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ACOUSTIC AGGLOMERATION OF POWER-PLANT FLY ASH

A Comprehensive Semi-Annual Progress Report

by

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February 1, 1980

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Pennsylvania State University
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THE CENTER FOR AIR ENVIRONMENT STUDIES

Recognizing the interdisciplinary nature of problems involving the interaction of man and his air environment and the necessity for inter-college cooperation in efforts to seek solutions to these problems, The Pennsylvania State University established the Center for Air Environment Studies in 1963. Organized as a unit of the Institute for Science and Engineering within the Intercollege Research Programs and Facilities, it draws on the resources and talents of many departments. Faculty members affiliated with the CAES hold joint appointments with academic departments; such as, Engineering, Plant Pathology, Chemistry, Forestry, Environmental Health, Veterinary Science, and others. There are additional faculty members who are associated with the Center through research projects alone.

The Center for Air Environment Studies fosters intercollege and interdepartmental cooperation and maintains a broad, flexible approach to air pollution research. The nature and direction of this research - supported by federal and state governments, industry, and the University - reflects the personal interests and abilities of the faculty and staff and responds to known problem areas. Typical areas of research are: studies on the biological effects of air pollutants on animals and vegetation; development of species resistant to specific pollutants; studies of combustion processes leading to lower contaminant emissions; determination of best methods of collection and sampling devices; research into small particle behavior; fundamental techniques of particle control; and fundamental research on the chemistry, photochemistry, and atmospheric reactions of airborne contaminants.

Reflecting the demand for atmospheric quality and the need for personnel with varying degrees of education, training, and specialization; several air pollution training programs have been initiated at the University under the auspices of the Center. As an intercollege unit, the CAES does not grant degrees nor offer any courses of its own; however, air pollution courses are taught in many academic departments of the University by CAES associated faculty members. These courses are supported by the Center through the administration of student training funds and through the provision of graduate assistantships. In an effort to expand the offerings in the field, an interdisciplinary Environmental Pollution Control Master's Degree Program was established in 1971 by the Graduate School and a number of the degree candidates conduct research under the direction of faculty associated with the Center. In addition to resident instruction and in response to external requests, public service instructional programs have been initiated through the Center. One example is the Visible Emissions Training Program offered by the Center and coordinated with the Bureau of Air Pollution and Noise Control of the Pennsylvania Department of Environmental Resources. Since federal legislation mandates that smoke inspectors be certified at six month intervals for their ability to estimate visually the density of plumes emitted from stacks or vents, this Program serves as the certification procedure for Pennsylvania Department of Environmental Resources employees as well as for industrial, state, and federal personnel.

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INTRODUCTION

In this semi-annual Progress Report on Contract Number DE-AC01-79ET11311, we describe our progress in considerable detail on each of the tasks, which are defined in the Statement of Work of the Contract as given in Item 2 entitled, "Scope of Work".

ITEMS OF PROGRESS

In this section of the Progress Report, we will first repeat the descriptions of the Task as given in the Statement of Work, followed by the present state of the project and the progress made to date.

TASK ONE

A second generation computer model of the agglomeration process employing acoustic means shall be developed. The model will take into account both gas temperature effects and the absorption of acoustic energy by particulates and also air. This task is important since it addresses the fact the flue gas temperatures of up to 1650° F may enter the agglomerator.

Report of Progress

The analytical model of the agglomeration process of the particulates, after a careful review and analysis and a study of the current literature, has been reformulated using the following basic assumptions:

1. The particles do not interact, except on contact.
2. All particles are initially identical, that is, the same material size and properties.
3. All collisions lead to agglomeration, that is, collision efficiency is equal to 1.

4. Agglomeration is determined by the collision rate.
5. The shape of the agglomerates will be near a porous sphere, rather than a chain of particles.

The analytical model of the agglomeration process continues to be based on two mechanisms, namely the diffusion mechanism and the orthokinetic mechanism. The temperature effects are included in the changes due to temperature in the speed of sound of the medium, and the sensitivity of the viscosity of the air to temperature variations.

The numerical solution procedures which have been formulated are based on the following six steps:

1. Computation of particle size classes and number, and the mass fractions.
2. Computation of every volume of agglomerates for each class.
3. Computation of the average velocity.
4. Computation of the minimum agglomeration time.
5. Computation of the average particle density of every class.
6. Checking that mass conservation has been satisfied.

It has been established that the complete formulation of the coagulation mechanisms, including both the diffusion processes and the orthokinetic mechanisms, results in a very complex computer program. Tests have therefore been formulated to establish which of the processes dominates the agglomeration process. By performing these tests, it has been possible to considerably simplify the numerical procedures and obtain a solution process which is considerably more economic of computer time. At the present time, the computer program is being formulated and in the near future will be tested.

TASK TWO

The already existing Penn State University acoustic agglomeration facility shall be rebuilt in such fashion as to increase the sound pressure level capability of the facility from a current value of 120 dB to that of 150 dB. To accomplish this, the inside walls shall be lined with essentially non-absorbing (1/4 inch) transite sheet. In addition, the existing Altec 209E electromagnetic driver, capable of delivering 0.7 acoustic watts (120 dB) maximum at 4000 Hz shall be replaced with a speed controlled and variable-speed siren, which is capable of delivering 600 acoustic watts at frequencies up to 4000 Hz.

