu/lb (1,600 kCal/kg) to almost 20,000 Btu/lb (11,010 kCal/kg). Ash contents can range from under 1% to 70%. This variation has a major effect on furnace and boiler design as well as on the design of the air pollution control equipment associated with it.

In addition to the effects on fuel handling, equipment preparation, combustion air and burner design, factors in furnace and boiler design which greatly affect air pollution control equipment are exit gas temperature, furnace volume and furnace plan area. Many problems with air pollution control equipment are caused by fuels, which can greatly deviate from that designed for the plant. Changes in fuel or fuel switching may be done for various reasons, but the two most common are fuel cost and the desire to attain a change in exit gas composition or fly ash concentration (grain loadings) to satisfy pollution control regulations.

The necessity for a detailed study, followed by a substantial test run cannot be emphasized enough if fuel changes of any magnitude are being considered. Many major and costly problems can occur with pollution control equipment caused by fuel changes where only a few factors such as sulfur content, ash content or cost were considered and an adequate study not made. In some cases, long-term fuel contracts for unsuitable fuels may have to be broken or modified.

Some of the factors that must be considered are listed below:

1. Gas volume: higher fuel moisture content will increase gas flow to be cleaned. Higher fuel moisture contents will also lower the heating value of the



coal. This would typically require more fuel be fired to achieve the same heat rate in the boiler. This is illustrated in the following two Figures.

Figure 5-1 illustrates the amount of fuel required to maintain a constant heat input to an 800 MW boiler (large boiler) when firing different blends of West Virginia low sulfur coal with a PRB coal.

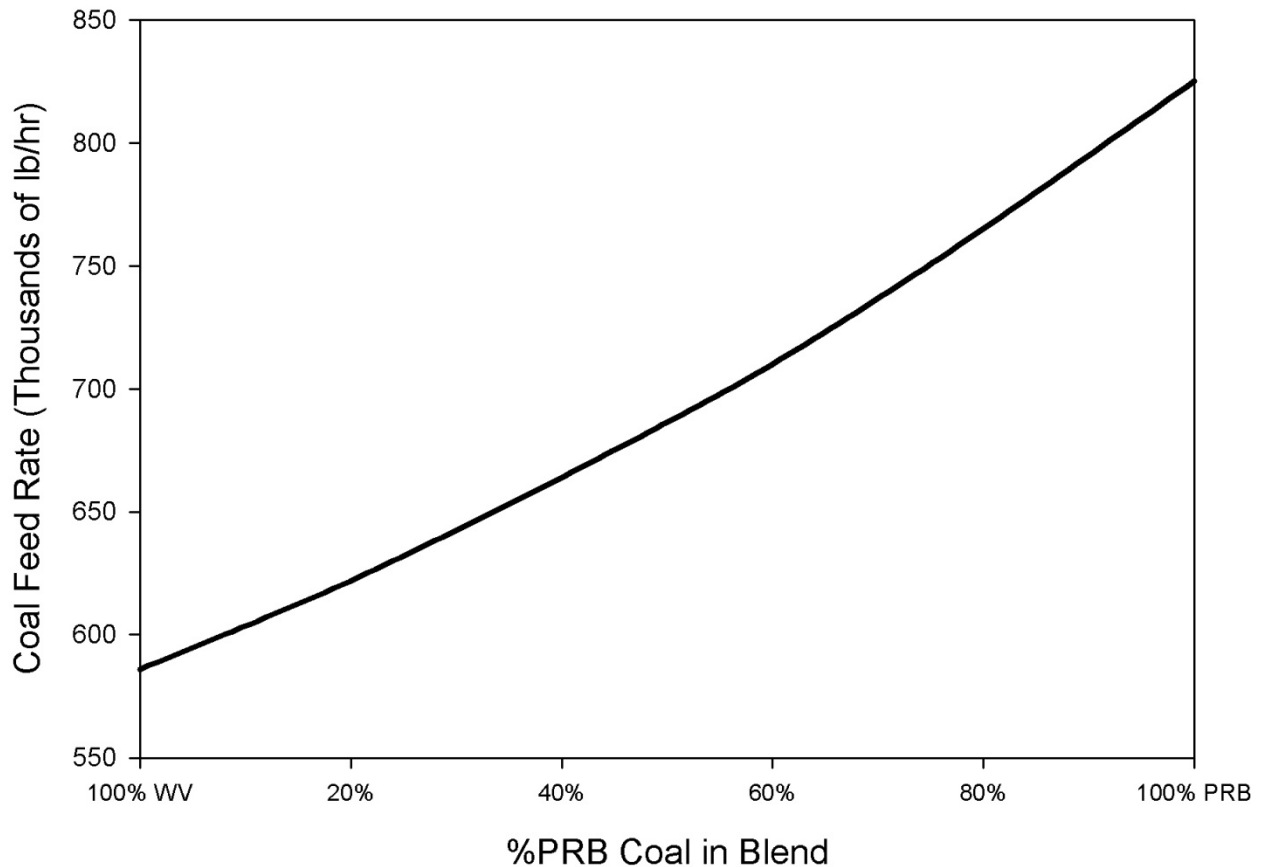


Figure 5-1: Fuel Feed Rates Assuming Constant Heat Input For Various Blends of WV and PRB Coals



Figure 5-2 illustrates the same effect on the gas flow through the boiler train using the same coal blends shown in Figure 5-1.

