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Project Summary

Third Symposium on the Transfer and Utilization of Particulate Control Technology: Volume II. Electrostatic Precipitators

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Summarized herein is Volume II of the four volumes of proceedings of the Third Symposium on the Transfer and Utilization of Particulate Control Technology held in Orlando, FL, March 9-12, 1981. Volume II papers deal particularly with electrostatic precipitators (ESPs) as particulate control devices. The papers discuss fundamentals of the design and fabrication of ESPs, additions to the theory and the analysis of the operation of ESPs, the operation and maintenance of ESPs, advanced designs and concepts, and the application of ESPs fired by other than conventional fuels.

Volumes I, III, and IV are described in three separate project summaries.

This Project Summary was developed by EPA's Industrial Environmental 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

The papers in Volume II of the four volumes of proceedings were presented at the Third Symposium on the Transfer and Utilization of Particulate Control Technology in Orlando, FL, March 9-12, 1981, sponsored by the Particulate Technology Branch of EPA's Industrial Environmental Research Laboratory at Research Triangle Park, NC.

The symposium brought together researchers, manufacturers, users, government agencies, educators, and students to discuss new technology and provided an effective means for the transfer of this technology out of the laboratories and into the hands of the users.

The three major categories of control technologies—electrostatic precipitators (ESPs), scrubbers, and fabric filters—were the major concern of the symposium. These technologies were discussed from the perspectives of economics new technical advancements in science and engineering, and applications. Several papers dealt with combinations of devices and technologies, leading to a concept of using a systems approach to particulate control, rather than device control. Additional topic areas included novel control devices, high-temperature/high-pressure applications, fugitive emissions, and measurement techniques.

The symposium was conducted as a series of parallel sessions, each containing four to six related papers. The sessions were scheduled to avoid conflict due to simultaneous sessions dealing with the same topic. Each series of related sessions represented a thread of technology. These parallel threads, extending over the total period of the symposium, provided a highly integrated approach to the total subject of particulate control technology, with strands of specialized technologies. These strands of specialized technologies, or perspectives, provided the basis for the division of the papers into four volumes, each volume containing a set of related session topics so as to provide easy access to a unified technology area.

Volume II Papers

Volume II, summarized here, was devoted to ESPs, the major thread of the symposium. One section of Volume II consists of papers dealing with the fundamentals or theory of ESPs. Several papers were devoted to mathematical modeling; some of the modeling was devoted to ionic conduction of flyash layers, back corona, total system modeling, and rapping reentrainment and opacity modeling. Several papers in this section dealt with measurement and interpretation of various parametric data. A number of papers described attempts to measure and formulate reentrainment phenomena. The general topics of particle transport in the electrohydrodynamics field, turbulent diffusion, and the application of laser doppler instrumentation to particle transport measurements indicate a new depth of theoretical studies in ESP. In the section on operation and maintenance, the concept of "intelligent" ESP controls was introduced; it is certain that this concept will be developed further in the near future as it provides use of the microprocessor in comparing and weighting several parameters to determine operating voltages and rapping intervals with a degree of precision heretofore not possible.

A special section of Volume II is devoted to advance design in ESPs. Two-stage and multi-electrode devices are explored in depth. Prechargers are treated in several papers, and one of the papers deals with temperature-controlled electrodes. Several papers dealt with the physics of pulse-energization as well as operating experiences with pulsed power operation. A final small section of Volume II deals with the use of ESPs in connection with boilers using unusual fuels and multiple fuels.

Section A—Fundamentals

Mathematical Modeling of Ionic Conduction in Flyash Layers

R. Mosley, Southern Research Institute

Electrical conduction in flyash layers placed between two metal electrodes is discussed in terms of ionic migration. Mathematical models are formulated based on the solution of the current transport equation coupled with Poisson's equation. Thermal diffusion and field dependent ionic mobilities are considered. Since the electrodes are assumed to be blocking in nature, the models account for both cations and anions. The appropriate representations of the mathematical solution to the coupled transport equations which apply in the different regions of the flyash layer are discussed. The electric field, the potential, and the charge-density profiles in these different regions are expressed in terms of hyperbolic functions, Airy functions, or algebraic functions. To the extent possible, the models are compared with available experimental measurements.