Report of Progress

The major activity during this reporting period was the design and development of the high frequency-high intensity variable speed siren. The siren has to be capable of delivering at least 600 acoustic watts at frequencies up to 4,000 Hz, with a lower frequency of 1,000 Hz. We have completed the design of the siren. A layout drawing of the siren is shown in Figure 1. The manufacturing of the siren, which is taking place in the Machine Shop of the College of Engineering at The Pennsylvania State University, is essentially complete. Assembly and check-out of the siren will be carried out during the latter part of March, 1980.

The principles on which a siren operates are rather simple. A rotor, with teeth at its periphery, is attached to the armature of a variable speed electric motor. As the motor turns, the teeth alternately open and close holes called ports, through which compressed air is forced. The acoustic power generated by the cutting and opening of the air stream depends on the mass flow of the air through the ports, and the nature of the cut-off and

FIGURE 1: CUTAWAY VIEW OF PSU SIREN

cut-on process. The frequency of the sound depends on the speed of the rotor and the number of teeth and ports on the rotor and the porting arrangement. In the analysis of the siren, the first step is to determine the air flow necessary to produce the 600 acoustic watts. Mednikov⁽¹⁾ presents a semi-empirical formula of the form of Equation (1).

$$W_{AC} = \alpha_c (1 + \delta) Q_M L_{AD} \eta_{AC} \quad (1)$$

where:

α_c = constriction coefficient of air stream cut off by a tooth

δ = leakage coefficient

Q_M = theoretical compressed air flow (M^3/s)

L_{AD} = theoretical work done in the adiabatic expansion of $1m^3$
of compressed air ($N-M/m^3$)

η_{AC} = acoustic efficiency of the siren

W_{AC} = acoustic power

The last term of the acoustic power equation, the acoustic efficiency, depends on the shape of the rotor teeth and the ports, the compressed air pressure, the frequency, the type of horn, and various engineering features such as the gap between the rotor and stator and the wobbling of the rotor. Rather than try to determine all these factors, the term η_{AC} was used simply as a function of the chamber pressure inside the siren, the frequency, and the type of horn. Under these conditions, the acoustic efficiency is approximately given by Equation (2).

(1) References given at the end of this section.

$$\eta_{AC} = \frac{\rho(P_c)}{1 + 0.5 (ka)^2 + \beta a} \quad (2)$$

where:

P_c = chamber pressure

$k = 2\pi/\lambda$ - wave number

λ = wavelength at excitation frequency

a = width of opening

β = expansion factor of the exponential horn

$\rho(P_c)$ = function of chamber pressure

Preliminary calculations showed that the last two terms in the denominator were negligible for the frequencies at which the Penn State siren will operate. Thus, the acoustic efficiency is a function only of chamber pressure.

$$\eta_{AC} \approx \rho(P_c) \quad (3)$$

The values of this function, assuming the ambient pressure into which the siren radiates as simply atmospheric pressure, are given in Table I. The values of the function $\rho(P_c)$ for higher chamber pressures are not presented here because they would result in a choked flow condition in the siren ports.

This method of determining efficiency was compared with the efficiencies quoted by Jones⁽²⁾ for his fifty-horsepower siren. The large siren was used for comparison since the efficiency would be more dependent on the flow process than on small leaks or slightly improper balancing. The acoustic efficiencies stated by Mednikov and Jones were different by only 2%.

TABLE I

P_c (atm)	$\rho(P_c)$
1.0	1.000
1.1	0.888
1.2	0.813
1.3	0.758
1.4	0.712
1.5	0.675
1.6	0.642
1.7	0.618
1.8	0.595
1.9	0.577

The adiabatic work term from the acoustic power equation is:

$$L_{AD} = \frac{\rho_c}{2} w^2 \quad (4)$$

where:

ρ_c = density of compressed air

w = air flow density at exit

The air flow density is found by assuming an isentropic relation for the flow through the ports. Thus:

$$w = \sqrt{2g \frac{\gamma}{\gamma-1} \frac{P_c}{\rho_c} \left[1 - \left(\frac{P_k}{P_c} \right)^{\frac{\gamma-1}{\gamma}} \right]} \quad (5)$$

where:

γ = ratio of specific heats

g = acceleration of gravity

P_c = chamber pressure (absolute)

P_k = ambient pressure (absolute)

Therefore, the adiabatic work term is a function only of chamber pressure and the pressure ratio.

Recalling that the acoustic efficiency term did not take into account the characteristics of the siren, these effects, as well as the constriction coefficient and the leakage coefficient, will be lumped into one term, θ , called the siren coefficient. Thus, the acoustic power equation now reads:

$$W_{AC} = \theta Q_M L_{AD} \eta_{AC} \quad (6)$$

Since the proposed design of the siren is similar to that published by Allen and Rudnick in 1947⁽⁵⁾, the value of θ was determined from the known chamber pressure, flow rates, and acoustic power outputs of the siren built and tested by Allen and Rudnick. The value best describing their results was $\theta = 0.34$.