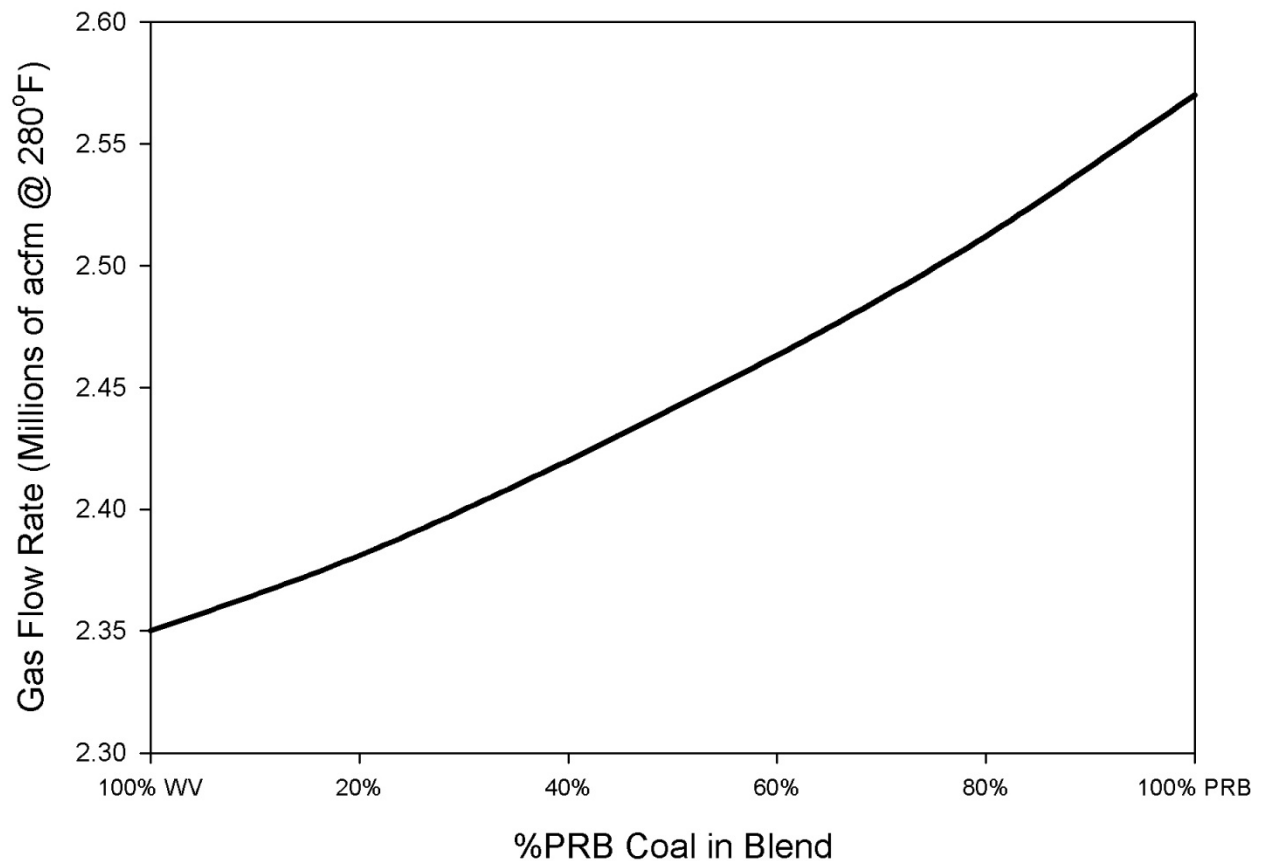


Figure 5-2: Gas Flow Rates Assuming Constant Heat Input For Various Blends of WV and PRB Coals

From the example, a fuel switch from WV low sulfur coal to a PRB coal would cause an increase in fuel feed rates from 293 ton/hr (586,000 lb/hr) to 412.5 ton/hr (825,000 lb/hr). This is a 40% increase in the coal feed rate to maintain a constant heat input to the boiler. This same fuel switch also caused almost a 10% increase in gas flow rates. The higher gas flow rates will affect



precipitator collection efficiency, pressure drops, fan power and overall boiler efficiency.

2. Ash combustible content: a fuel change can result in poor mill performance. Coal fineness of over 0.5% retained on 50 mesh or less than 80% through 200 mesh will cause increased combustible content and poorer air pollution control especially in particulate mass emissions. The use of low NO_x burners or staged combustion will often result in higher combustible content especially in single-wall-fired units and roof-fired units. Tangentially-fired furnaces are less affected. Fuel switching often magnifies these problems especially in the case of marginal furnace volumes. A switch to partial or total firing of a low volatile fuel such as petroleum coke invariably causes problems.

Unburned combustibles can also greatly affect the performance of an electrostatic precipitator. **Figure 5-3** shows typical measured resistivity values for an ash containing a significant amount of unburned carbon.

The differences between the ascending and descending temperature mode data shown in **Figure 5-3** are due to the presence of unburned combustibles in the sample. Between the two test modes, the samples are equilibrated in dry air for 14 hours (overnight) at 850°F. This overnight annealing process typically removes between 60% and 90% of any unburned combustibles present in the samples (note the weight change of -13.9% shown in the data to the right-hand side of the figure).

Exactly how carbon works as a charge carrier is not understood, but it is known to significantly reduce the resistivity of a dust. After removal of the unburned combustibles during the above-mentioned annealing procedure, the descending temperature mode curve shows the typical inverted "V" shape one might expect.

