United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

EPA-600/7-78-112
June 1978

Research and Development

Rapping Reentrainment in a Near Full Scale Pilot Electrostatic Precipitator

Interagency Energy/Environment R&D Program Report

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EPA-600/7-78-112
June 1978

Rapping Reentrainment in a Near Full Scale Pilot Electrostatic Precipitator

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Contract No. 68-02-1875
ROAP No. 21ADL-027
Program Element No. 1AB012

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

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ABSTRACT

This report summarizes the results of an initial study to define the reentrainment characteristics of fly ash being removed from the collection electrodes of an electrostatic precipitator by rapping forces. The details of the study are presented in EPA-600/2-76-140, one of the Environmental Protection Technology Series of Documents entitled "Rapping Reentrainment in a Nearly Full-Scale Pilot Electrostatic Precipitator", May 1976. This study was conducted at the Rosemont Laboratory of FluiDyne Engineering in Minneapolis, Minnesota under the sponsorship of the Industrial Environmantal Research Laboratory of the U. S. Environmental Protection Agency at Research Triangle Park, N. C.

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INTRODUCTION

This document constitutes the final report under Contract 68-02-1875. The technical results of the study were published in Report E.P.A. 600/2-76-140, "Rapping Reentrainment in a Nearly Full-Scale Pilot Electrostatic Precipitator." This report summarizes the project including a discussion of the inclusion of rapping reentrainment in the E.P.A. electrostatic precipitator model. The study included a preliminary laboratory investigation to evaluate the measurement techniques; a preliminary field study at the FluiDyne Engineering pilot precipitator to evaluate the precipitator; a detailed field study to provide the rapping reentrainment data with analyses and finally, inclusion of rapping reentrainment data into the EPA-SRI electrostatic precipitator computer systems model.

The overall objective of this research program was to obtain the data necessary to provide a method for representing rapping reentrainment in the computer systems model. The fundamental processes in an electrostatic precipitator, including charging, particle transport and collection can be mathematically modeled from first principles. This, however, does not apply to reentrainment. The quantity and particle size distribution of the reentrained material must be determined in order to include these data in the computer system model.

This report discusses the results of an experimental investigation of rapping reentrainment using a nearly full-scale pilot precipitator at FluiDyne Engineering Corporation's Rosemont Laboratory. The work had three main objectives: (1) a study of the basic mechanics of removal of dry dust by rapping and the variations in the removal mechanisms with changes in dust properties, (2) quantification of rapping reentrainment in terms of the percentage of the total losses, and of the particle size distribution of the reentrained dust, and (3) modification of the E.P.A. - S.R.I. computer systems model to include losses due to rapping reentrainment into the computation process.

The laboratory study carried out under Task I utilized the E.P.A. pilot scale electrostatic precipitator located at S.R.I. to evaluate the proposed measurement techniques for use on the FluiDyne facility. The collection electrodes in the pilot E.S.P. were instrumented with an accelerometer system that had been calibrated by the use of an electromagnetic shaker facility.

Experiments were conducted to evaluate the ability of the instrumentation to discern the presence of rapping puffs. Individual impactors were operated during the particulate collecting period and during the rapping period to check their operation. Movies of the behavior of the dust layer were made during rapping to evaluate that system. The experiments showed that the equipment could be used to make measurements to identify the contribution of rapping puffs to the overall emission in the FluiDyne pilot precipitator facility.

Tasks II and III are covered in detail in Report No. E.P.A. - 600/2-76-140, Rapping Reentrainment in a nearly full scale Pilot Electrostatic Precipitator, dated May, 1976. These two tasks are summarized in this report.

SECTION II

TEST PROGRAM

A ten day test program was conducted at the FluiDyne test site as indicated in Table I. A schematic of the Fluidyne facility is shown in Figures 1 and 2. Figure 3 shows a block diagram of the test program.

The experimental program included a fundamental study of the mechanics of removal of dry dust by rapping and the quantification of rapping reentrainment in terms of the percentage of total emissions and particle size distribution of the reentrained dust. The percentage of dust removed from the plates depended on the mass per unit area of dust collected on the plates as predicted by theory. The build-up of a residual dust layer was observed. A residual dust layer developed that could not be removed with the available rapping intensities (up to 20 G's).

