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Project Summary

Fly Ash Resistivity Prediction Improvement with Emphasis on Sulfur Trioxide

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Research has been conducted to improve and extend the capabilities of a technique for predicting fly ash resistivity from the ultimate coal analysis and the coal ash composition. Emphasis was placed on determining the quantitative effect of adsorbed sulfuric acid (H_2SO_4) vapor on resistivity. Ten fly ash samples were used in order to have a reasonable spectrum of ash composition. Resistivity was determined as a function of temperature in air environments containing 5% and 10% water. Isothermal resistivity was measured for each ash at three temperature levels using three concentrations of sulfur trioxide (SO_3). With respect to resistivity predictions for conditions not including SO_3, the present data did not suggest any modification of Model I of the resistivity prediction. However, the much larger and improved data base recently acquired with respect to environments containing SO_3 has required a new approach for predicting this effect. The report presents these data and illustrates Model II of the resistivity prediction.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Several years ago a model was developed to predict fly ash resistivity as a function of temperature and the concentrations of water and SO_3 in the flue gas. Input data for the predictions of resistivity are the as-received ultimate coal analysis and the chemical composition of the coal ash; i.e., ash produced by laboratory ignition. Alternate input data that can be arbitrarily selected are water and SO_3 concentrations and fly ash compositions.

From the beginning, the model for predicting resistivity has had two features that require additional attention. One, which is not experimentally addressed in this report, is the technique that is used to estimate the amount of H_2SO_4 vapor that will be present in the flue gas at the inlet to a precipitator under given conditions. A method is needed to objectively establish a multiplier to convert the stoichiometrically calculated SO_2 value to a SO_3 concentration for specific circumstances. The second feature requiring further effort is the set of equations used to calculate the quantitative effect of H_2SO_4 vapor on fly ash resistivity. For the original predictive model, these equations were based on a small quantity of laboratory data. Since the predicted resistivity is very sensitive to the characteristics of these equations, and since the characteristics of the equations are extremely sensitive to ash composition, temperature, and SO_3 concentration, additional research was undertaken to establish an improved data base for this feature of the model. These results and a revised model are discussed in this report.

Experimental Procedure

The fly ashes used were characterized with respect to chemical composition, water soluble sulfate, loss on ignition, Bahco particle size classification, and helium pycnometer density. Resistivity (as a function of temperature, in an air environment containing nominally 5 and 10 percent water, and using an electric field intensity of 4 kV/cm) was determined prior to the experiments with H_2SO_4 vapor. These tests were done in accordance with IEEE Standard 548-1981, descending temperature technique.

The equipment used for the isothermal resistivity tests in environments containing acid vapor is described in report EPA-600/7-78-035. An ash layer between two concentric electrodes is equilibrated with the test environment in an environmentally controlled chamber within a thermally controlled oven.

The ash sample was thermally equilibrated in dry air overnight at the highest temperature of interest for the experiment being conducted. The environment was converted from dry to moist air. When the monitored current resulting from a periodically applied 2 kV voltage no longer increased, the injection of SO_3 into the system was started. Resistivity was periodically determined until the 1 mm thick ash layer under test had equilibrated with the environment. This equilibration was arbitrarily defined as a resistivity decrease of <30 percent in 24 hours. After the resistivity data for the highest temperature had been recorded and without breaking the continuity of the test, the equilibration was repeated at successively lower temperatures. At the lowest temperature in the series and after equilibration had been achieved, resistivity was determined as a function of field strength intensity. The concentration of water and H_2SO_4 vapor in the environmental exhaust was evaluated at least daily, and average values were reported. More than 100 data points were acquired, relating resistivity to temperature for environments containing SO_3.

Discussion

A computer program, described in report EPA-600/7-79-204 and designated Model I, was developed to predict fly ash resistivity as a function of temperature and the important flue gas constituents, water and SO_3. The method used the as-received ultimate coal analysis and the coal ash chemical composition to make the calculations. About 40 fly ash samples were used to obtain the experimental data necessary to produce the correlations required for the predictive technique. It was believed that the use of a large number of fly ash samples produced from all ranks of coal in several types of commercial furnaces adequately defined the influence of ash composition on resistivity while minimizing the role of ash particle size distribution and ash layer porosity with respect to resistivity. The effect on resistivity of environmental water concentration and electric field intensity was extensively examined. Due to limitations related to funding and time, minimum data were obtained to quantify the effect of environmental H_2SO_4 vapor on resistivity. Consequently, it was recommended that additional research be conducted to enlarge and improve the data base correlating resistivity with H_2SO_4 vapor. Also, it was pointed out that improvement was needed in the method of estimating the amount of SO_3 (H_2SO_4 vapor) that will be measureable at the inlet to a cold-side precipitator from the stoichiometrically calculated SO_2 concentration.

Between the publication of Model I and the research reported here, laboratory data relevant to the resistivity prediction model were periodically obtained. Usually these data simply verified previous observations. However, tests were conducted using fly ashes having high concentrations of calcium and magnesium that showed extra sensitivity to environmental water concentration with respect to resistivity. This deviation from the previous resistivity/water vapor correlation used in the Model I resistivity prediction was incorporated in the computer program, and the program was designated Model IA.

The principal objective of the experimental work reported here was to expand the data base upon which the predicted effect of H_2SO_4 vapor on fly ash resistivity is based. Experiments were conducted to evaluate the relationships between resistivity, fly ash composition, temperature, and SO_3 concentration in an air and water vapor environment. To keep the test matrix within the limits of the research program, 10 fly ashes were selected, representing the spectrum of ash composition. An attempt was made to have available ashes with: 1) low concentrations of sodium and calcium, with iron concentrations varying from low to medium to high; 2) low concentrations of sodium and iron, with calcium concentrations varying from low to medium to high; and 3) low iron concentration, moderate sodium concentration, and calcium concentrations varying from low to high.