One problem that has been experienced with unburned combustibles is low precipitator current readings at elevated voltages. This same phenomenon has been noted in the laboratory. In the laboratory, no current is measured as small amounts of voltage are applied to the sample. As voltage is increased, a point is reached where current floods through the sample overloading the potentiometer. Sensing an overload, the power supply then automatically switches off.

The same thing is believed to happen in a precipitator. Voltage is typically applied by the controls until either a current limit is achieved or a spark is sensed. The controls apply voltage until onset of corona occurs. However, just as in the laboratory, the onset of corona occurs at higher than normal



voltages. Once corona begins, this higher voltage floods the controls with current, which is sensed as a spark. The controls then back down on voltage. Thus, little or no current is evident on the precipitator readings at relatively elevated voltage levels.

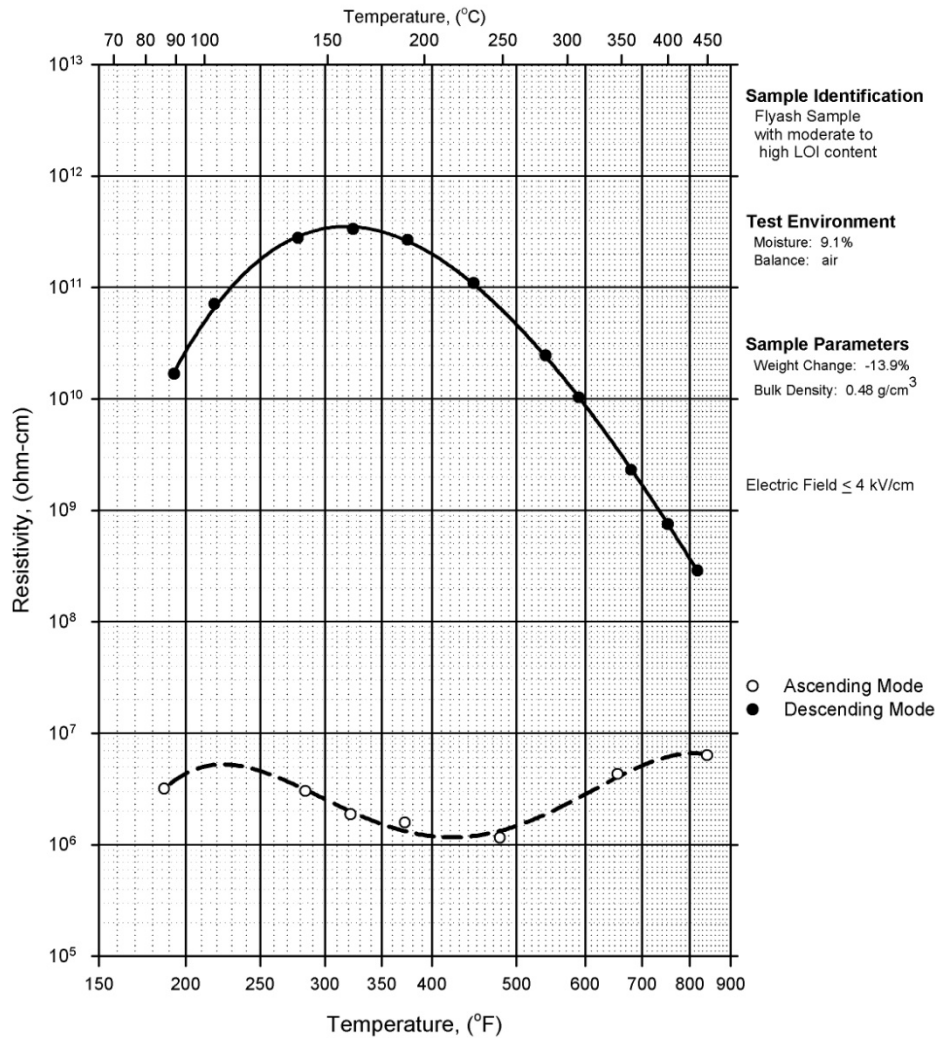


Figure 5-3: Resistivity Measured in Accordance with IEEE Standard 548-1984, Ascending and Descending Temperature Modes.



3. Gas temperature: an increase in gas volume results in an increase in gas temperature and may result in poorer gas temperature distribution.

4. Ash electrical resistivity: Fly ash from solid-fuel-fired furnaces has an electrical resistance to current flow. The magnitude of the resistance is dependent on chemical composition, temperature, ash particle structure and the degree of adsorption of sulfuric acid from the gas onto the particle surface. All of these factors plus others such as ash particle size are all interrelated in an extremely complex manner.

Any change in fuel will probably affect several of these factors and may result in a change in the ash resistivity, either favorable or unfavorable. A computer analysis of the projected resistivity and its application to a mathematical model of the precipitator can assist in evaluating prospective fuels. It must be pointed out, however, that these tools have their limitations and results must be properly interpreted.

Resistivity values higher than 2×10^{10} ohm-cm would be expected to inhibit precipitator performance. Consider a corona-discharge system with a dust layer deposited on the collection electrode. If the dust is a good conductor, there is little or no disturbance of the corona discharge. However, as the dust resistivity is increased, a point is reached where the corona ions begin to be impeded by the resistance of the dust layer. This causes the voltage to increase across the layer and to correspondingly decrease across the gas, with the result that the corona falls somewhat. As the dust resistivity is further increased, the voltage across the layer continues to increase and finally causes dielectric breakdown of the layer.