The contribution of rapping reentrainment to total emissions ranged from 53% to 18%, depending on rapping conditions. These percentages corresponded to 5.4% and 2.7%, respectively, of the dust collected on the plates being emitted during plate rapping. A significant decrease in total rapping emissions was obtained by increasing the time interval between raps. This decrease was related to the resulting larger mass per unit area collected on the plates before rapping.

Particle size distribution measurements showed that the mass median diameter of the particles emitted during the raps increased with increased time between raps. As expected, this produced lower overall emissions. The increase in the size of the particles emitted during rapping was ascribed to an increase in the agglomeration of the particulate removed from the precipitator plates with the respective increase in the mass per unit area collected on the plates (thicker dust layers) before the plates were rapped. A major portion of the reentrained material resulted from hopper "boil-up". A small portion of the dust would pass directly through the precipitator in a short burst at the velocity of the gas passing through the unit, while the remaining portion of the material was observed to fall into the hoppers, to rebound, and finally to escape slowly over the baffles and out of the precipitator. This produced a significant vertical concentration gradient in the dust emitted from the precipitator due to rapping reentrainment.

TABLE I

FLUIDYNE TEST PROGRAM

June 16	Unloaded and set up equipment.
June 17	Clean plate rapping accelerations, equipment checked.
June 18	Conditioned impactor substrates, tested for weight gains, clean plate V-I characteristics, gas velocity at sampling locations, adjusted for desired flow, measured gas velocities at entrance and exit planes of the precipitator, tested dust feed system, tested real time sampling system.
June 19	Measured inlet particle size distribution, inlet mass loading, and tested load cells. Checked mass trains and impactors to detect rapping puffs. Measured dust resistivity and adjusted for 10^{10} Ω-cm.
June 20	Ran efficiency test with following conditions: Dust feed Current density - 23 nA/cm^2 Gas velocity between plates - ∿0.91 m/sec Rapper intensity - 80% of maximum Rapper interval - 30 minutes inlet - 60 minutes outlet
June 23	Start intensive test program. All variables except rapping intensity and time interval between raps were held constant. The quantity of dust reentrained and the variables affecting reentrainment were measured. <u>Test 1</u> 150 minutes between raps, rapping intensity 100% of maximum, 1 rap <u>Test 2</u> 120 minutes between raps, rapping intensity 100% of maximum, 1 rap

TABLE I

FLUIDYNE TEST PROGRAM
(continued)

June 24	Test 3	12 minutes between raps, rapping intensity 80% of maximum, 6 raps
	Test 4	32 minutes between raps, rapping intensity 80% of maximum, 3 raps
June 25	Test 5	12 minutes between raps, rapping intensity 100% of maximum, 6 raps
	Test 6	32 minutes between raps, rapping intensity 100% of maximum, 3 raps
June 26	Test 7	52 minutes between raps, rapping intensity 80% of maximum, 3 raps
	Test 8	52 minutes between raps, rapping intensity 100% of maximum, 2 raps (rain and wind knocked out electrical power and burners, test was terminated 15 minutes after second rap)
June 27	Test 9	Deleted due to internal electrical short in the precipitator.

