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Sub-Pilot Testing of an Acoustically Enhanced Cyclone for PFBC

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CONTRACT INFORMATION

Contract Number DE-AC21-88MC25010

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Period of Performance September 23, 1988 to July 31,1993

Schedule and Milestones

Program Schedule

	FY 1989	FY 1990	FY 1991	FY 1992	FY 1993
Phase I Facility Design					
Phase II Test Prep & Execution					
Phase III Commercial Evaluation					

OBJECTIVES

The overall program objective is to demonstrate, on the subpilot-scale, the effectiveness of an acoustically enhanced cyclone collector under high temperature, high pressure conditions found in coal-fired pressurized fluidized bed combustion (PFBC) combined cycle power generating systems. The data obtained will be used to design an acoustically enhanced cyclone gas cleanup system which can meet the New Source Performance Standards (NSPS) particulate control level with capital and operating costs significantly lower than currently available with conventional cyclones and post turbine particulate control.

BACKGROUND

In coal-fired PFBC combined-cycle power generation systems, gas turbines are used to recover energy from the high temperature gases exiting the PFBC. Before the gases enter the turbine, most of the fly ash from the coal must be removed by a hot gas cleanup device in order to protect the turbine components from erosion, corrosion, and deposition of the ash. Conventional, high efficiency cyclone systems are thought to be capable of removing a sufficient quantity of ash to protect the turbine hardware; however, these systems are not capable of meeting the stringent environmental particulate emissions regulations. A hot gas cleanup system that meets both turbine protection and environmental emissions requirements without post-turbine cleanup devices should have improved overall system economics compared to a system with conventional cyclones prior to the gas turbine and a baghouse or electrostatic precipitator after the turbine.

Acoustic agglomeration can increase the cyclone collection efficiency by increasing the average particle size of the ash. In this concept, the ash-laden effluent stream from the PFBC is passed through a high intensity sound field prior to entering the cyclone train. The high intensity sound causes the smallest particles to oscillate with the sound waves, while the largest particles travel with the bulk gas flow, unaffected by the sound. Due to the increased motion of the smallest particles, the number of collisions between the small and large ash particles increase. When the ash particles come into close contact, they agglomerate, being held together by molecular forces. The design and operational simplicity of acoustic agglomeration prior to a conventional cyclone train offers significant economic advantage over other hot gas cleanup methods.

A major goal of this program is to establish whether a full-scale agglomerating cyclone system can meet NSPS particulate emission standards and still provide a 15% reduction in the fixed and operating costs of the cleanup system relative to conventional hardware (conventional cyclones coupled with post-turbine control).

PROJECT DESCRIPTION

The project duration has been extended from its original two-year study, to four and a half years. The program is divided into three phases covering the test facility design, experimental testing, and commercial assessment.

Phase I

The initial phase of the program consisted of a detailed design of the subpilot-scale acoustic agglomeration test facility and the preparation of an experimental test plan. Due to the high costs and unavailability of operating PFBC's and the need to accurately control the input flow parameters, the test facility has been based upon a simulated PFBC effluent stream in which fluidized bed fly ash is injected into a high temperature, high pressure vitiated air stream. High intensity sound is produced within the agglomeration chamber with a natural gas fired pulse combustor.

Phase II

The second phase covers the fabrication and installation of the test hardware and the execution of the acoustic agglomeration tests. The testing includes detailed parametric tests to identify the dependence of critical operating variables on the agglomeration efficiency, and duration test to assess the durability of the system. Comparisons of the experimental data with computer predictions of acoustic agglomeration will also be made.

Phase III

The final phase will provide a commercial assessment of the system. First, a base-case full-scale design for an acoustically enhanced cyclone system integrated with a PFBC combined cycle power plant will be developed.

Based upon this design, a cost analysis of the full-scale hot gas cleanup train consisting of an acoustic agglomerator and high temperature cyclones will be performed. This analysis will determine if an acoustically enhanced cyclone system, which meets the NSPS for particulate, can be built for a capital cost and used at an operating/maintenance cost which are each 15% less than that of a conventional cleanup train consisting of hot, high pressure cyclones for turbine protection and post-turbine particulate control for meeting NSPS.