Depending on conditions, the localized breakdown of the dust layer may either propagate across the corona gap and thus cause a spark, or remain localized and form a stable back corona crater. In general, for dust resistivity values just above the critical value, high corona voltages and currents are required to spark through the dust layer, and complete breakdown of the corona gap ensues. With even higher resistivity values, usually above 10^{12} ohm-cm, breakdown of the dust layer occurs at corona voltages too low to cause a spark to propagate across the entire gap.

Low resistivity values will also cause problems. Resistivity values below 10^8 ohm-cm will not cause sufficient attraction forces to the collecting electrode when permeated by the corona current. Without these attraction forces, the particles will not form a cake on the collection plates. Instead, they will become re-entrained in the gas stream before rapping occurs.



5. Ash content of fuel: All things being equal, an increase in fuel ash content will result in increased opacity and increased mass emissions.

6. Fuel analysis: Do not use the average fuel analysis in forecasting air pollution control equipment performance. A computer program has been developed which utilizes the range of analysis or alternatively the sigma to produce an analysis of the MPWC (most probable worst case) fuel and ash. This covers 99% of the fuel from the stated source, not 50% as the average does. Design for the MPWC.

7. Preliminary screening of fuel: Some fly ash characteristics cause substantial difficulties. A preliminary screening can eliminate some of these. Ash with a combined silica and alumina content of 80% or more produces a high resistivity ash with a non-porous structure above a gas temperature of 300°F. (150°C.). This will be discussed in detail in the next section (General Fuel and Ash Characteristics).

8. Gas conditioning: Conditioning with sulfur trioxide (SO₃) will not work above 350°F. (177°C.) or with high silica high alumina ash. When switching fuel, do not rely on conditioning above these limits. This will be discussed in detail in the next section (General Fuel and Ash Characteristics).

Dual conditioning, with both ammonia and sulfuric acid, can alleviate re-entrainment problems. A “sticky” by-product, ammonium bisulfate, precipitates in the ductwork and is collected in the precipitator. This “sticky” by-product holds the collected filter cake together until it is rapped from the plates and gathers in the hoppers.

When an excess of sulfuric acid vapor is present, ammonia conditioning alone can also help with re-entrainment problems.

With the advent of SCR for NO_x control, other problems may arise. A certain percentage of the available sulfur dioxide will inevitably be converted to sulfur trioxide across the catalyst bed. In many cases, this will be between 0.5% and about 2% of the available sulfur dioxide. In some cases, as much as 3% of the available sulfur dioxide can be converted. Even with a lower sulfur Eastern coal, this amount of SO₃ could cause corrosion problems along with an acid plume problem.



General Fuel and Ash Characteristics

Eastern US High Sulfur or Medium Sulfur Coal

Coals from western Pennsylvania, West Virginia, Ohio, most of Indiana, Tennessee, Virginia and Western Kentucky are generally above 2% in sulfur content and produce ash well suited to collection via electrostatic precipitators.

Ashes from these coals contain a moderate to high amount of iron oxide (Fe_2O_3). Even moderate amounts (greater than about 8%) of iron oxide act like an oxidation catalyst in the boiler converting readily available sulfur dioxide (SO_2) to sulfur trioxide (SO_3). Many of these coals have sufficient sulfur contents and iron contents in the ash to naturally create enough SO_3 for resistivity conditioning purposes. Figure 5-4, illustrates typical resistivity curves as a function of temperature and SO_3 concentration for these types of coals.

At a temperature of 300°F, the resistivity value without any sulfuric acid conditioning in the flue gas would be slightly greater than 10^{11} ohm-cm. Values above 2×10^{10} ohm-cm are considered high resistivity values, which can inhibit the performance of a precipitator.

The predicted flue gas make-up shown on the right of Figure 5-4 suggests a natural SO_3 concentration of 2.2 ppmv. This amount is believed to be conservatively low. However, even this low amount of SO_3 will attenuate the resistivity values for this ash. From the Figure, the curve represented by the right-side-up triangles shows the resistivity values for this ash under the predicted SO_3 concentration. At 300°F, the resistivity value has been attenuated down to 2×10^9 ohm-cm.