Measurements of Electrical Properties of Flyash Layers

R. B. Mosley, Southern Research Institute

The results of a series of measurements of the electrical conduction properties of flyash are discussed. Current-voltage curves for flyash layers between two metal electrodes were measured under a variety of conditions. Measured electric potential and resistivity profiles demonstrate that the electric field and the charge-carrier densities are non-uniform within the flyash layer. Activation energies associated with the electrical migration of alkali metal ions were measured. The net charge accumulated in the layer as a result of steady state conduction of ions was measured. A thermal anneal experiment designed to measure the thermal diffusion coefficient of the alkali metal ions (particularly sodium ions) in some flyash layers is described. Some observations of the electrical breakdown properties of flyash layers also are described. The dependence of the breakdown voltage on gas pressure is presented, and the breakdown process is discussed.

Laser Doppler Anemometer Measurements of Particle Velocity in a Laboratory Precipitator

P. A. Lawless, Research Triangle Institute

A laboratory ESP was constructed to permit direct measurement of particle velocities by means of laser Doppler anemometry. Components of velocity in the direction of flow and perpendicular to the walls were measured for a range of electrical conditions and particle sizes. Data are presented and interpreted in light of current theories for particle charging and electric field configurations. The effects of back corona on the particl motion are noted.

Progress in Modeling Back Corona

P. A. Lawless, Research Triangle Institut

Computer modeling of the electrica conditions in the wire-duct geometry ha been pursued, reducing the number of a hoc assumptions and including sucl effects as differing negative and positiv ion mobilities, ion-ion recombination, an avalanche breakdown in the dust layer The ability of the model to reproduce th effects of back corona is presented.

A Computer Model for ESP Performance

P. A. Lawless, Research Triangle Institute

A computer model has been developec for describing ESP performance. It incor porates theoretical particle charging the ory and electric field calculations, anc empirical estimates of turbulent diffusion and corona wind effects. Rapping and sneakage reentrainment losses are accounted for. Using realistic estimates for unmeasured quantities, it predicts the performance of full scale ESPs quite well, if back-corona conditions are avoided. Methods of handling back corona are discussed.

Measurement and Interpretation of Current Density Distribution and Charge/Mass Data

M. Durham, Denver Research Institute

Techniques have been developed for measuring charge-to-mass ratios (Q/M) and current density distribution (CDD) in ESPs. Q/M is measured by an in-stack Faraday cage device. Details of the design of the probe are presented, and sampling precautions are described. The role of particle-size distribution in interpreting Q/M data is also discussed.

Corona current density distribution is measured by a plate consisting of 96 isolated 2-in. squares. By means of a picoammeter and a switching box, the current from a single square or a combination of squares can be measured. This device has been used to analyze the performance of several corona electrodes, as well as the effect of pulsed excitation. Experimental data are presented and interpretation of results is described.

The Relationship Between Gas Stream Turbulence and Collection Efficiency in a Lab-Scaled Electrostatic Precipitator

B. E. Pyle, Southern Research Institute

Experimental measurements of the turbulence transport properties of micron-sized particles have been carried out in a laboratory scale ESP of conventional wire/plate design. The relationships between ESP collection efficiency, particle size, level of gas turbulence, and the electrical operating conditions of the ESP were investigated. The results of these measurements are compared with the theoretical predictions of an ESP mathematical model based on a turbulent mass-transport principle. The agreement between the theoretical predictions and the experimental results is shown to depend to a large degree on the boundary conditions assumed at the collector plates. One result obtained from these investigations was that the ESP collection efficiencies were found to be inversely related to the level of turbulence in the gas stream.

Particle Deposition Profiles and Reentrainment in a Wire-Plate Electrostatic Precipitator

E. Arce-Medina,
North Carolina State University at Raleigh

A recently devised radiotracer technique has been used to measure local particle deposition profiles and friction and impaction reentrainment in the EPA pilot-scale ESP at Research Triangle Park, NC. Reentrainment rates are shown to vary with gas velocity and inlet dust loading, and with the magnitude of the dust layer thickness on the plate. The implications of the results on ESP performance and modeling are discussed.

Particle Transport in the EHD Field

T. Yamamoto, Denver Research Institute

The study of the motion of fine particulates in the EHD (electrohydrodynamic) field has become important not only in the design of ESPs, but also in electrostatic painting.

Experimental and theoretical studies have been conducted in the case of two-dimensional, two-wire, plate configuration ESPs. In the numerical study, the external force (which consists of the electrostatic field and space charge density) was first obtained. The second step was to solve the Navier-Stokes equations in the form of vorticity-stream function equations with appropriate boundary conditions. The particle trajectories were computed by integrating the equations of motion in accordance with the electrostatic and the EHD forces.