RESULTS

Test Facility Design

The acoustic agglomeration test facility consists of a vertical, refractory lined agglomeration chamber which has a maximum residence time of approximately 3 seconds. High pressure air (150 psia) is preheated to approximately 1650°F with a natural gas combustor and fly ash is injected into the air stream to simulate PFBC operating conditions. Natural gas fired pulse combustors are used to generate high intensity sound at selected frequencies to enhance acoustic agglomeration of the fine, fly ash particulate. A two-stage high temperature, high pressure cyclone system is used to separate the ash particles from the bulk air flow. A heat exchanger and a sintered metal filter are used to cool the air and remove particulate for local environmental control. Samples of the fly ash particulate are removed from the gas stream in three areas: near the exit of the agglomeration chamber, between the two cyclones, and after the final cyclone. These samples are analyzed for particle size distribution and mass loading within the gas stream to determine the effects of the high intensity sound and other operating parameters on the agglomeration of the fly ash.

High Frequency Agglomeration. A flow diagram of the acoustic agglomeration test facility for high frequency agglomeration is shown in Figure 1. In this arrangement, air enters the system through the preheat combustor at the bottom of the agglomeration chamber. The bulk flow of the air is in an upward direction. Ash is injected near the bottom of the chamber, and the particle sample is withdrawn from the top of the chamber. The pulse combustor sound source is located at the top of the agglomeration chamber firing downward. This produces a counter-current flow between the ash particulate flow direction and the sound propagation direction. With this configuration, the combined fuel and air flow rate of the high frequency combustors is approximately 15-30% of the total gas flow into the system.

Low Frequency Agglomeration. With the low frequency pulse combustors, the total air and gas flow rate drawn through the pulse combustor is expected to increase relative to the bulk flow through the agglomeration chamber. To minimize the variation in air flow between the agglomer-