Now that θ has been determined, the compressed flow rate, Q_M , can be found as a function only of chamber pressure. The results are presented in Table II.

The search for a compressed air source to meet the above flow requirements resulted in the choice of a Roots Type 25045 blower. This blower is capable of delivering 124 scfm at 10 psig (1.68 atm) when coupled with a 10 hp motor. The blower-motor package was purchased from Tate Engineering Inc. and is being installed in the Research Unit space.

This selection allows the siren to be designed to operate at $P_c = 1.6$ atm.

The cross sectional area necessary to carry the 124 scfm is found from (4):

$$S_o = \frac{1}{\epsilon_o^w} Q_M \left(\frac{P_c}{P_k} \right)^{1/\gamma} \quad (7)$$

where

S_o = cross-sectional area for air flow

ϵ_o = coefficient giving the extent the openings are cut off by the rotor teeth

Comparison with the data on Allen and Rudnick's siren showed that $\epsilon = 0.34$ was the best value, and thus, $S_o = 5.79 \text{ cm}^2$.

TABLE II

P_c (atm)	Q_M (scfm)
1.1	418
1.2	242
1.3	182
1.4	153
1.5	135
1.6	124
1.7	115
1.8	109
1.9	103

The requirements of the siren's application determined the motor to be used. The maximum frequency of 4,000 Hz called for a high speed motor. Part of the power of the siren motor would be used to overcome skin friction drag. The power needed to turn an enclosed rotating disk is⁽⁴⁾

$$P_{SF} = C_F \rho \omega^3 a^5 \quad (8)$$

where

P_{SF} = power to overcome skin friction

ρ = density of air

ω = angular velocity of rotor

a = radius of the rotor

C_F = skin friction constant

A conservative value of the skin friction constant, determined by assuming a turbulent boundary layer with a universal velocity profile, is $C_F = 0.02375$.

More power is needed since the air flow, while passing through the rotor teeth, receives a circumferential acceleration. For a conservative estimate, it was assumed that all the air passing through the siren is accelerated to the rotor tip speed. The power required to do this is:

$$P_F = \dot{m} (R\omega)^2 \quad (9)$$

where

P_F = power needed to accelerate the flow

$\dot{m}$ = mass air flow

R = radius of rotor

These equations give conservative estimates of the power requirements for Allen and Rudnick's siren. They predicted that the new siren would need a 1/4 horsepower electric motor.

However, there was one more important requirement for the motor. Testing on the acoustic field indicated that a siren producing a warble tone would reduce the large variations in sound pressure level within the chamber that could result from pure tones. Thus, a much larger motor was needed. It was determined that a two-horsepower Dumore motor used by Federal Signal Corporation in their Thunderbolt sirens would have the power needed to produce a warble tone. The Federal Signal Corporation motor has three excellent design features that are needed: 1) the large size for a universal motor, 2) a reasonable speed, 6500 rpm, and 3) maximum cooling by passing the air flow over the motor field and armature.

One of the most critical parts of the siren is the rotor. High strength aluminum is being used to minimize the weight while retaining strength. The stresses in the rotor are minimized by using an exponential thickness distribution as shown in Figure 2.

The equation for the thickness of the rotor is⁽⁵⁾:

$$t = A e^{-br^2} \quad (10)$$

where:

t = thickness

A = thickness at center

b = exponential coefficient

r = radius

The normal stress in the radial or tangential direction in a rotating disk

FIGURE 2
Drawing of Rotor for PSU Siren

of exponential thickness is related to the exponential coefficient⁽⁵⁾.

$$\sigma = \frac{\rho \omega^2}{2b} \quad (11)$$

where

σ = normal stress

ρ = material density

For the Penn State siren's rotor, $b = 0.1835 \text{ in}^{-2}$; and the stresses were thus on the order of 320 lbf/in^2 . This analysis, while it does not take into account the stress concentrations due to holes in the rotor, or the stress concentrations at the teeth, still shows that the stresses should be well within the strength of the material.

The ports through which the air exits have a diffusing angle of six degrees (see Figure 3). This angle is a good compromise between smaller angles which allow more wall friction losses for the same change in area, and large angles where there can be flow separation from the walls.⁽⁶⁾ The gap between the rotor and the ports is controlled by the thickness of the layers of shimstock. This will allow operation with clearance of 0.001 inch. The flow exits from the ports into an exponential horn. The horn has a cut-off frequency of 500 Hz and provides the best possible acoustic coupling between the siren and the agglomeration chamber. The electronic circuit to control the speed of the motor is now under investigation. The present plans include purchasing a silicon controlled rectifier (SCR) and modifying it so that the voltage to the motor can be varied around a mean value. By matching the variations in voltage to the inertial and inductive properties of the motor, a warble tone will be produced.

FIGURE 3
Top Piece of PSU Siren Including Exit Ports

FIGURE 4
Photographs of Fabricated Siren Parts

FIGURE 5
Photograph of Fabricated Siren Parts

At the present time (February 1980), most of the parts of the siren have been fabricated in the machine shop of the College of Engineering. Figures 4 and 5 are photographs of the fabricated parts. The Roots blower compressed air supply has been procured and is being installed next to the agglomeration chamber. The exponential horn is also being fabricated.