The implications of the results to ESP performance and design are discussed by introducing the dimensionless EHD charge number. The calculated numerical results demonstrate close agreement with the experiment.

Surface Reentrainment of Collected Fly Ash in Electrostatic Precipitators

M. Mitchner, Stanford University

Experiments have been performed in a horizontal-flow wire-and-plate ESP (plate-to-plate spacing, 0.25 m) to study the effects of flow speed (from 3 to 22 ft/sec) and corona-type on the reentrainment of collected flyash. The deposited dust layer is observed to exhibit a well-defined structure, with regions of highly compacted dust separated by regions of loosely packed dust. At lower flow speeds, the loosely packed areas are considerably deeper than the surrounding regions; whereas at higher speeds, the reverse is the case. Surface reentrainment is observed to take place primarily from regions corresponding to locations of loosely packed dust. Two modes of reentrainment are observed: a continuous erosion process which becomes more pronounced at higher speeds, and a relatively infrequent large-scale fall-off process which tends to occur at lower speeds. It is shown that the dust layer structure results from the variation of corona current density, J, on the collector surface: the compacted regions occur where J is large, and the loosely packed areas occur where J is zero (or small, in a time-average sense).

Electromechanics of Precipitated Ash Layers

G. B. Moslehi, Stanford University

The electrical field distribution in a current-carrying ash layer, modelled as a regular array of uniform resistive spheres, is found analytically as a function of contact area for the cases of volume conduction, surface conduction, and the combined case. The electrical compressive stress is then evaluated, from which the contact area is found. Hence the field distribution, average layer resistivity, and average cohesive stress are determined self-consistently in terms of fundamental quantities.

The theory predicts that the layer resistivity decreases with current (or applied field) in agreement with experiment. It also shows that there is a strong field enhancement (above the average value) around the contact points. This effect results in a much enhanced cohesive stress compared with that calculated from the average field. It also appears to explain the onset of back discharge as due to the intermittent micro-arcs between the spheres. Experiments are in progress to test various aspects of the theory.

Experimental Measurements of the Effect of Turbulent Diffusion on Precipitator Efficiency

G. L. Leonard, Stanford University

The Deutsch model for predicting particle collection in an ESP assumes uniform particle concentration profiles, and thus infinite mixing by the turbulent flow. Recent theories (which treat the mixing process as finite and thus allow for the formation of non-uniform particle concentration profiles) predict efficiencies far in excess of Deutsch predictions. This paper presents optically determined *in situ* particle concentration profiles in a parallel plate ESP and compares them with the predictions of these newer theories. Experiments were designed to permit separate control and precise measurement of the degree of turbulence and of particle mobility in the ESP. These measurements, combined with the development of a new technique to achieve accurately controlled charging of a monodisperse aerosol, enable a critical assessment of these new theories to be made.

Can Reentrainment be Explained Using a New Precipitator Formula?

S. Maartmann, Flakt Industri AB

According to ESP literature, reentrainment is defined as a decrease in migration velocity calculated according to the Andersson-Deutsch formula when gas velocity is increased above a certain limit.

Despite many efforts, there is as yet no generally accepted formula which covers the variation of efficiency within the whole gas velocity range including that in which reentrainment takes place.

The paper describes how investigations of test results, particularly from tests with pilot ESP plants, lead to the development of a new expression for efficiency. The possibility of using the expression as the base for a new ESP formula is discussed, as well as the possible general use of the new efficiency expression.

A Laboratory Furnace for the Production of Synthetic Flyash from Small Coal Samples

K. M. Sullivan, Australian Coal Industries Research Laboratory

A laboratory furnace was developed to produce a synthetic flyash from a small coal sample. Similarity was achieved by subjecting pulverized coal particles to a similar thermal and chemical history to that experienced in a full-scale power station boiler. The furnace was designed to accommodate small coal samples, while operating parameters were defined to produce similarity between the synthetic flyash and isokinetically sampled flyash from power stations, in each instance when using the same coal.

Subsequent confirmative testing has shown the ability of the furnaces to produce synthetic flyash that is similar to power station flyash. The furnaces are used to investigate proposed coal mining areas which are intended for future use for power generation. For this to occur, a number of bore-core coal samples are examined and the derived synthetic flyash is tested electrically, physically, chemically, and microscopically to rank and ascertain the variability of flyash from the proposed mining area. In this way, the furnaces are used as an early means of assisting future coal mining/power station development.