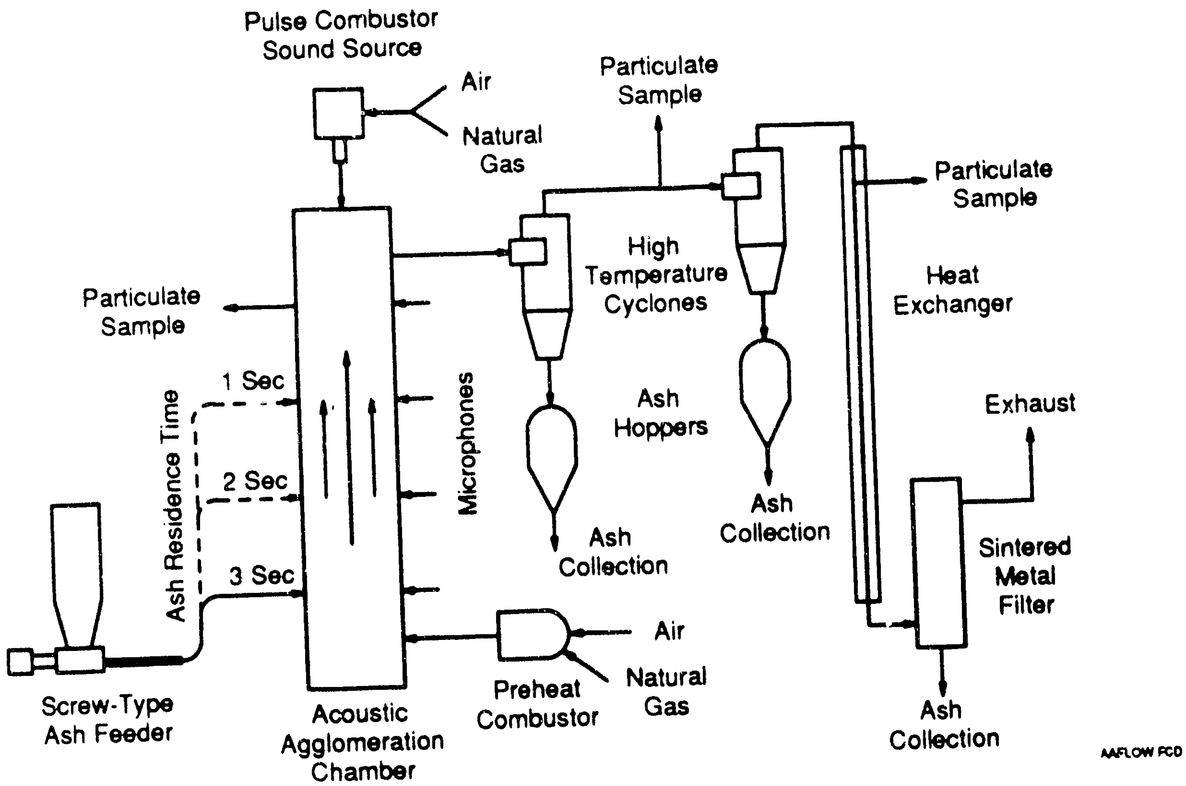

Figure 1. High Frequency Agglomeration Schematic

ation chamber and the cyclones, the test facility will be modified as shown in Figure 2. The preheat combustor will be moved to the top of the agglomeration chamber and a refractory-lined duct will be installed between the bottom of the chamber and the inlet to the first stage cyclone. The ash will then be injected near the top of the chamber and the particulate sample withdrawn near the bottom. The bulk flow of the gas will then be downward, with the co-current flow between the injected ash and the sound waves. Additional microphone ports will be added in the cyclones to measure the sound attenuation through these devices. The remainder of the test facility will be unchanged.

Facility Characterization

The facility shakedown and characterization tests have been completed. Several facility modifications were required to complete these shakedown tests.

Ash Feed System. The original ash feed system planned for this program was a rotary disc feeder. Problems with this feeder in feeding the fine fly ash were experienced due to an insufficient angle of inclination within the ash hopper and the narrow groove width on the rotary disc. An existing auger-type feeder was used in place of the disc feeder. This auger feeder proved successful in feeding the fly ash stably over the range of ash feed rates necessary for the planned acoustic agglomeration tests.

Particulate Sampling. Fly ash particulate is removed from the flowing gas stream, through three water cooled sample probes located within the agglomeration chamber, between the two cyclones, and after the final cyclone. After the ash sample is removed from the gas stream,, it is collected in either an Andersen Cyclade™ or a Balston Filter. The Cyclade consists of 6 small cyclones in series followed by a backup filter and is used to segregate the ash into discrete size