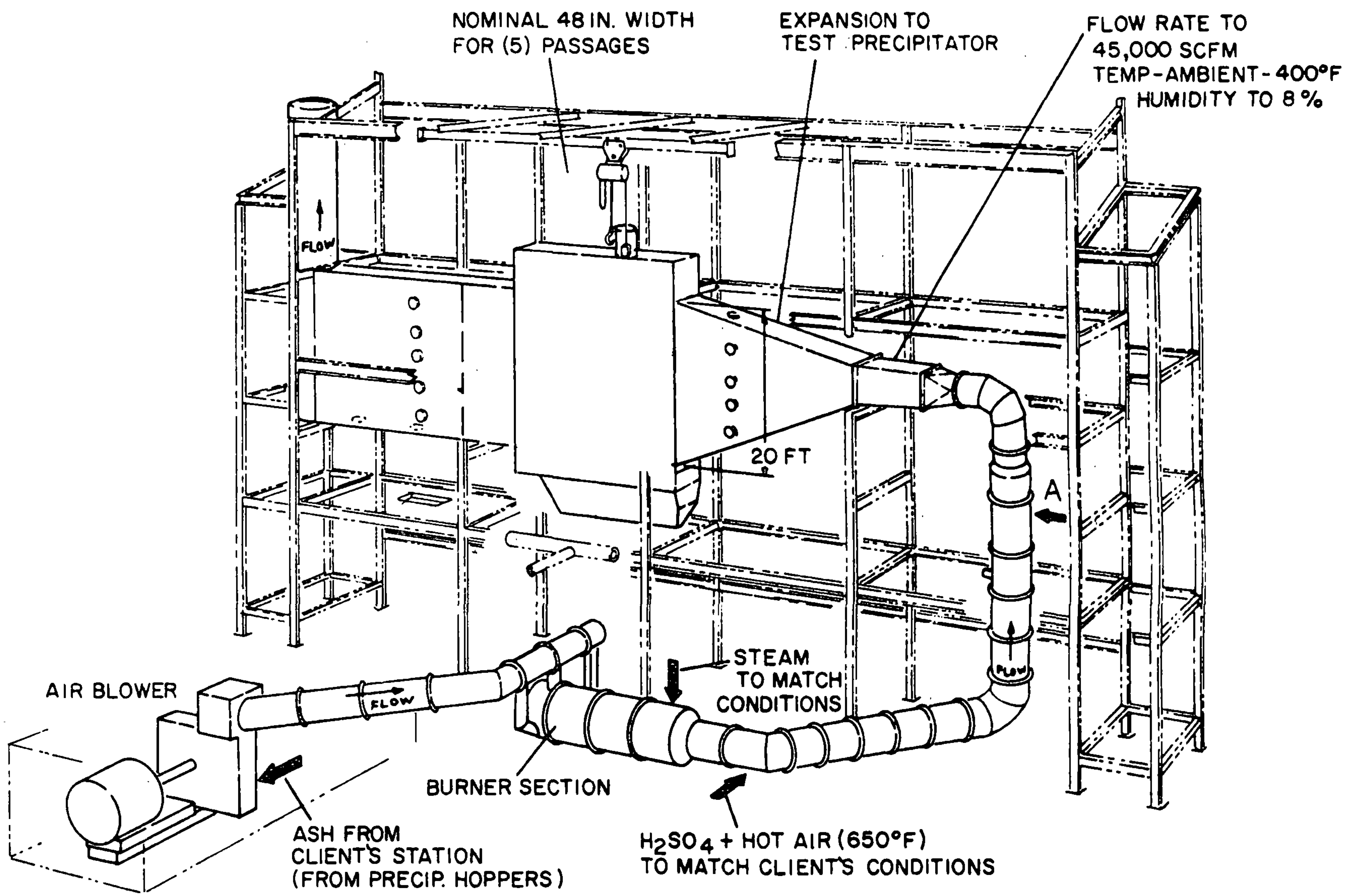

Figure 1. FluiDyne test facility