Computer Simulation of the Wide Plate Spacing Effect

E. A. Samuel, Buell Envirotech

A numerical simulation code has been developed to analyze the coupled electro-aerodynamic phenomena within an ESP, including the perturbations to the space charge distribution introduced by the dust-laden gas flow. The ESP collection efficiency calculated from the trajectories of the charged dust particles showed good agreement with that measured for oil drops in model ESPs using light scattering techniques. The computer model had been used to predict the existence of an optimal wire-to-wire spacing for a given plate spacing. This study investigated the effect of plate spacing on the collection efficiency with a view toward explaining the wide-plate spacing effect presently claimed industrywide to be advantageous. The effect on the collection efficiency of using mixed plate spacings in a single ESP is discussed.

Simultaneous Measurements of Aerodynamic Size and Electric Charge of Aerosol Particles in Real Time on a Single Particle Basis

M. K. Mazumder, University of Arkansas

An instrument has been developed for measuring the aerodynamic relaxation time (t_p) and electrical migration velocity (V_p) of aerosol particles in real time and on individual particle basis in the range from 0.3 to 10.0 μm in diameter. The instrument uses a laser Doppler velocimeter (LDV) to measure particle motion in an applied electric field. It operates by electrically charging the particles, subjecting them to the oscillatory electric field, and then measuring the amplitude (V_p) and relative phase lag (ϕ) of the particles with respect to the electrical field. A microcomputer-controlled signal processing and data storage system measures both ϕ and V_p, computes d_a and q for individual particles, and stores the data to generate the size- and charge-distributions of the aerosol particles. The distributions can be compared with the size distribution of both charged and uncharged particles to examine the fraction of particles that are charged, as well as the relative magnitudes of the charge.

Application of Laser Doppler Instrumentation to Particle Transport Measurements in an Electrostatic Precipitator

M. K. Mazumder, University of Arkansas

Development of two-laser based instruments—a two-color, frequency-biased laser Doppler velocimeter (LDV), and a single-particle aerodynamic relaxation time (SPART) analyzer—and their applications to ESPs are discussed. The LDV provides simultaneous measurements of two orthogonal velocity components, one along the flow direction and the other along the electrical field, of flyash particulates at any desired point inside the ESP. The SPART analyzer measures, in real time, the aerodynamic size distribution of particulates in the respirable range, 0.1 to 10.0 μm in diameter. Experimental data on the measurement of free stream an boundary-layer turbulence, electrical mi gration velocity, particle flux, and collec tion efficiency as a function of size an electrical properties of aerosol particu lates are presented. The results ar compared with those from the presentl available mathematical models of th ESPs.

The Application of Measurements of Aerosol Charge Acquisition by Bipolar Ions to the Problem of Back Corona

R. Fjeld, Clemson University

Experiments were conducted to measure charge acquisition by aerosols exposed simultaneously to positive anc negative ions of unequal current densities. Initially uncharged, highly monodisperse aerosols in the submicrometer diameter size range were subjected tc countercurrents of positive and negative ions in the presence of low electric fields. The ratio of positive to negative ion current density was varied between zero (the unipolar negative case) and infinity (the unipolar positive case) to determine the effect of countercurrent ions of opposite polarity on unipolar charge acquisition. Comparisons of experimental data with theory are presented, and the potential implications of the measurements with respect to the effects of back corona are discussed.

Identification of Back Discharge Severity

S. Masuda, University of Tokyo

As a parameter to identify qualitatively the severity of back discharge, the charge impairment factor is proposed. This factor can be theoretically calculated from the values of positive and negative ionic current density. To measure these two quantities, a bipolar current probe was developed, and its test results are presented. Finally, a comparison is shown between the measured particle charge and its calculated value from the probe diagnosis data. This reveals that back discharge occurs in a very irregular distribution, especially when dust resistivity is not too high (less than 10^{12} ohm-cm), so that the measured value of particle charge provides a much higher value than that calculated from the probe data obtained at an active channel of back discharge. This means that the space factor of back

discharge must also be taken as an important parameter.

