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Project Summary

A Self-Consistent Deutschian ESP Model

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The electrostatic precipitator (ESP) model developed by Southern Research Institute (SRI) for EPA provides an acceptable simulation of the performance of cold-side utility fly ash ESPs with typical values of inlet mass loading. To increase the accuracy of model predictions in unusual situations, such as high inlet mass loading or abnormally low current, a revised version of the model has been developed. The revised model is unique in that it rigorously calculates the effects of particulate space charge on the interelectrode electric field and on subsequent particle charging.

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

A more general and more powerful mathematical model of electrostatic precipitation (ESP) has been developed by Southern Research Institute (SRI). The standard version of the ESP model developed by SRI for EPA, now in its third revision, provides an acceptable simulation of the performance of cold-side utility fly ash ESPs with typical values of inlet mass loading. To increase the responsiveness of the ESP model to situations having high inlet mass loading and/or abnormally low corona current, a revised version of the model has been prepared.

Both versions of the model apply the Deutsch equation to narrow particle size bands over short ESP length increments to determine particle collection efficiency. In the standard version, the effects of particulate space charge are estimated by a formula that predicts an effective mobility for combined ions and particles and a reduced ion density for particle charging. These estimated values are then used to separately calculate the electric field at the plate and the particle charge which are required for the Deutsch equation.

The revised version differs from the standard version in that the former treats the particulate space charge explicitly, allowing the interrelation of the particle charge and electric field calculations. The charge and field calculations are alternated until they become self-consistent within each length increment throughout the entire ESP. Self-consistency occurs when the charge used for the space charge in the field calculation is the same as that calculated using the results of the field calculation. The explicit treatment of the space charge directly relates the particle charge and electric field calculations, and therefore the collection efficiency calculation, to the dust load present in the gas stream.

The revised ESP model report includes:

- operating instructions for the revised model,
- descriptions of the input data, the video display during operation, and the output data,
- a discussion of the underlying theory of the revised model, and

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- comparisons of the revised and standard (Revision 3) models in terms of logic and calculated results.

Operating Instructions

Although the revised ESP model described in this report was developed on a main-frame computer, it can be run on an IBM PC-compatible microcomputer. Because the model performs a large number of mathematical calculations, equipping the microcomputer with a math coprocessor minimizes the time required for running the model. The revised ESP model, ESPREV.FOR, is written in Microsoft-compatible FORTRAN and occupies 67,574 bytes of memory. The executable file, ESPREV.EXE, occupies 264,298 bytes of memory.

To run the model, type ESPREV and press enter. The program will prompt the user for the names of a file containing input data and a file into which to write the output data. The revised ESP model reads the same input data format as the standard version of the model. The instructions for creating a data set, excerpted from the standard model instruction manual, are given in an appendix. Descriptions of the video display generated by the model and the output data are given in the report. Due to the large amount of data generated by this model, the output data are written to a file. To obtain a hard copy of the data, it is necessary to print this file using a PRINT command. An option for shortening the amount of output data generated is provided.

Theory

The underlying assumptions for the revised version of the model are listed below.

1. The space charge due to charged particles is constant in a given length increment and is uniformly distributed in the gas stream. This allows the development of a rigorously Deutschian model, as these were the conditions for which the Deutsch equation was derived. The assumption of uniformity is particularly good for fine particles in a turbulent gas flow. The fine particles are especially important in ESP modeling as these are the most difficult particles for an ESP to collect.

2. The space charge due to ions is neither uniformly distributed nor constant because the ions follow the electric field lines, which are non-uniform in the interelectrode space.

3. The total space charge density is the sum of the particulate and ionic space charge densities. In the revised model, the particulate and ionic densities are treated separately and explicitly, in contrast to the estimated treatment of a combined ionic and particulate space charge found in the standard version of the model.

4. The current is ionic except in the laminar boundary layer at the collection plate. This is due to the assumption that the particles are stationary in a given length increment. This is a good approximation since the particulate mobility is several orders of magnitude less than the mobility of the ions. Since the particles are stationary, only the ionic current density appears in the current continuity equation.

5. The ionic mobility is used only in the calculation of the ionic current density on the plate. The mobility drops out of the equations in the remainder of the interelectrode space.

6. The particulate current density is included when determining the total current density on the plate and is computed from the calculated charges and Deutsch migration velocities of the different size particles.

7. Overall electric field convergence is tested using the measured average plate current density.

8. The calculations of the electric field and the particle charge are alternated until self-consistency is obtained in each incremental length before proceeding to the next incremental length in the ESP. The self-consistency is determined by comparing the changes in the average electric field between successive field-charge iterations. When the change in the field is sufficiently small, the calculation is assumed to have converged.

9. The algorithm in the revised ESP model includes corrections for the non-ideal effects of gas sneakage, non-uniform gas flow, and rapping reentrainment. The gas sneakage calculation is made at the end of each section of the ESP. The non-uniform gas flow, and rapping reentrainment calculations are made at the end of the efficiency calculation.

Evaluation

The primary reason for the development of the revised ESP model was to provide an ESP performance model that is responsive to changes in dust loading. This goal has been met. Data comparisons show that the revised model clearly demonstrates the effects of its explicit space charge calculation. Examination of the calculated particle charging rate with changes in inlet dust load show charge retardation and then suppression as the dust load is increased. Similar suppression of charging due to high mass loading has been measured on a pilot ESP SRI. The standard ESP model gives same charging rate for all dust loads.

The second reason for revising the ESP model was to eliminate the three deficiencies that have been identified in the standard model:

1. The space charge effects are not explicitly calculated but are estimated based on an effective mobility which accounts for fast moving ions and slow moving particles. The effective mobility is not a composite of mobilities but is given by an equation that applies only to small particles near the collection plate.

2. The electric field and particle charge calculations are not mathematically connected.

3. An empirical correction factor must be applied to the average migration velocities of small particles to make their calculated efficiencies match measured data.

The first two deficiencies were eliminated by the structure of the revised model. It was hoped that making the revised model rigorously Deutschian would remove the need for an empirical correction factor for small-particle migration velocities (the third deficiency). A comparison of measured migration velocities to migration velocities calculated by the revised mo for 10 cold-side utility ESPs chosen f the SRI ESP data base shows that t. was not the case. By including an empirical correction factor similar to the one in the standard model, the performance projections can be corrected.

Conclusions and Recommendations

The revised ESP model represents an improvement over the standard model in that the calculations of particle charge and collecting electric field required for the Deutsch equation are not separate but are interrelated such that the charging and field calculations are made self-consistent in each length increment of the ESP. The algorithms used in the revised model are conceptually rigorous, except for the continued use of an average interelectrode electric field in the charging calculation. These features result in a model that is responsive to changes in dust load as well as electrical conditions.

Following the theoretical efficiency calculation, two non-rigorous corrections are applied to model predictions: the calculation of rapping reentrainment and the correction of small-particle migration velocities. The rapping correction must be empirical in nature because no applica theory exists. That a correction factc

ᐠcessary for a rigorously Deutschian del to match the small particle migra- ᴗn velocities in full-size ESPs indicates a shortcoming in the Deutsch theory, possibly due to an oversimplification in the underlying assumptions of the theory. At this time, however, no competing theories of ESP particle collection do not also require empirically derived constants. The revised model has been tested against the SRI data base of conventional utility fly ash ESPs to verify that the same answers are obtained as from Revision 3. However, a careful measurement program on several high-dust-load ESPs is required before the revised model can be validated.

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The complete report, entitled "A Self-consistent Deutschian ESP Model,"(Order No. PB91-149518/AS; Cost: $17.00, subject to change) will be available only from:
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