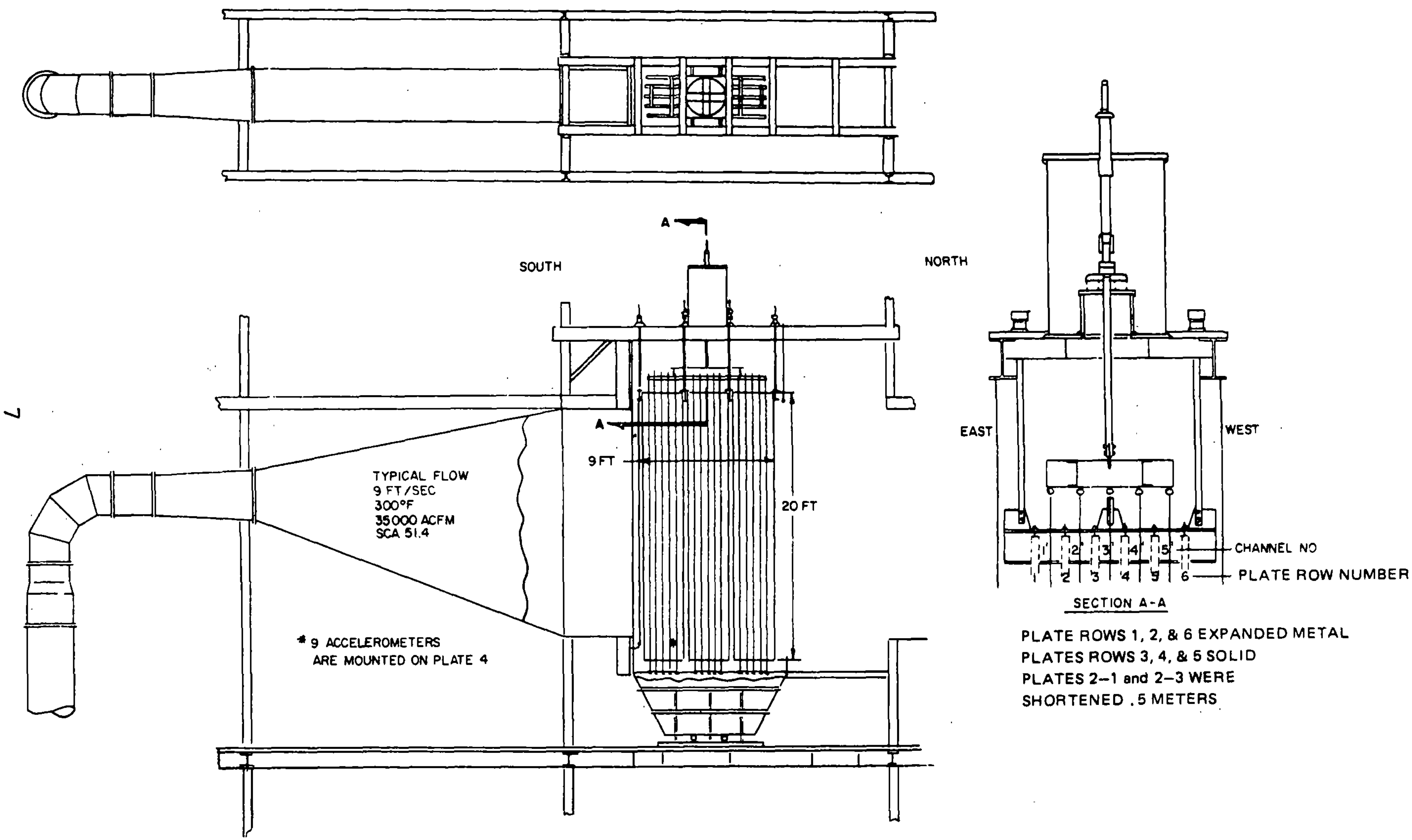

Figure 2. Various views of FluiDyne pilot precipitator.