Section B—Operation and Maintenance

Modeling of Electrostatic Precipitators with Respect to Rapping Reentrainment and Outlet Opacity

M. G. Faulkner,
Southern Research Institute

Revisions of the EPA mathematical model of ESP, which allow a dynamic time-dependent representation of rapping reentrainment and predictions of outlet opacity, are discussed. The new rapping reentrainment scheme allows different rapping schedules for the various independent sections, reentrainment due to rapping of a specified percentage of the total mass collected in a given increment of length with a specified particle size distribution, recharging and recollection of reentrained particles, a representation of hopper boil-up, and a time history of dust layer thickness. The addition of opacity calculations based on Mie theory allows the prediction of total and fractional opacities based on predicted outlet mass loadings and particle size distributions, a specified complex index of refraction, particle density, and stack diameter. Simulations demonstrating the predicted effects on outlet particulate emissions and opacity are presented.

New Precipitator Technology for Particulate Control

J. R. Zarfoss, Environmental Elements

All ESP designs must accommodate the requirement of adequately cleaning the internal components. However, the collection of highly resistive particulate matter is considered to be one of the more demanding applications. The fundamental capabilities needed to meet this challenge are the collecting surface response to rapping and the discharge electrode characteristics. This paper outlines a development program on this subject which spans 6 years, beginning with laboratory studies and concluding with the results from working installations. One of the basic studies quantifies and compares the rapping response, full size, of three popular collection surface designs. Levels of surface accelerations, frequency, and uniformity are described. Techniques for altering the voltage and current characteristics of the discharge electrodes are also presented. All of the information relates to actual measurements and is useful in all ESP designs.

Low-Frequency Sonic Cleaning Applied to Electrostatic Precipitators

J. A. Schwartz,
KVB, Inc., A Research Cottrell Co.

Low-frequency acoustic devices (horns) have been demonstrated to solve many of the dust buildup problems associated with the operation of ESPs. Dust particles clinging to surfaces are dislodged by sound-wave vibrational energy. While horns have been widely used in Europe since 1969, they were only recently introduced into the U.S. Horns appear to be a significant improvement, in terms of reliability and maintenance costs, over cleaning methods which vibrate equipment parts.

Most applications to date have been to the inlet area of the ESP; i.e., inlet ducts, turning vanes, and distribution plates. The horns have proven very effective in these applications, and the paper details several case histories. The paper also addresses the potential for cleaning ESP internals (plates and wires), with a discussion of limited application results in this area and plans for future tests.

The Impact of Intelligent Precipitator Controls

N. Z. Shilling, Buell Envirotech Corp.

This paper describes both operational hardward and the supporting software required for the implementation of computer control of an ESP. Specific examples are drawn from an operating ESP with a microcomputer control system (Intelligent Precipitator) which is serving a utility boiler.

Various features of the logical software which permit feedback control of the ESP operation are described. These include adaptive/recursive control of ESP secondary voltage, and plate and wire rapping frequency and intensity. Criteria are derived for obtaining minimum ESP power consumption for a given collection efficiency. Instrumentation and potential regimes of unstable operation with feedback control are defined. Finally, logical control sequences for control of the ESP in response to various plant operational and emergency conditions are described.

An Energy Management System for Electrostatic Precipitators

R. R. Crynack, Wheelabrator Frye, Inc.

As the emphasis of air pollution control regulation shifts toward maintaining daily compliance with stringent standards, the user must direct more attention to maintaining optimum performance from this control equipment. With rising energy costs and the connected load of an ESP serving a utility boiler over 1% of the total generating capacity, the energy cost of operating an ESP is substantial. To deal with this situation, an energy management system is proposed which can monitor ESP electrical equipment and optimize energy consumption while maintaining continuous compliance. The energy management system is a microprocessor-based device which is connected to the power supply controls and auxiliaries and regulates electrical power in response to actual on-line ESP operational needs. A prototype energy management system has been operating on an ESP serving a utility boiler for over a year, with a high degree of success.

Relationship Between Electrostatic Precipitator Performance and Recordkeeping Practices

S. P. Schliesser,
PEDCo Environmental, Inc.

This paper discusses the sensitivity of the performance and reliability of ESPs to the quality of their operation and maintenance (O&M). It also discusses the factors on which O&M quality depends, including: (1) instrumentation to monitor key performance parameters, (2) recordkeeping practices, and (3) an understanding of the relationship between key parameters and performance. The discussion presents evidence of this relationship between ESP performance and O&M quality, identifies key performance parameters and associated instrumentation, and provides criteria for evaluating O&M and performance levels. An established relationship between particulate emissions and electrical operating conditions can serve as a measure of the performance of the O&M team and the ESP itself. These same principles will prove beneficial

when applied to other control technologies.