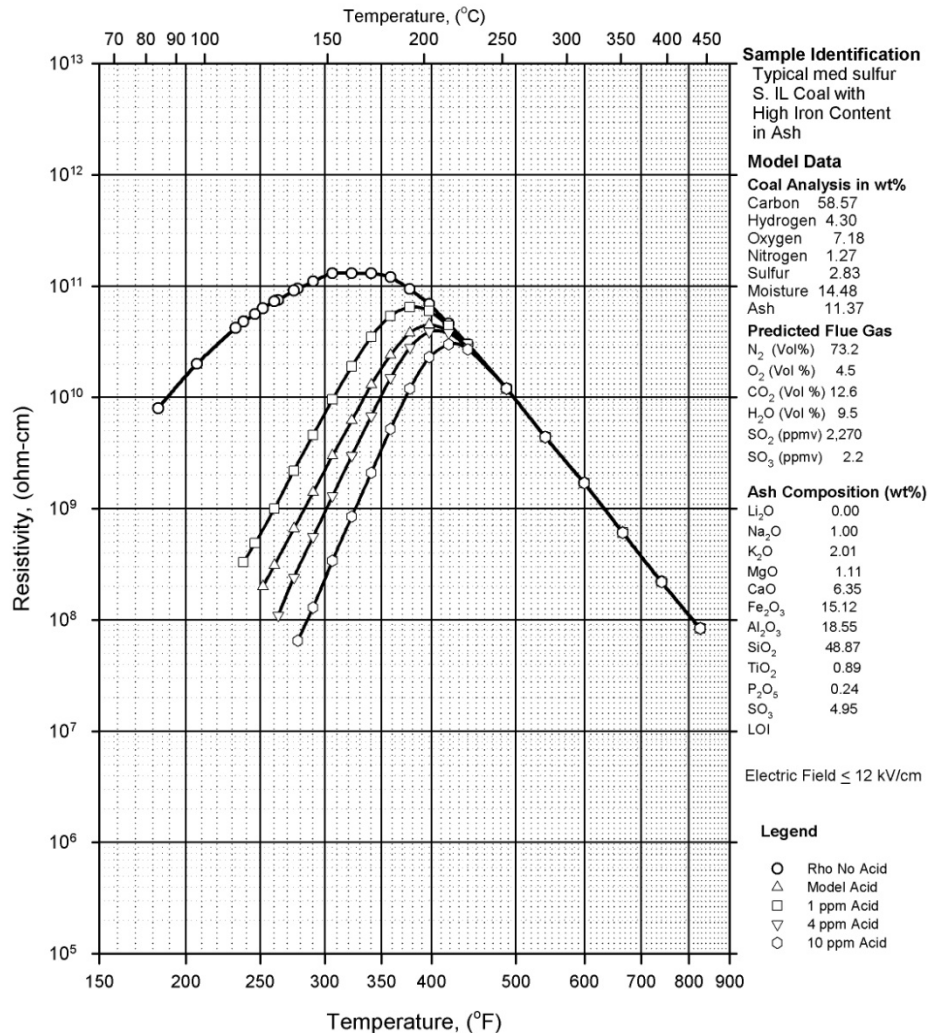


Figure 5-4: Typical Resistivity Curves for High Sulfur or Medium Sulfur Eastern Coals

Eastern US Low Sulfur Coal

Coal from East Kentucky and portions of West Virginia, Virginia and Maryland are generally 1% sulfur or less and tend to exhibit moderate to low iron contents in their ashes. As previously discussed, iron is a major catalytic constituent in converting natural SO₂ to SO₃ in the boiler. It also has the property of enhancing acid conditioning in the precipitator.



With lower sulfur and ash iron contents, only 1.9 ppmv of SO₃ is predicted as being naturally produced by this fuel. Iron also affects the slope of the resistivity curves in Eastern low sulfur coal ashes. As can be noted, the slopes of the acid curves shown in Figure 5-5 are almost vertical with respect to temperature. This type of ash is considered to be unconditionable with respect to SO₃.

The main reason for this is the narrow temperature region where SO₃ conditioning will attenuate the resistivity values. At the outlet of a rotating air heater, the flue gas temperature can easily vary 50°F from one side to the other. For the curves shown in Figure 5-5, more than 10 ppmv of SO₃ would have to be present for acid conditioning to enhance the resistivity at 300°F. This curve is represented by the hexagonal symbols.

On the cold side of the duct, the temperature may be as low at 275°F. At temperatures below this, the duct will be below the acid dewpoint for this concentration. This means that any more than 10 ppmv of SO₃ in the gas will condense into an acid mist and cause corrosion problems. At the other side of the duct, the temperatures may reach 325°F. The resistivity values on this side of the precipitator will be above 10¹¹ ohm-cm, causing high resistivity problems.