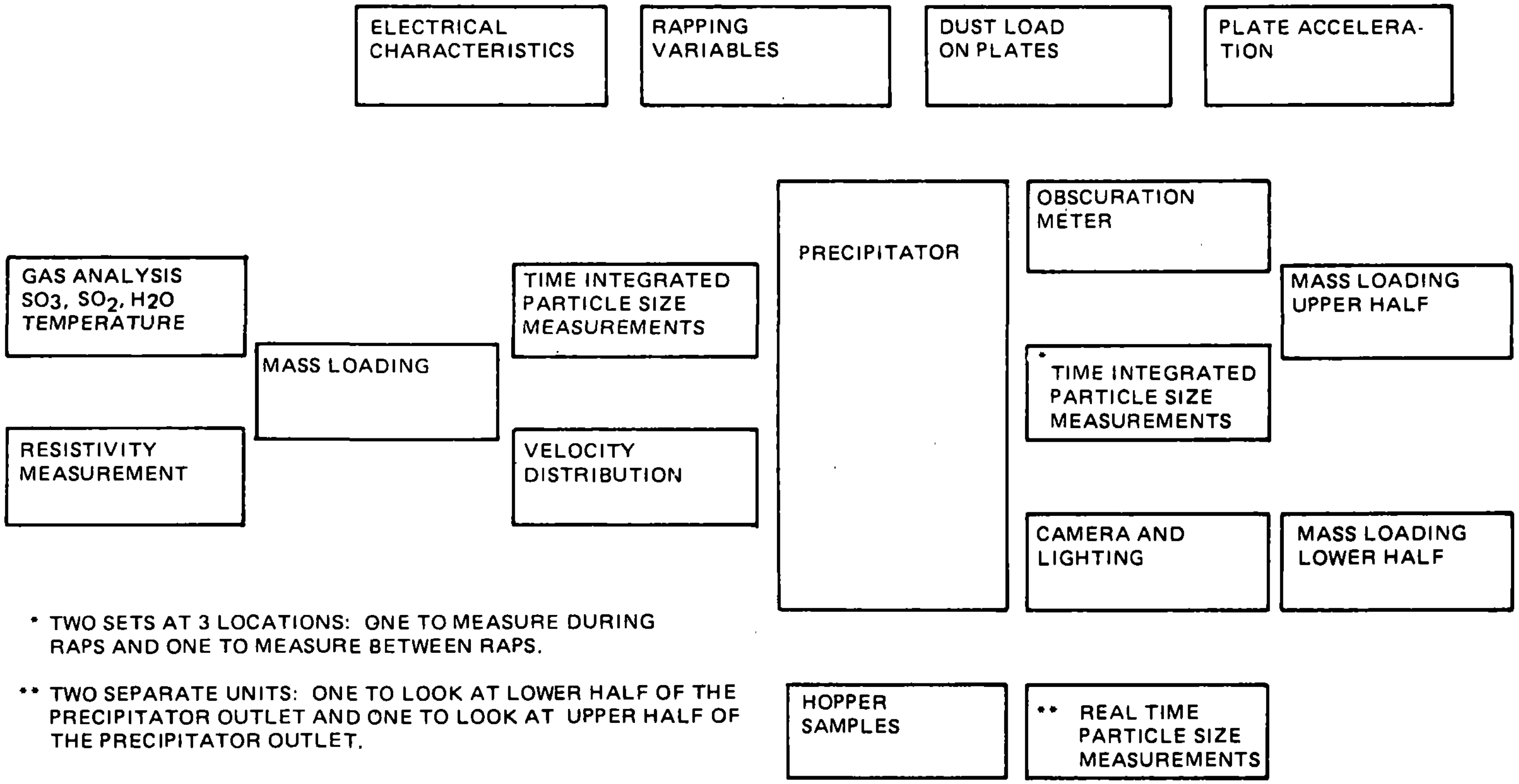

Figure 3. Block diagram of experimental layout for rapping reentrainment study.

The fractional collection efficiencies of the precipitator excluding and including rapping reentrainment emissions were determined and compared with theoretical values. Rapping reentrainment increased the discrepancy between theory and measured fractional collection efficiencies for particles larger than 5μm. However, rapping reentrainment did not account for all of the discrepancy. Reentrainment between raps and sneakage through the nonelectrified regions of the precipitator were considered to contribute to overall emissions.

The experiments provided data that suggested some problems in detailed mathematical modelling of rapping reentrainment. It is difficult to predict the quantity of dust removed from a plate by an individual rap. The calculation of the recollection of the reentrained material is difficult for several reasons. The particle size distribution of the reentrained particles can be changed significantly by moderate changes in rapping variables and hopper boil-up also contributes to the difficulty in modelling since much of the reentrained material is introduced into nonelectrified regions of the precipitator. However, the experiments supplied some information that could be used to estimate the effects of rapping reentrainment on the size of a precipitator required for a given collection efficiency.

Two simplified assumptions were used to estimate the significance of rapping reentrainment. The first assumption was that a fixed percentage of rapping emissions was emitted from a precipitator independent of the size of the unit, while the second assumption was that the same percentage of material was reentrained and emitted from each section due to rapping. The recollection efficiency for the reentrained material was assumed to be the same as that for previously uncollected material for all sections. The estimates based on the above showed that the increase in precipitator size needed to recover the rapping emissions can range from 6% to greater than 80% of the original size of the unit for the cases considered. Rapping reentrainment emissions computed on the basis of the percentages obtained at FluiDyne account for a significant portion of precipitator emissions.

Initially, four weeks of tests were planned for Tasks II and III. At the conclusion of the test period described previously in Table I, the status of the test results and the funding situation was reviewed. It was determined that:

1. Additional funds would be required to conduct two more weeks of tests.

2. The results of the tests to date provided sufficient data for the pilot test facility.

Therefore additional pilot scale tests were cancelled.

During the period of this research contract, the Electric Power Research Institute had funded a study of Rapping Reentrainment at a number of full scale installations. The Industrial Environmental Research Laboratory of E.P.A. and the E.P.R.I. agreed to cooperate on the rapping reentrainment study. The result of the E.P.A. pilot study served as a guide for establishing the test program for the E.P.R.I. field tests.