We expect to start testing the siren system during the latter part of March 1980.

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- (4) White, Frank M., Viscous Fluid Flow, McGraw-Hill Book Company, 1974, p. 171.
- (5) Morley, Arthur, Strength of Materials, Ninth Edition, William Clowes and Sons, Ltd., Great Britain, 1940. p. 402.
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TASK THREE: CONFIRMATION OF PRIOR TEST RESULTS OBTAINED FROM ACOUSTIC AGGLOMERATION OF PARTICULATES

Particulates-agglomeration using acoustic stimulation shall be undertaken in the improved PSU treatment facility. Conditions prevailing in prior PSU exploratory research shall be re-studied on a small scale to both confirm the accuracy of the earlier studies and check out the capability and effectiveness of the modified PSU acoustics agglomeration test facility. Because of the particular pertinence of fly ash agglomeration to the DOE Division of Power Systems program objectives, the major portion of this Task shall be concerned with fly ash aerosols. However, a limited number of particulate-agglomeration tests employing kaolin clay and for carbon black aerosols also shall be run so as to provide secondary checks on both equipment effectiveness as well as techniques. Special effort shall be expended to improve the counting technique essential to the conduct of the product dealing with the treatment of large numbers of minute particles. The possible use of mechanized counting methods such as those used in scanning electron microscope technology shall be investigated. Approximately 50 tests employing acoustic means for agglomerating both micron and sub-micron particulates shall be carried out under the following general conditions.

1. Frequencies: 1,000, 2,000, 3,000 and 4,000 Hz
2. Amplitudes: 100, 110, 120 dB
3. Mass loadings 2, 4, and 6 g/m³
4. Exposure times of 10, 20, 30, and 40 seconds
5. Aerosols of fly ash, kaolin clay, or carbon black
6. Size-number distributions similar to those used in the previous PSU tests with a mean size of about 0.5 micron

Report of Progress

Introduction

Two major efforts were carried out in this Task during this reporting period: 1) We felt that it would be advisable to completely re-build the aerosol generation system in order to obtain better control of the generation process, as well as more reliable measurement of the aerosol generation system. In addition, we felt that since the system had been dormant since 1975, that it would be appropriate to completely clean and re-build and rearrange the system. 2) In reviewing the earlier work that was done in the acoustic agglomeration research, we established that the acoustic field had not been mapped in the detail in terms of the spatial distribution of the acoustic pressure that would be desirable. It is well known that in a chamber of the size that we are dealing with, and at the frequencies in the 1,000 to 4,000 Hz range, that many standing waves would be generated by a pure tone source, again such as had been used. We therefore believed that it would be very important to establish the spatial distribution of the sound field in order to assure that representative measurements will be made of the sound field in the chamber. Ideally, we would like to have the so-called "diffuse" sound field, meaning that the sound pressure is the same throughout the acoustic agglomeration space. For the case of standing waves, as would be generated by the pure tone source, variations of as much as 30 dB would be expected to exist in such a reverberant space. We therefore made it our aim to first of all establish the acoustic field as it exists from a pure tone source, and then to develop means for at least approaching a diffuse field, meaning that we wanted to reduce the spatial variations of

the sound pressures in the space so that the aerosol would be exposed to as uniform an acoustic field as could be practical.

Rebuilding of the Aerosol Generation System

In order to initiate the research project, maintenance had to be performed on the air flow and dust generation system. The old system was dismantled and cleaned. Pipes were re-sized for better flow and flow control. A control panel, shown in Figure 6, was built and installed to facilitate ease of operation. The basic flow configuration of this original system was retained, but a dessicant bed air dryer and two Balston coalescing filters were added to increase the cleanliness and decrease the moisture content of the air used in the generation of the dry dust, as shown in Figure 7. A diagram of the air flow system is attached as Figure 8. The agglomeration chamber was also disassembled and the mixing manifold cleaned; repairs were made to the system as necessary (see Figure 9).

Fly ash for the project was obtained from the University power plant and transported to the Center for Air Environment Studies (CAES) in drums. This material had to be processed in two steps. In order to obtain particles whose size did not exceed approximately $38\text{ }\mu\text{m}$, a cyclone separator was used. After testing several procedures, this method was selected as the best way to handle the large quantities which were required. Over 2000 pounds of fly ash was processed to obtain 125 pounds of the fine material. The second step was to send this material to Sturtevant Mill Co., where it was air milled to further reduce its size to an average of about $2\text{ }\mu\text{m}$. The quantities obtained should be adequate for the entire project.

FIGURE 6

Photo of the Twin Dry Dust Generators
and Pressure Gauges

FIGURE 7

Photo of Main Air Line and Filters

(Note where the line enters the
chamber at the far right of the
photo)

FIGURE 8

FIGURE 9

Looking Down the Chamber Into the Exponential Horn

(Note the holes where the dust actually enters the chamber. This horn will be replaced by a high-output acoustic siren in the near future)

All rotometers were calibrated individually and placed in the system. The total flow into the agglomeration chamber was measured as well, and calibration curves were drawn. As a second check, the air flow velocities were measured at each of the eight tubes in the manifold where they entered the chamber using a pitot tube and a precision manometer. These velocities were checked at several flow rates to confirm the total flow as measured by the rotometers. Velocities were also checked at the sampling point using a Thermosystem's velocity transducer and velocity checks were made over the cross sectional area of the chamber at the sample point.