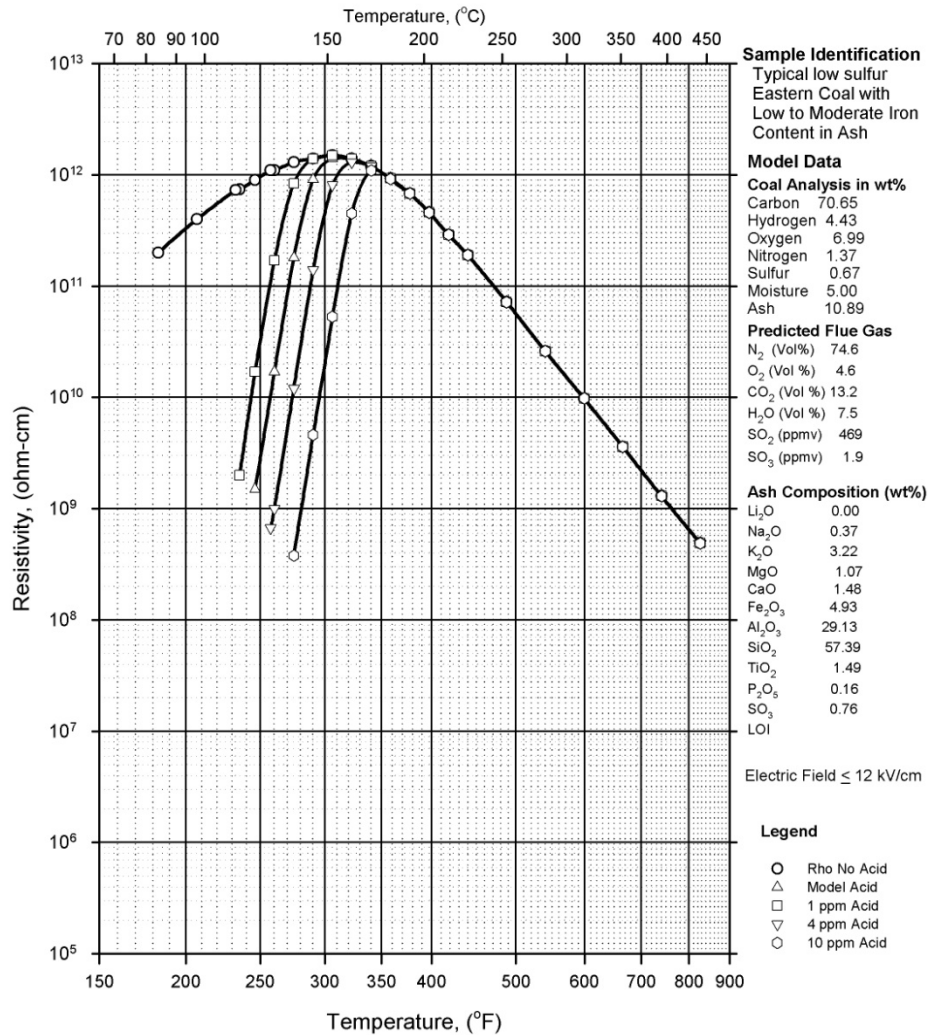


Figure 5-5: Typical Resistivity Curves for Low Sulfur Eastern Coals with Low to Moderate Iron Contents in Their Ashes

Western US, Powder River, Hanna Basin and Montana coal. Sub-bituminous

These fuels have lignitic ashes with high lime and magnesia contents. Their ashes will also typically have higher sodium contents than their Eastern counterparts. The fuels will generally have high moisture contents.



Electrical conduction through an ash layer (on a precipitator's collection plates) is believed to be ionic in nature. The lighter cations (lithium and sodium) are believed to control this conduction mechanism. Lithium is only a trace element in most coal ashes, so sodium is therefore the main ion of concern.

With higher sodium concentrations in the ash, all resistivity curves are lowered. This can be noted when comparing the resistivity curves without SO₃ conditioning between **Figure 5-5** and **Figure 5-6**. The resistivity values at 300°F drop from 10¹² ohm-cm to 3 x 10¹⁰ ohm-cm between the two figures.

The peaks of the curves also shift to the right (to a higher temperature). This is caused by the increase in concentrations of calcium and magnesium in the PRB ash and follows with the general ionic theory of how the conduction mechanism works.

At higher temperatures, above 500°F, electrical current is believed to be volumetrically conducted through an ash layer. This phenomenon is described as volumetric conduction and is noted as a straight line on the figures in this temperature range. As the temperature falls below about 450°F, a layer of moisture is physically adsorbed onto the surface of the particles. Current then begins to flow over the surfaces of the particles.

The higher concentration of alkali metals (sodium) and alkali earth metals (calcium and magnesium) in PRB coals enhances the physical adsorption of the layer of moisture onto the particle surfaces. The conduction of electricity across this layer is enhanced by the addition of sulfuric acid to the flue gas. This augmentation is an equilibrium reaction between the gas phase and the layer of moisture/acid that is adsorbed onto the particle surfaces.

This explains why, with low iron concentrations in the ash, the acid conditioning curves for western coals show attenuation with SO₃. Another effect is the gradual slope of the acid conditioning curves. This means that acid conditioning will be effective across a broad temperature range for these coals.

The higher alkali earth metal (magnesium and calcium) concentrations may, however, not be such a panacea for acid conditioning. Another problem that can occur is the fact that the layer of physically adsorbed acid and moisture must remain in equilibrium with the gas. The alkali earth constituents within the ash will preferentially react with the layer of acid to form calcium sulfate (gypsum). This chemically reacted acid is no longer available for resistivity conditioning. Gypsum will also require a water of hydration, trying to dry the particle surface. This effect can actually raise the resistivity values when the dust layer is under-conditioned.



From this, greater conditioning feed rates may be required for resistivity attenuation than shown in **Figure 5-6**. The injection feed rates should be correlated with actual equilibrium concentrations measured at the precipitator outlet. Otherwise, acid conditioning may actually cause the reverse of the desired effect. It may take a theoretical injection rate of 8-10 ppm SO₃ to reach an equilibrium concentration of 2 ppm at the precipitator exit. Currently, the only accurate and reliable method of determining the SO₃ concentration in flue gases is the controlled-condensation technique.