This field test program included rapping reentrainment measurements at six installations described as follows:

- Two cold side units collecting fly ash from the combustion of low sulfur Western coal.
- Two cold side units collecting fly ash from the combustion of high sulfur Eastern coal.
- One hot side unit collecting fly ash from the combustion of low sulfur Western coal.
- One hot side unit collecting fly ash from the combustion of low sulfur Eastern coal.

The results from these tests have been reported, in draft form, to the E.P.R.I. in a document entitled "Electrostatic Precipitator Rapping Reentrainment and Computer Model Studies", August 15, 1977. A copy of this draft report was submitted to the Industrial Environmental Research Laboratory, Environmental Protection Agency, Research Triangle Park, North Carolina for review.

SECTION III

COMPUTER MODEL MODIFICATION

Task IV of the E.P.A. contract was to include rapping reentrainment into the E.P.A. - S.R.I. electrostatic precipitator computer systems model. The results of the measurement program conducted at the above six full scale field installations have been reviewed, analyzed and used to develop a calculation procedure for approximating the magnitude of rapping reentrainment emissions as follows:

1. The dust concentration removed from the flue gas by the last field was estimated from the Deutsch equation and the overall mass efficiencies obtained during the test programs at each installation.

2. The overall mass emission (in mass/volume of flue gas) attributable to rapping were graphed as a function of the dust calculated to have been removed by the last field for each of the six installations.

3. The rapping emissions were represented as a function of the dust removal in the last field by a simple exponential expression, and the expression was programmed into the computer model.

4. Data from the six installations were used to construct an average apparent size distribution of a rapping puff. This size distribution is then applied to the mass emissions caused by rapping and calculated in step 3 above to obtain a histogram of rapping emissions as a function of particle size.

5. The size dependent rapping emissions are then added to those calculated by the model to originate from the steady-state, non-rapping precipitator process.

A draft report has been transmitted to I.E.R.L. that describes this expanded version of the computer systems model. This updated a previous report No. E.P.A. - 650/2-75-037, "A Mathematical Model of Electrostatic Precipitation", dated April, 1975. This new version of the model contains the currently available rapping reentrainment computer program modifications as well as other modifications developed under E.P.A. Contract 68-02-2114.

SECTION IV

RECOMMENDED RESEARCH

The method utilized to represent size-dependent rapping losses in the computer model described previously in this report is an empirical one based on an average apparent size distribution of particulate emissions attributable to rapping. The size distribution data were obtained from full-scale field tests. The total mass emissions from rapping are also represented empirically. The procedure used is based on a simple relationship between the mass calculated to have been collected in the last field of the precipitators and the rapping emissions measured during field tests. Although this procedure represents a useful interim technique for estimating rapping reentrainment in precipitators, it is desirable to include rapping into the model in a more fundamental way for modeling precipitator performance.

The ESP computer model program calculates particle collection rates for representative particle sizes as a function of length through the precipitator. This basic calculation procedure is suitable for including a dynamic representation of reentrainment resulting from a particular rapping system design. The particulate reentrained as a result of rapper activation in a given field at a given point in time may be thought of as a pulse in the particulate concentration in the field under consideration. A technique to model the reentrainment of dust from first principles should include consideration of the following problems:

1) What are the size distributions of the reentrained particulate from the various fields and what fraction of the collected mass is reentrained?

2) To what extent is the particle charging process disrupted by the sudden reintroduction of a significant particulate concentration?

3) To what extent are the reentrained particle remixed with the gas stream?

4) What collection mechanism can best represent the recapture of reentrained particulate? Since a Deutsch-type mechanism is valid only for smaller particles which follow the motion of the gas stream, we anticipate that the reentrained

material (dominated by the larger agglomerate, >5 μm diameter) will require a different mathematical expression to represent the trajectory.

5) Does the pulse of dust resulting from a rapper activation cause a momentary decrease in sub-tenth micron particulate emissions due to the sudden increase in potential surface area for agglomeration.