A sampling system was designed so that two simultaneous samples could be collected on filters using a vacuum pump; samples may also be deposited on electron microscope grids using an electrostatic precipitator. By the use of glass fiber and Nuclepore filters, it will be possible to obtain samples to determine the concentration of particle matter in the chamber and at the same time acquire a sample for use in the scanning electron microscope (SEM). The samples submitted for SEM analysis will allow for automated particle sizing and save many hours. It is anticipated that the electron microscope will be used to ascertain whether a significant number of particles are not being counted by this method, since the SEM has a lower limit of about 1.0 μm . It should be possible, by using both the SEM and the electron microscope, to obtain accurate particle size distributions.

Several tests have been run to check out the dust generating system and to determine the settings required to obtain appropriate dust concentrations. All systems are now functional. The next step is to make some preliminary tests to check out the counting and sizing methods to be used on the SEM and the electron microscope. Sampling times must be established such that parti-

cles will be distributed evenly on the Nuclepore filters and electron microscope grids and not overlap or be stacked on one another. Once these tests are completed, the specified testing will begin.

Sound Generation and Measurement

The field was created and measured by an assortment of equipment. Initially, the frequency signal was generated by an HP Model 200AB Audio Oscillator and measured by an HP Model 5210 Electronic Counter. This signal was fed into a McIntosh Unity-Coupled Amplifier Type M-210-A which sent a signal to the Altec-Lansing driver, which is mounted on the exponential horn. A 1/2 inch B&K microphone was connected to the B&K Type 2121 Frequency Analyzer, and we could observe the wave form on a Dumont Type 304-AR Cathode Ray Oscilloscope. A B&K Type 2304 Level Recorder will be used in the future. When working with warble tones, a B&K Automatic Frequency Response and Spectrum Recorder Type 3326 was used, and a Random Noise Generator was used to create the white noise. Initially the microphone sat on a holder and was manually moved throughout the chamber. We have recently purchased a transversing mechanism from Velmex and drove it with a Sigma Stepping Motor Driver and monitored the microphone's position on a Stepping Motor Digital Controller designed and built by a Penn State graduate student on another research project. In the future, our plans are to connect a D/A converter to the Controller and feed the signal to an X-Y plotter. Unfortunately, the converter has not arrived from Analog Devices yet.

Developing a Method to Achieve a "Diffuse" Sound Field

Upon preliminary investigation of the acoustic field in the agglomeration chamber, it was clear that a uniform acoustic field did not exist. The spatial

sound pressure variations were very large, with lengthwise variations along the central axis of the chamber exceeding 30 dB ref 10^{-12} watts and cross-sectional variation of over 20 dB ref 10^{-12} watts as shown in Figures 10-19. No mention of these variations was made in Dr. Volk's report, and it appears that the exponential decrease in the sound pressure level along the central axis of the chamber which he promulgated seems to be a rough approximation at best. Probably the most practical method of achieving a diffuse field in a dust-loaded chamber is to modify the sound itself and not the chamber. By this, we mean a warble tone superimposed with narrow bands of random noise.

To investigate how a warble tone would affect the acoustic field, the B&K Automatic Frequency Response and Spectrum Recorder Type 3326 was used (as mentioned before) to generate the signal. This machine has the capability of varying the modulation swing from 0-200 Hz and the modulation frequency from 0-32 c/sec. by a geometric progression. After a rather extensive procedure (see Table III), it was determined that an optimum combination of modulation swing and modulation frequency did exist (namely 200 Hz at 4 c/sec). This combination, which will be able to be duplicated by the new siren-driver apparatus which has been designed by Dr. Reethof and S.J. Shane and is now being built, effectively reduces variation in sound pressure from over 30 dB ref 10^{-12} watts to about 10-12 dB ref 10^{-12} watts. Results are shown in Figures 16 through 19.

A Random Noise Generator was used with a mixer to superimpose a band of white noise on the warble tone. However, initial investigation has shown that the white noise has a minimal effect on the variation (see Figure 17), but this could be due to the low intensity level of the white noise in comparison to the high level produced by the warble tone generator. In the

Graphs 1-5 ARE OF SOUND PRESSURE VS.
DISTANCE ACROSS THE CHAMBER AT A
CONSTANT HEIGHT OF 37.5cm AND VARIABLE
FREQUENCY
 $L^* = 160\text{cm}$
Graph # 1

*L Represent Distance of the Measured Plane
From the exponential horn taken along the
chamber axis.

*dB = sound pressure level Referred to 10⁻¹² watts
The sound pressure was set at 100 dB
AT THE POINT WHERE VOLK DESCRIBED THE
"SPL" OF THE CHAMBER - (NAMESLY ABOVE THE
WIRING HOLE).