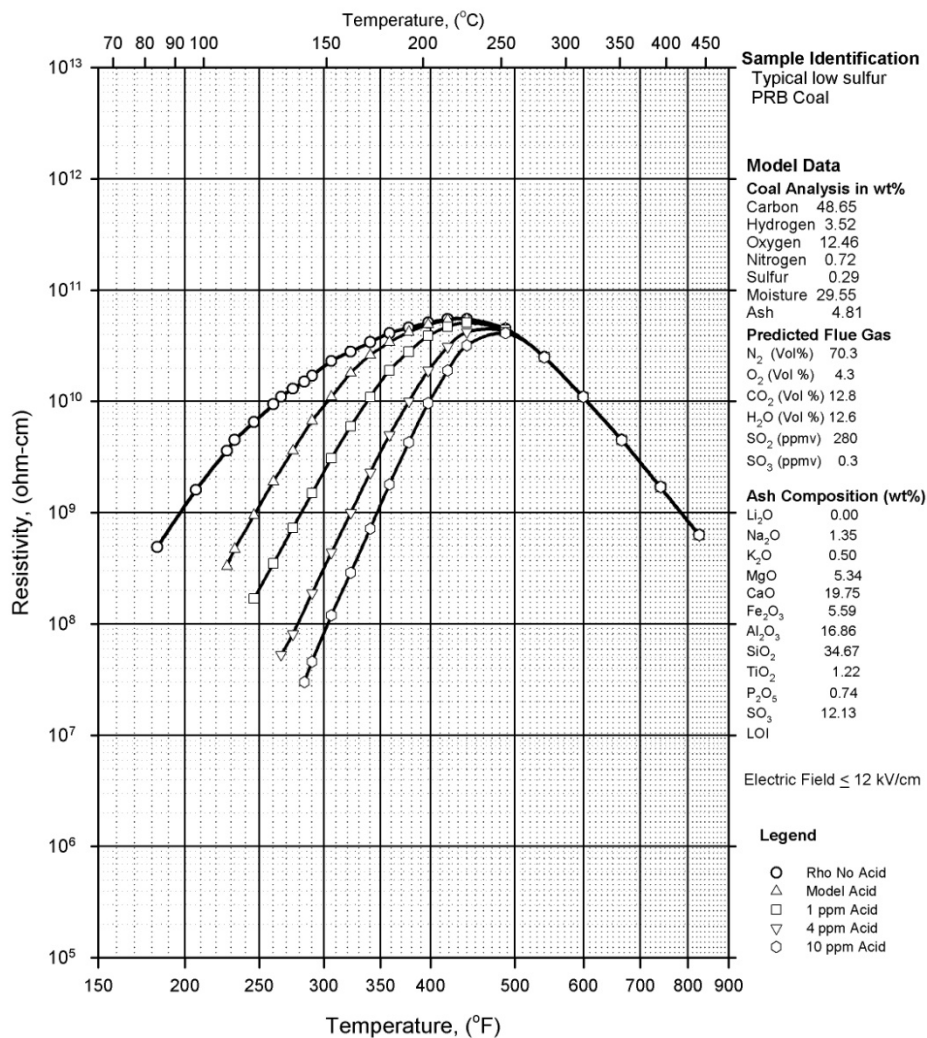


Figure 5-6: Typical Resistivity Curves for a Low Sulfur Western Coal (PRB) with High Calcium and Magnesium Contents in Their Ashes



Western US, Utah, Colorado, New Mexico

These fuels are high rank sub-bituminous or low rank bituminous, are generally low in sulfur and are readily collectable in electrostatic precipitators and fabric filters. Gas conditioning with SO_3 is necessary unless the gas temperature is below 300°F . (150°C .) for precipitators.

Lignites – US

Substantial deposits of lignite exist in North Dakota, Texas and Louisiana. These lignite coals have high moisture and ash contents. The Dakota fuels are easily collectible with electrostatic precipitators and fabric filters. This is because the Dakota fuels typically have extremely high sodium concentrations in their ashes. Some of them so much so that it can cause fouling problems on boiler tubes. The excess sodium will vaporize in the flame and condense as a sticky ash on the boiler tubes.

The Texas lignites are somewhat more troublesome with both precipitator and fabric filters. There are successful units of both types but they may be conservatively designed. Because of the sticky nature of the ash from Texas lignites, special attention must be paid to rapping or bag cleaning and ash removal.

Typical resistivity curves for a Texas lignite are shown in **Figure 5-7**. The ashes have lower sodium and iron concentrations like a low sulfur Eastern coal, yet moderate calcium and magnesium concentrations. The lower sodium content raises values for the resistivity curve without acid conditioning (circles). The moderate amounts of alkali earth metals allow resistivity attenuation with SO_3 .