An Operation and Maintenance Program for a Phosphate Rock Electrostatic Precipitator

D. B. Rimberg,
North American PEMCO, Inc.

An extensive investigation was performed on a weighted-wire ESP to improve its performance on opacity. The application was on a phosphate rock fertilizer calciner. The program was designed to upgrade ESP performance without major investment in new pollution control equipment. Through a sampling and cleaning program, it was determined that resistivity conditioning by moisture control was required. The investigation resulted in achieving compliance with no capital equipment investment. Sampled grain loading was reduced by a factor of ten. A regulated preventive maintenance program was instituted, thereby maintaining continuous mass and opacity compliance status. Details of the management and technical procedures implemented to effect such a program are described.

Section C—Advanced Design

Electrostatic Precipitator Performance with Pulse Excitation

D. Rugg, Denver Research Institute

A laboratory ESP was energized by pulsed power supplies. The voltage-current characteristics were measured under clean and high-resistivity dust conditions. The results, which illustrate the voltage limitations for pulse excitation, are shown. Charge-to-mass ratios, particle-size distributions, and mass-efficiency were analyzed to determine the major factors which account for the increase in mass efficiency for pulse excitation compared to efficiencies obtained with dc excitation. The data and the results of the analysis are presented.

Development of a Charging Device for High Resistivity Dust Using Heated and Cooled Electrodes

G. Rinard, Denver Research Institute

An efficient cooled-pipe charger/collector, capable of controlling back ionization and allowing efficient charging of particles, has been developed. It has also been shown to be an excellent collector. Feasibility tests were conducted, utilizing parallel heated pipes and corona discharge wires placed in a plane normal to gas flow, to determine if the dust resistivity, and thus back ionization, could be controlled by heating a small collector surface area. The success of these tests led to the development of a more practical design utilizing cooling on the collector pipes. Cooled pipes are more practical for many applications since they do not require the input of high quality heat. The results of the testing of the heated and cooled electrodes that led to the present design are given.

The Evaluation of Novel Electrostatic Precipitator Systems Using a Transportable Prototype

G. Rinard, Denver Research Institute

A program is presently being conducted to advance the development of economically feasible, two-stage ESPs for collection of high resistivity dust. The objectives of this program are to: (1) evaluate the SoRI precharger on various sources of high resistivity dust, (2) optimize the downstream collector for use with a precharger, and (3) evaluate alternative ESP designs. These goals will be achieved through the design, fabrication, and testing of a transportable ESP (TEP) on problem sources of high resistivity dust. In order to determine alternative ESP designs for testing in the TEP, a program to investigate novel precharger and collector technology was undertaken. The design goals for the TEP and configuration for the first series of testing are presented. Results of the testing for the downstream collector are also presented.

Analysis of the Electrical and Charging Characteristics of a Three Electrode Precharger

K. J. McLean, University of Wollongong

The SoRI/EPA Three Electrode Precharger is analyzed by examining its electrical characteristics and a limited set of charge/mass measurements. It is concluded that, for the test conditions operating at the time, the biasing of the grid reduces the back corona component of the total current flowing to the discharge electrodes for a restricted range of operating conditions.

Particle Charging in an Electrostatic Precipitator by Pulse and DC Voltages

L. E. Sparks, USEPA

Measurements of particle charge as function of particle radius for dc and pul energization were made at the exit of pilot plant ESP. The experimental app ratus utilizes a Milliken cell which allo measurement at three values of du electrical resistivity—low (approximate 10^{10} ohm cm), moderate (approximate 10^{11} ohm cm), and high (greater than 1C ohm cm). All experiments were conduct using a resuspended flyash. To compa the charging characteristics of dc a pulse supplies, the average current de sities for both cases were kept identic The results are compared with theory a previous experimental data.

Particle Collection in a Two-Stage Electrostatic Precipitator with Various Collector Stages

L. E. Sparks, USEPA

Data for pilot plant studies of partic collection in a two-stage ESP are pr sented. The ESP consisted of the EPA Southern Research Institute precharg followed by various downstream collect configurations. The configuration of th collector was changed by changing th discharge electrode geometry and meth of energization. Discharge geometri studied included wires, grid, and flat pla discharge electrodes. Pulse and dc ene gization was also studied. The exper ments show that significant improv ments in ESP performance are possible a properly designed two-stage system.