FIGURE 10

FIGURE 11

FIGURE 12

FIGURE 14

FIGURE 19

TABLE III

Table of Sound Pressure Level in dB ref 10^{-12} watts for various locations on a cross-sectional plane and various warble characteristics. The results were measured at 3000 Hz (pure tone), but readings were also taken at 1000 and 4000 Hz

D*-M*	MODULATION SWING (c/sec)										
	0	20	40	60	80	100	120	140	160	180	200
10-1	99	99	100	100	100	100	100.5	101	101.5	102	102
-2	99	99	99.5	100	100	100	100.5	101	101.5	102	102
-4	99	99	99.5	100	100	100.5	100.5	100.5	101	101.5	102
-8	99	99	99.5	99.5	100	100.5	100.5	100.5	101	101	101.5
-16	99	99	99.5	99.5	100.5	101.5	101.5	101.5	101.5	101.5	101.5
20-1	101.5	101	101.5	101.5	102	102.5	103	103	103	103	103
-2	101	101	101	102	102.5	102.5	102.5	103	103	103	103
-4	101	101	101	102	102.5	102.5	102.5	103	103	103	103
-8	101	101	101	102	102.5	102.5	102.5	102.5	102.5	102.5	102.5
-16	101	101	101.5	102	103	103	103	103	103	103	103
40-1	95.5	95.5	98	98.5	98	98	98.5	98.5	99	99	98.5
-2	95.5	95.5	98	98.5	98	98	98.5	98.5	99	99	99
-4	95.5	96	98	98.5	98.5	98	98	98.5	98.5	98.5	99
-8	95.5	95.5	97.5	97.5	98.5	98	98	98	98	98.5	98.5
-16	95	98	98	98	99	98.5	98	98	97.5	98	98
30-1	105.5	105.5	105.5	105.5	105.5	105.5	105.5	105.5	106	106	106
-2	105.5	105.5	105.5	105.5	105.5	105.5	105.5	105.5	106	106	106
-4	105.5	105.5	105.5	105.5	105.5	106	106	106	106	106	106
-8	105.5	105.5	105	105	105.5	106	106	106	106	106	106
-16	105.5	105.5	105	105.5	106	106	106	106	106	106.5	106.5
50-1	102.5	102	102.5	102	102	102	102.5	102.5	102.5	102	102
-2	102.5	102	102.5	102.5	102	102	102.5	102.5	102.5	102	102
-4	101.5	101.5	102	102.5	102	102	102	102.5	102.5	102	102
-8	101	101	102	102	101.5	101.5	101.5	102	102	101.5	101.5
-16	101	101	102	102	101.5	101.5	101.5	101.5	101.5	101.5	101.5
60-1	106.5	106.5	106	106	106.5	106.5	106.5	106.5	106.5	106.5	106.5
-2	106.5	106.5	106	106	106.5	106.5	106.5	106.5	106.5	106.5	106.5
-4	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5
-8	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5	106.5
-16	106.5	106.5	106	106.5	106.5	106.5	107	107	107	107	107
70-1	104.5	104.5	103	104	105	105	105	105	105	105	105
-2	104.5	104.5	103	104	105	105	105	105	105	105	105
-4	104.5	104.5	103	104	105	105	105	105.5	105.5	105.5	105.5
-8	104	104	103	104	104.5	105	105	105	105.5	106	106
-16	104.5	104.5	104	104.5	105	105	105.5	105.5	106	106	106.5

TABLE III (Continued)

D*-M*	MODULATION SWING (c/sec)										
	0	20	40	60	80	100	120	140	160	180	200
80-1	103.5	103.5	103.5	103	103.5	103.5	104	104.5	104.5	104.5	104.5
-2	103.5	103.5	103.5	103	103.5	104	104	104	104	104	104.5
-4	103.5	103.5	103.5	103.5	103.5	103.5	104	104	104	104	104
-8	103.5	103.5	103.5	103.5	103.5	104	104	104	104	104	104
-16	103.5	103.5	103.5	103.5	104	104.5	104.5	104.5	104.5	104	104

D* - Distance along the cross-sectional plane from the far wall of the chamber (cm)

M* - Modulation frequency setting (c/sec)

** - Note that measurements were made at 1000 Hz and 4000 Hz also.

future, the white noise will be amplified and another complete investigation of the chamber will be made.

Mathematical Model of the Acoustics of the Agglomeration Chamber

The agglomeration chamber, because of its rather complex geometry, presents some difficulties in analytical modeling of the wave phenomenon in the chamber. We must recognize that, at one end, we have the exponential horn which contains the acoustic driver, and at the other end, we have step-wise discontinuity and the continuation of the duct as shown in Figure 20. The whole arrangement then could be modeled more in terms of a duct, one end of which is terminated by an exponential horn. On the other hand, the discontinuity at the end of the agglomeration chamber as it ends in the muffler region can be considered also as a reflective termination. As a first attempt, then, we have modeled the agglomeration chamber as a rectangular enclosure providing an equation for the pressure distribution given in the form of Equation (12):

$$p_{11}(w,y,z) = \frac{c^2 Q_0 \rho \omega \cos(n_x x/l_x) \cos(n_y y/l_y) \cos(n_z z/l_z)}{V(4\omega_n^2 k_n^2 + 2(\omega^2 - \omega_n^2)^{1/2}} \quad (12)$$

where

Q_0 = rms volume velocity of the source, m^3/sec

V = volume of the room, m^3

ω_n = normal angular frequency for nth mode, radians/sec

ω = frequency of the source, radians/sec

$x, y,$ and z = coordinates of the point, m

l_x, l_y, l_z = room dimensions, m

n_x, n_y, n_z = positive integers

HORN
LOCATION

AGGLOMERATION REGION

MUFFLER REGION

HOLE (EXIT)