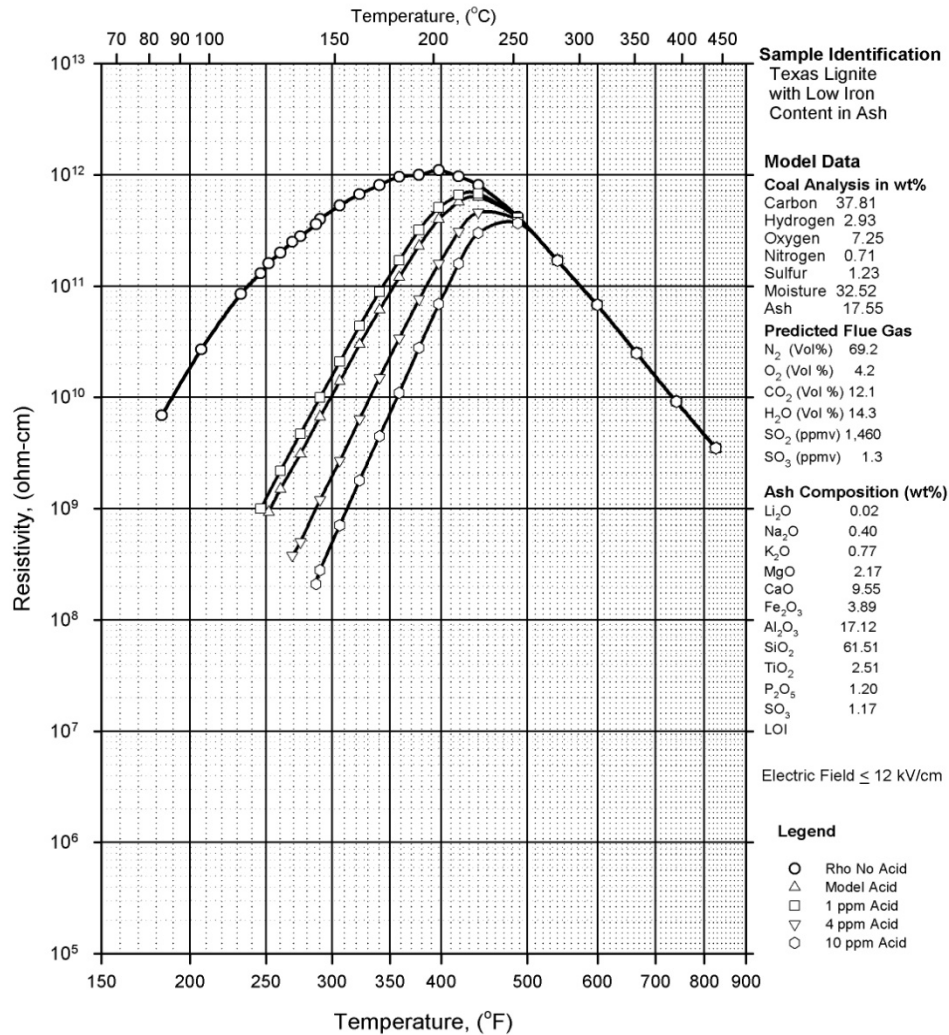


Figure 5-7: Typical Resistivity Curves for a Texas Lignite

Lignites – World

Lignites are used extensively for fuel at power plants in Germany and Northern Poland as well as in Turkey and Greece. The German and Polish lignites produce few problems. In Turkey and Greece as well as in the Baleric Islands of Spain sticky ash prevails. In the state of Victoria in Australia, extensive use of lignite is made with very satisfactory precipitator performance.



Bituminous Coal – World

A wide variety of coals are used throughout the world with sulfur contents ranging from as high as 7% in Sardinia in Italy to 0.2% to 0.3% at the El Cerajon Mine in Columbia, South America. Major coal exporters are Australia, South Africa, Columbia, Camas, Venezuela, Poland and the Ukraine, as well as the United States. In many cases, the best coal is exported while the poorer fuels are used for local consumption. All of the precautions noted regarding the American bituminous fuels plus in some cases the presence of chlorides may cause additional difficulties.

Anthracite Coal

Anthracite coal is used in Spain and Korea. With this fuel, the low volatility makes substantial furnace volumes necessary for control of carbon in the fly ash. The same is true of petroleum coke.

Coals from India, Pakistan, Indonesia and Thailand

These fuels are generally bituminous coal which are characterized by high ash content due at least in part by a lack of coal preparation facilities such as washing and drying plants, as well as less sophisticated mining methods which tend to mix overburden and foreign materials with the fuel. In most of these areas during the annual monsoon season, June-October, the fuel tends to be very wet at times since storage and transport facilities including rail cars, trucks and conveyors are uncovered.

Coals from China and the Russian Federation

These fuel deposits tend to vary considerably in quality. Most are bituminous coals. Quality can be quite good based on care in mining practices and the extent of coal preparation facilities. These can vary substantially in sulfur content. Some are quite low in sulfur, especially Siberian and Northwest China coal.

Australian Coals

In addition to the Victoria lignite previously mentioned, Australia has some substantial preserves and mines for high quality bituminous coals in New South Wales and Queensland. These coals are low to very low in sulfur and fairly low in ash content and moisture. Most have heating values from 12,500 to 13,700 BTU per pound. The fly ash is, however, very high in combined silica and alumina and therefore does not condition well with SO₃ unless the temperature



of the gas is in the 280 degree F. range. Fabric filters are generally the collectors of choice for fly ash from these coals.

South African Coals

These bituminous coals vary substantially in sulfur content from medium to very low. Exported fuel tends to be well prepared and is fairly low in ash. Fuel burned locally tends to be higher in ash content.

Coal Characteristics

Coal is discussed at length in the fuel switching section of this study, but we can give an overview here. Fuel cost is, of course, a major factor in electric power production. The need for economy in this area is well understood. Environmental requirements have distorted the coal procurement picture and will continue to do so.

One problem which occurs with the emphasis on environmentally dictated fuel procurement is, however, the tendency to emphasize the issue of the moment, be it sulfur, nitrogen oxide, mercury and heavy metals or area visibility to the exclusion of other factors. This often misdirected emphasis has resulted in substantial unexpected expense to users who are caught with unexpected costs in maintenance, shutdown, load limits and, worse, with contracts for unstable coal.

When looking at prospective fuels, it is important to take a long term view of the consequences of a commitment to a certain fuel which meets sulfur and cost criteria but leaves the utility with the consequences of excessive slagging, other troublesome fireside deposits, coal mill problems or particulate excursions. Taking a comprehensive view of all possible factors in choosing a fuel will often avoid unpleasant long term consequences.

In addition to the cost, fuel value, transportation costs and sulfur content, other factors must be considered. Some of these relate to ash disposal costs, salability of fly ash and bottom ash, slagging potential, mill suitability, nitrogen content, heavy metal content such as mercury, cadmium, selenium and arsenic, burner suitability, ash content and composition and furnace volume. There are many others. Neglect in making a thorough evaluation is extremely short sighted.

There is no reason to avoid a test burn of a prospective fuel for a long enough period to evaluate it properly. A paper study of all prospective fuels and test burns of serious prospects should be conducted. During such test burns, sufficient testing should be

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done, data recorded and visual observations made so that as many factors as possible can be used in the evaluation before a commitment is made.

Purchasing, engineering, environmental and operations should be involved in the evaluation. Much more effort should be placed here than was customarily used in the past.