High Intensity Ionizer Development

M. H. Anderson,
Southern Research Institute

Results from parallel laboratory ar field studies to characterize the perfor ance of a "double-bellmouth" hig intensity ionizer (HII) are presented. The studies include measurements after th HII of particle charge as a function particle diameter, charge-to-mass rati the gas velocity distribution downstrea from the HII, electrical effects in transitic cavities containing highly charged par cles, and effects on particulate matt collection for a 1 MW HII/ESP combin tion. The studies show that the HII charg

fine particles in accordance with field charging theory; the gas velocity distribution after the HII can be adjusted by varying the anode purge air conditions; space charge precipitation effects can be significant in transition cavities following the HII; and the HII improves performance of an ESP for small-scale HII/ESP combinations, depending on ESP operating conditions.

Demonstration of Air Pollution Systems High Intensity Ionizer/Electrostatic Precipitator on an Oil-Fired Boiler

G. Raemhild and A. Prem,
Air Pollution Systems, Inc.

A study was performed to evaluate the applicability of Air Pollution Systems High Intensity Ionizer (HII) to the ESP of particulate emissions from a high-sulfur oil-fired boiler. The study was conducted on a 350 MW boiler at Long Island Lighting Company's Northport Station, Unit 1. Testing was done at 360 and 125 MW and included total mass samples, cascade impactor tests, and ultra-fine particle analysis. The electrical and physical parameters for the three field ESP in the mobile/HII/ESP pilot plant were adjusted to simulate the south-side ESP on Unit 1 as closely as possible. Simultaneous inlet/outlet particulate sampling was performed using the same methods as on the main ESP. Performance tests were conducted with the HII both "on" and "off" at 8400, 7000, and 3500 acfm. The results showed a significant decrease in particle penetration when the HII was energized.

Primary and Secondary Ionization in an Electron Beam Precipitator System

W. C. Finney, Florida State University

Recent investigation into the possibility of using energetic electron beams for generating high ion current densities for particle charging in ESPs has shown exceptional promise. Copius ion current densities, at least 500 times that in a conventional corona-driven ESP, have been reported earlier. Experimental results, however, have indicated a secondary charging phenomenon in a parallel plate system which affects the charge density stability.

The results of a study of the onset and extent of secondary ionization are presented here. Current vs. voltage experiments were performed using the parallel plate system used in previous ion current density investigations. The electron beam flux delivered to the system was restricted to determine the effect of primary ionization alone; then the transition to secondary ionization was explored.

The plate system's variable parameters were analyzed to quantify the conditions for initiation of secondary ionization. This secondary ionization is thought to be the result of the combined effects of space charge and plate voltage in the ESP section.

Influence on Particle Charging of Electrical Parameters at DC and Pulse Voltages

H. J. Joergensen,
Technical University of Denmark

Enhanced particle charging is considered to be one of the reasons for the improved performance of pulse-energized ESPs. For a pulsed condition, the charging levels obtained are influenced by several electrical parameters, such as underlying dc voltage, pulse level, and pulse repetition frequency. The reported investigation examines these influencing factors. The measurements are performed by a Faraday cage method on a conducting ball of 3-mm diameter, charged within the interelectrode space of two circular cylindrical electrodes. The investigation includes dc, as well as pulse energization. The results of the dc situation are compared with the saturation charges expected from the field charging theory. In the case of pulse energization, a simple model for the field charging under pulsed conditions is suggested and is used for a similar comparison.

Boxer-Charger Mark III and Its Application in ESPs

S. Masuda, University of Tokyo

The latest model of Boxer-Charger (denoted Mark III) uses double-helix electrode units and very-fast-rising pulse voltages with 40-300 ns duration time for their excitation. The helical discharge wires of a double-helix unit are insulated not by ordinary insulators but by coils which effectively reflect such a fast-rising, short duration pulse voltage. This is called "inductance-insulation." Its charging performance and effect on the collection performance of an ESP are presented. The collection performance at dust resistivity of 10^{11}-10^{12} ohm-cm can be greatly increased to a level equal to that obtainable under no back-discharge condition, when the precharging is made in front of each collection field repeatedly and the collection field energized with dc-plus-pulse voltage.