-39-

FIGURE 20
THE CHAMBER

The normal modes which would exist in the room are then modeled by Equation (13), which provides the frequency for each one of the modes for a rectangular parallelepiped of dimensions l_x , l_y , l_z .

$$f_n = c/2 [(n_x/l_x)^2 + (n_y/l_y)^2 + (n_z/l_z)^2]^{1/2} \quad (13)$$

Experimental work with the chamber indicates that some of the modes can indeed be well predicted, but because of the particular terminations at both ends, some other modes are not well modeled with this relationship. We are therefore proceeding with a more complex set of relationships wherein we are actually treating the agglomeration system as terminated at one end by the exponential horn, with the other end being treated as an infinitely long duct. We expect with this kind of model to get a better relationship for the modal content of the acoustic field in the agglomeration chamber.

The Use of Computer Evaluation of Scanning Electron Microscope Images of the Particle Size Distribution and Particle Shape Characteristics

In the previous research on acoustic agglomeration carried out at Penn State University and terminated in 1975, a transmission microscope technique was used to determine the particle size distribution and particle shape characteristics. This required the very laborious manual counting of the number of particles in each size increment. Hours upon hours were spent by the graduate students to carry out this process for the samples that were required to obtain a statistically significant measurement. Today, however, we are fortunate to have available to us at the Materials Research Laboratory at Penn State a unique computer-controlled scanning electron microscope technique for the determination of the particle size distribution and the particle shape characteristics. This system incorporates a JEOLCO 50A SEM with

a Digital Equipment Corporation Model PDP 11/20 computer and the associated interface hardware. This permits the computer to control the scan of the SEM. For doing chemical analysis, an energy dispersive x-ray detector and multichannel analyzer are used.

The interaction of an electron beam with a sample generates many signals which may be monitored or photographed to gain information about the sample. Three common signals generated are the secondary electrons (SE), the back-scattered electrons (BS), and the characteristic x-ray spectrum.

A scanning electron microscope forms an image somewhat like a television tube in that the electron beam is rastered across the sample on a predetermined point and line density. In the usual mode of operation, a SEM may use either a 512 x 512 or 1024 x 1024 point spacing. This square grid gives equal importance to everything on the sample.

With the CESEMI system, the computer controls the electron beam so that areas of little or no interest are scanned very quickly, while areas of interest are scanned more slowly and in greater detail. The computer recognizes an area of interest (particle, pore or crystal of a different chemical composition) when either the SE or BS signal exceeds a pre-set background level.

Once the beam is "on phase", the computer determines the length of the first chord and then locates the perpendicular bisector of the first chord to determine a second chord. The computer continues this process until it locates the center of the area of interest. The beam then determines the length of eight diameters (every 22.5°) and averages these values to arrive at an average diameter. The computer then positions the beam at the center of the particle to take x-ray counts and establish the composition.

The system currently uses a Kevex multichannel analyzer (MCA) to determine the chemical composition of the area of interest. Up to seven windows can be set on the MCA so that seven elements can be detected simultaneously. The system averages the two channels on each side of the window to determine the background for the element. This background is subtracted from each window, leaving the integrated x-ray counts for each element. The mineralogy of each particle is established by the combination of elements that are present in each particle.

The computer retains data on all particles and also each chemical type of particle. After data has been collected on a sufficient number (usually a minimum of 600) of particles, the following data is available: 1) The average size and standard deviation for all particles and for each chemical type; 2) The aspect ratio and standard deviation for all particles and for each type; 3) The number of particles of each type; 4) Size versus percent of particle histograms for all particles and for each chemical type containing at least 50 particles; 5) Aspect ratio histograms as in Number 4; and 6) The volume percent of each chemical type.

If the particles tend to be multiphasic, 4 or 9 points on each particle can be sampled to determine the homogeneity of the particular particle. This is especially useful when the particles are large and tend to be mixed phases.

Line scan programs are also available. Using a line scan technique, from 2 to 128 points can be sampled across the surface of a sample. This will detect phase boundaries or inhomogeneities in the sample.