Between the publication of Model I and the research reported here, an IEEE standard was issued for resistivity testing in air environments containing water vapor. Also in this time frame, new test equipment was installed in the laboratory. To ensure that the new equipment and procedures would yield results identical to those produced previously, the resistivities of the 10 ashes described above were evaluated as a function of temperature in test environments consisting of air containing 5 and 10 percent water vapor using the descending temperature technique of the IEEE standard.

The resistivity data acquired with air environments containing either 5 or 10 percent water vapor were reviewed with respect to:

- The slope of the high temperature segment of the resistivity/temperature curve.
- The difference between measured and predicted (Model I/Model IA) data at 150 and 350°C.
- The effect of water concentration on resistivity as a function of temperature.

A review of these points concluded that there was no justification for modifying Model I/Model IA with respect to the prediction of resistivity for environments containing no SO_3.

Each of the 10 ashes was evaluated using a minimum of three SO_3 concentrations at each of three temperatures in an air environment containing 10 percent water vapor. In a given test series using a constant SO_3 concentration, resistivity was determined at three successively lower temperatures. About 100 data points were generated in this fashion, and these data were reviewed with respect to:

- Resistivity attenuation under a fixed set of conditions: 144°C, $E = 4kV/cm$, an air environment containing 10 percent water and 4 ppm of SO_3.
- Resistivity as a function of SO_3 concentration under the above conditions.
- Resistivity as a function of temperature for three concentrations of SO_3.
- Resistivity as a function of electric field intensity for three levels of SO_3 concentration and several temperatures.

These data made it apparent that fly ash composition plays a major role in the relationship between resistivity and adsorbed H_2SO_4 vapor. The resistivities of ashes that contain moderate amounts of either iron (>1.0 atomic percent) or magnesium plus calcium (>5.0 atomic percent) are readily affected by H_2SO_4 vapor. Those ashes that contain lesser amounts of both elemental groups are more difficult to condition. It was also observed that resistivity values determined under the influence of adsorbed H_2SO_4 is more sensitive to electric field intensity than the resistivity values determined in environments containing no SO_3.

With respect to the prediction of resistivity as influenced by H_2SO_4 vapor, Model II (based on the experimental data described here) takes a different approach than Model I/Model IA. Each step or correlation used to calculate resistivity (except electric field intensity) is tempered or influenced by the ash composition. It is believed that the resistivity prediction method, Model II, is a significant improvement over the previous models. Use of Model II has provided results that are in good agreement with additional laboratory resistivity data, precipitator electrical characteristics, and in situ resistivity data.

In addition to the new equations used for predicting resistivity, the technique for estimating the concentration of SO_3 to be expected in the flue gas entering the precipitator based on a given coal analysis has been altered for Model II. An effort has been made to take into account the amount and composition of the fly ash. First, an expression has been inserted to attenuate the estimated amount of SO_3 if the amount of ash in the coal exceeds 10 percent. Second, the estimated amount of SO_3 is determined as a percentage of the SO_2 value. The SO_2 is calculated from the stoichiometric combustion of the as-received coal analysis using a specific amount of excess air. In the case of Models I and IA, a single multiplier was used to convert calculated SO_2 values to SO_3 for all coals. A recent review of field test data suggests that two multipliers should be used. Consequently, Model II selects the desired multiplier based on fly ash composition. The uncertainty regarding this estimate of the SO_3 concentration is clearly the weakest link in the prediction of resistivity based on coal analysis.

The user should be alerted to two other aspects of Model II. First, the characteristics and amount of laboratory data available for the development of Model II require that resistivity can be predicted on a step-function basis with respect to fly ash composition. Consequently, it is possible that specific fly ashes differing only slightly in composition can have substantially different predicted resistivity values for a specific combination of temperature and acid concentration. Second, there has been little experience using Model II with coals having large concentrations of ash and/or water; e.g., 50 percent. For a given sulfur content, fuels of this type should produce disproportionately large amounts of SO_3. It is not known whether this excess SO_3 will appear in the precipitator flue gas.

Extensive use of Model II, as it applies to SO_3, will define the merit of the procedure. It is not a replacement for either laboratory or in situ measurements of resistivity. In fact it is highly recommended that all three sources of resistivity data should be considered for comparisons with the precipitator electrical characteristics. Possible uses of Model II include:

- Anticipating the effect of coal cleaning on fly ash resistivity.
- Substantiating either laboratory or in situ resistivity data.
- Selection of coals or coal blends for specific situations.
- Developing a topographic map of a coal field with respect to ash resistivity.
- Modeling precipitators for design fuel composition.
- Troubleshooting poorly performing precipitators.
- Determining the applicability of flue gas conditioning with respect to the amount of SO_3 required for a given temperature and ash composition.
- Determining the required sodium addition for sodium-conditioning a given coal.

Recommendations

An improved computer program is available to calculate fly ash resistivity as a function of temperature for flue gas compositions containing SO_3. Additional research would be of value: 1) to determine the H_2SO_4 vapor conduction mechanism, 2) to estimate the concentration of H_2SO_4 vapor in flue gas with greater confidence, and 3) to understand the variation in the effectiveness of H_2SO_4 conditioning with different fly ash compositions.

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The complete report, entitled "Fly Ash Resistivity Prediction Improvement with Emphasis on Sulfur Trioxide," (Order No. PB 86-178 126/AS; Cost: $11.95, subject to change) will be available only from:

National Technical Information Service
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