The Performance of an Experimental Precipitator with an All-Plate Zone

J. Dalmon,
Central Electricity Research Laboratories

An All-Plate ESP collector zone has been developed by the C.E.G.B. and tested in a small research rig at atmospheric temperatures. To provide data more closely related to power station ESP conditions, a program of tests has been carried out with the permission of the EPA on their experimental ESP facility at Research Triangle Park (NC). This consists of a four-zone, single-lane unit; for the tests, the conventional discharge wires in one zone were replaced by a single charged plate. In all zones, the spacing between the earthed plates was 200 mm. The gas velocity was kept constant at 1.6 m/s and the gas temperature ranged from 17°C to 150°C. The test dust was flyash having a mass median diameter of 7.2 μm and a resistivity of 2 X 10^{12} ohm cm.

The performance was evaluated as an "Effective Migration Velocity" (EMV) enhancement factor, with plate-plate electrodes/EMV with wire-plate electrodes. The factor averaged 3.1 for Zone 3 ESP.

The results indicate a clear advantage for an ESP incorporating an all-plate zone.

The Physics of Pulse Energization of Electrostatic Precipitators

L. Menegozzi, Research-Cottrell

Analytical/numerical computations for pulser operation are given for a simple geometry. The model describes and calculates the negative ion density produced by corona discharge due to a dc voltage with superimposed pulses. The space charge is then used to estimate wire-quenching effects, and compute the charging and collecting fields. The computer calculations also provide the amplitude and duration of the resultant current pulses. This information is needed for analytical treatment of back-corona suppression with pulse energization. Finally, the ESP enhancement factors for both large and

small particles are obtained. The results indicate that pulser application is a conceptually sound technology that would improve ESP performance in power-limited situations such as those arising with high resistivity dusts. The results also give a deeper insight into the dynamics of pulse energization.

Advanced Electrode Design for Electrostatic Precipitators

S. Bernstein, Flow Research Co.

The subject of this paper is a wavy-electrode ESP which employs a new collector electrode. The wavy-electrode ESP incorporates a contoured collector electrode geometry which produces nearly uniform electric field along the electrode. This feature allows operation with higher average electric field strengths near the electrode than for conventional designs. The wavy electrodes provide separated flow zones within their "valleys" which fluid-dynamically shields particles from the main stream. The design also provides mechanical rigidity to vertical bending without the sharp flanges normal to the flow commonly found in conventional ESPs. These features permit increased performance for all particle sizes, but especially help in the ESP of fine particles, which are normally the most difficult to collect. The paper describes the features of this advanced electrode design and an analysis of its significantly improved performance over conventional systems.

Section D—Industrial Applications

Problems in Applying an Electrostatic Precipitator to a Salvage Fuel-Fired Boiler

C. R. Thompson,
Naval Facilities Engineering Command

This paper addresses the problems encountered in applying ESP technology to a trash-burning, salvage, fuel-fired boiler. The ESPs were designed and constructed between 1972 and 1976. Stack emission tests after construction was completed showed that the emissions were 0.86 gr/dscf at 12% CO_2. The Virginia Air Emission Standard was 0.14 gr/dscf at 12% CO_2. Outlined are the steps undertaken to achieve final compliance. Each improvement to the ESPs (such as correction of inlet gas flow patterns, plate and wire alignment, wire improvements, increasing the number of collecting fields, and increasing power to the fields) is described and discussed. Also, improvements to the salvage fuel-fired boiler operating mode (such as tra feed, overfired and underfired air, a excess air) are outlined. Finally, t designed and actual operating paramete for the ESP are presented and compare

The Application of Electrostat Precipitators to Boilers Firing Multiple Fuels

R. L. Bump, Research-Cottrell

Recent years have seen a swing boiler designs which afford versatility the fuel. This is, of course, a result of t economics and availability of conventior fuels. Many process industries are usi their own waste products as a princip fuel source. The varying conditions i posed on the air pollution control devi as a result of this practice are discuss in this paper. Case histories are pr sented, as well as a discussion of some the operational considerations whi must be recognized. Since the pulp a paper industry has been a forerunner this activity, the majority of data present derive from this application.

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***Dale L. Harmon** is the EPA Project Officer (see below).*
The complete report, entitled "Third Symposium on the Transfer and Utilization of Particulate Control Technology: Volume II. Electrostatic Precipitators," (Order No. PB 83-149 591; Cost: $34.50, subject to change) will be available only from:
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