6) What relationships can be formulated to represent the cumulative mass size distribution of the reentrained material as a function of the following variables?

   a) Rapping interval

   b) Ash and gas composition, temperature, and size distribution of collected dust, which determine dust cohesive and adhesive properties.

   c) Plate acceleration

   d) Plate response

   e) Mass loading of dust on plate

   f) Plate geometry

   g) Gas velocity

   h) Electrical holding forces

It is apparent from the nature and the complexity of the reentrainment process that some degree of empiricism must be incorporated into a modeling approach. However, since the existing mathematical model is able to simulate the collection process with reasonable accuracy, a logical approach would be to use the existing program structure as a basis for calculating the recollection of reentrained dust. Once this task is accomplished, it would be possible to examine the effect of rapping frequency and certain precipitator design parameters on overall collection as a function of particle size for various assumed input cumulative mass distributions resulting from electrode rapping. The complete modeling of the reentrainment process must include the task described in item 6 above, which essentially involves the prediction of the rapping pulse in the various fields as a function of dust properties and precipitator design and operating parameters. Thus, there are two major subdivisions to the recommended approach for a more rigorous treatment of the reentrainment process: 1. Expanding the computer program to obtain the capability to calculate time-dependent emissions from the existing input data set (Electrical conditions, SCA, precipitator geometry, size distribution, etc.) plus a rapping interval schedule for the various fields and an assumed cumulative mass distribution for the rapping pulse. 2. Prediction of the rapping pulse distribution from dust properties and precipitator design parameters.

In view of the above considerations, our suggestions for follow-on work are as follows:

1) Expansion of computer program

   a) Develop a flow chart of a computer program based on the existing model, but with the capability of dynamically representing rapping programs with various intervals for the different fields in the precipitator.

   b) Develop appropriate mathematical relationships for representing the dynamic behavior of reentrained particulate in the precipitator. The objective is to formulate a collection mechanism theory appropriate for reentrained dust.

   c) Examine the data obtained previously with the objective of finding a procedure to represent the sporadic large particle emissions not associated with rapping.

   d) Develop a FORTRAN program with items 1-3 included.

   e) Use the expanded program with various assumed cumulative mass rapping pulses and the rapping frequencies of the rapping programs at the six test sites. Compare computed results with time integrated measurements obtained with impactors.

2) Prediction of rapping pulse size distribution

   a) Modify existing large particle real-time counting system to allow for traversing of the duct system. Develop procedures for calibrating the readout with absolute value of <u>in situ</u> particle concentrations.

   b) Design a test program to use the instrument at several sites with the objective of relating the rapping pulse (from various fields in the precipitator) to dust properties and precipitator operating parameters. The test requirements could be less than is normally required for control device evaluation because of the restricted data requirements.

c) Correlate results and use in 1 above to expand model capabilities.

The two major tasks described above could be conducted simultaneously or in series.

TECHNICAL REPORT DATA *(Please read Instructions on the reverse before completing)*		
1. REPORT NO. EPA-600/7-78-112	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Rapping Reentrainment in a Near Full Scale Pilot Electrostatic Precipitator		5. REPORT DATE June 1978 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Grady B. Nichols		8. PERFORMING ORGANIZATION REPORT NO. SORI-EAS-78-019 3489-Final
9. PERFORMING ORGANIZATION NAME AND ADDRESS Southern Research Institute 2000 Ninth Avenue, South Birmingham, Alabama 35205		10. PROGRAM ELEMENT NO. 1AB012; ROAP 21ADL-027 11. CONTRACT/GRANT NO. 68-02-1875
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 5/75-4/78 14. SPONSORING AGENCY CODE EPA/600/13
15. SUPPLEMENTARY NOTES IERL-RTP project officer is Leslie E. Sparks, Mail Drop 61, 919/541-2925. EPA-600/2-76-140 is an earlier related report.		

16. ABSTRACT

The report gives results of a research program to identify the characteristics of particulate matter reintroduced into a gas stream flowing through an electrostatic precipitator (ESP) attributable to collection electrode rapping. The study included both fundamental and experimental studies of dust layer behavior in a pilot-scale ESP with collection electrodes of a size that approximates those in a full-scale field unit. Results of the pilot study, together with those of a related study of full-scale ESPs collecting flyash from coal-fired boilers, were used to modify the EPA Computer Systems Model of an ESP to more nearly represent the actual behavior of this class of particulate control device.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Combustion	Air Pollution Control	13B	
Dust	Boilers	Stationary Sources	11G	13A
Electrostatic Precipitation		Particulates	13H	
Entrainment	Mathematical Modeling	Rapping	07D	12A
Fly Ash		Reentrainment	21B	
Coal			21D	

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Unlimited	Unclassified	21
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)