The results to date with the computerized electron microscope scanning electromicroscope technique are indeed encouraging. We are enclosing results in Figures 21 and 22 to give an indication of the sampling capability of this

DATA COLLECTION FOR 611 PARTICLES

MAX. DIAM. = 19.113UM MIN. DIAM. = 0.031UM

TOTAL LENGTH OF TEST LINE = 0.89912E-02M

SAMPLE: 15 SEC SAMPLE TIME NO SOUND 2/13

15-FEB-80

PART TYPE	CHEMICAL NAME	AVERAGE DIAM. MEAN (UM)	MIN/MAX SIGMA	VOLUME %	REL. VOL. %	SURFACE/ VOLUME SV
ALL TYPES		1.56	1.2 0.44 0.27	7.97	100.0	0.00597

PLOTS ? 1

15 SEC SAMPLE TIME NO SOUND 2/13

15-FEB-80

FOR ALL TYPES

AVERAGE DIAMETER DISTRIBUTION (# PERCENT)

CLASS LIMIT	0	1	2	3	4	5	6	7	8	9	10	CLASS %	NO.
0.06 E	0	0	0	0	0	0	0	0	0	0	0	0.00	0
0.10 E												0.33	2
0.16 E												0.33	2
0.25 E*												2.13	13
0.40 E****												8.18	50
0.63 E*****												11.62	71
1.00 E*****												16.69	102
1.60 E*****												23.08	141
2.50 E*****												19.48	119
4.00 E*****												13.09	80
6.30 E**												4.58	28
10.00 E												0.49	3

FIGURE 21

FOR ALL TYPES

MIN/MAX DIAMETER DISTRIBUTION

CLASS %													
CLASS	0	1	2	3	4	5	6	7	8	9	10	CLASS	NO.
LIMIT	-----0-----												

FIGURE 21

FIGURE 21 (cont'd)

1,000x magnification

5,000x magnification

FIGURE 22
Photo Micrographs of Sample

technique. It appears that the scanning electronic microscope can very effectively and reliably measure sample size and size distribution down to about .05 microns, although we believe that a .1 micron limitation is somewhat more realistic. We are also including samples of the 1,000x magnification of the electron microscope image, and a 5,000x magnification image of the fly ash samples which we have used.

TASKS FOUR, FIVE, AND SIX

At the present time, we have not progressed to the stage where these tasks can be performed. We however expect in the very near future to begin carrying out these tasks with the modified agglomeration facility which has been described in the previous sections of this Progress Report.

CONCLUSIONS

At the present time in the program, we have made very significant progress in keeping with the agreed-to statement of work. We believe, however, that because of delayed delivery of some of the parts and the slowness in obtaining the machined parts for the siren, that we are two to three months behind schedule. We hope to be able to catch up some of the lost time, although we may have to request an extension of our contract with appropriate additional funding of on the order of two to three months in order to fulfill the complete commitments as outlined in our Statement of Work.

A two year program leading to an Associate Degree in Air Pollution Control Engineering Technology is offered at the Berks Campus of the Pennsylvania State University. The graduate of this program is trained to be responsible for the calibration, installation, and operation of air sampling and monitoring equipment.

Address requests for more information concerning the training programs to the Director, Center for Air Environment Studies, 226 Fenske Laboratory, The Pennsylvania State University, University Park, Pennsylvania 16802.

Publications Available

AIR POLLUTION TITLES, a current awareness publication, is a quick guide to current literature and has some capacity as a retrospective searching tool. Air Pollution Titles uses a computer-produced, Keyword-in-Context (KWIC), format to provide a survey of current air pollution and related literature. During the year over 1,000 journals are scanned for pertinent citations.

Subscriptions to Air Pollution Titles are available on a January-December subscription basis at a cost of \$24.00. The six bi-monthly issues are published as follows: No. 1, January-February; No. 2, March-April; No. 3, May-June; No. 4, July-August; No. 5, September-October; and No. 6, which is the cumulative issue for the year, includes the November-December citations. In addition to Air Pollution Titles subscriptions, cumulative issues for past years are available.

INDEX TO AIR POLLUTION RESEARCH was published in July of 1966, 1967, and 1968. Each Index included government sponsored research in the air pollution field; results of a survey of air pollution research projects conducted by the industrial, sustaining, and corporate members of the Air Pollution Control Association and the American Industrial Hygiene Association; and research supported by other industries and non-profit organizations.

The Index utilizes the Keyword-in-Context (KWIC) format for rapid scanning of project titles. In addition, this publication provides a complete bibliography with mailing addresses so additional information about the project may be obtained. Beginning with the 1967 edition, a section containing citations of papers resulting from research in progress is included. Copies are available.

A GUIDE TO AIR POLLUTION RESEARCH (PHS Publ. No. 981) was prepared in 1969 by the Center for Air Environment Studies under contract to the National Air Pollution Control Administration of the U.S.P.H.S. It is available from the Superintendent of Documents, Government Printing Office, Washington, D. C. 20402. The 1972 edition of the Guide was prepared by the Center under contract to the Office of Air Programs of the Environmental Protection Agency and is also available from the Superintendent of Documents.

HANDBOOK OF EFFECTS ASSESSMENT: VEGETATION DAMAGE was published in 1969. It describes in detail the many various sources of pollution and the effect of these pollutants on vegetation. Included are color slides depicting the characteristic symptoms of plant damage. This publication went into its second printing in 1974 and is available through the Center for Air Environment Studies.

Further information regarding orders for the above publications may be obtained from: Information Services, Center for Air Environment Studies, The Pennsylvania State University, 226 Fenske Laboratory, University Park, Pennsylvania 16802. Lists of other Center for Air Environment Studies Publications are available upon request.