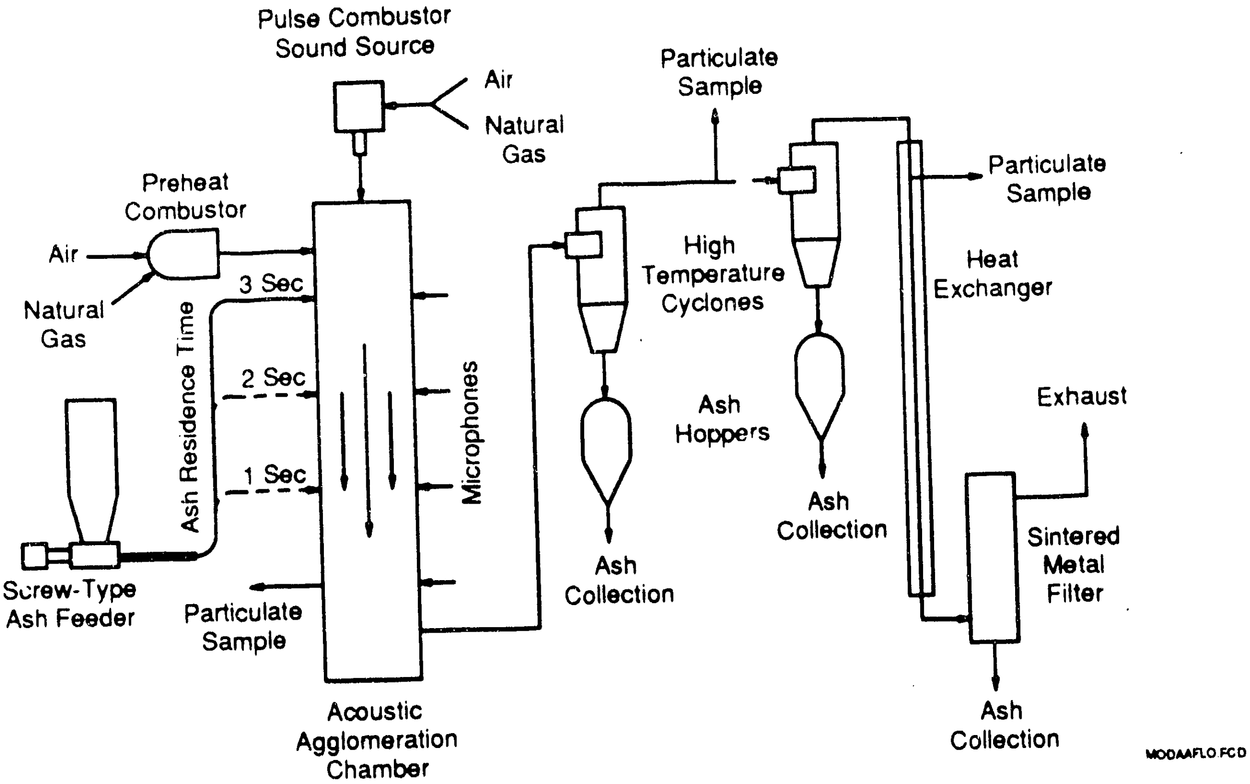

Figure 2. Low Frequency Agglomeration Schematic

classes. The Balston Filter is used to determine only the mass loading within the gas stream.

Excessive cooling of the particle laden gas sample occurred during operation of the sample probes such that water condensed along the walls of the transfer tubing between the water cooled sample probe and the pressurized canister holding the Cyclade and Balston Filters. This caused the ash to form a paste along the tubing walls, preventing it to flow into the filter. Electrical heaters were added to maintain the temperature of the sample above the dew point.

Ash Collection. The ash hoppers below the high temperature cyclones were originally designed as water cooled vessels with knife gate valves at the top and bottom of the hopper. The water cooling caused water to condense within the hopper and an insufficient angle of inclination on the hopper allowed bridging to occur above the knife gate valves, thus preventing the hoppers from emptying completely when the gate valves were opened. These hoppers have been redesigned with non-water cooled walls and a steep angle of inclination at the exit. The top knife gate valves have also been removed to simplify the system. These valves will be reinstalled prior to the system durability testing.

Pulse Combustor Operation. Three high frequency pulse combustor sound sources have been fabricated and tested by MTCI. The nominal 1000 Hz pulse combustor has been tested with the acoustic agglomeration test facility. Modifications to the fuel/air injectors have been made by MTCI to provide easier ignition and eliminate the potential of the flame to propagate back into the injector.

The 1000 Hz pulse combustor has been capable of producing sound pressure levels (SPL) (integrated from 0-10,000 Hz) as high as 165 dB at approximately 1170 Hz. The sound pressure level of the fundamental frequency was approximately 6-10 dB lower than the integrated value. One of the planned test variables for the agglomeration tests was to vary the SPL over a range of 145 to 165 dB. The stable operating envelope of the pulse combustor does not allow this wide of a range in SPL output. Reducing the fuel input to the combustor by half only reduced the SPL within the agglomeration chamber by approximately 6 dB. Therefore, sound intensity will not be used as an independent variable on the acoustic agglomeration tests.

The SPL has been measured to be nearly constant down the length of the agglomeration chamber with only a 2 to 5 dB attenuation during the initial characterization tests. The 2000 and 3000 Hz T-burners have not achieved high intensity pulsations in this test facility. New fuel injectors are being fabricated and will be used with these combustors.

Acoustic Agglomeration Test Plan

The acoustically enhanced cyclone collector is being evaluated with three distinct goals in mind: 1) determine the effects of the major operating parameters on acoustic agglomeration efficiency, 2) optimize the agglomeration system performance for maximum particulate removal efficiency, and 3) demonstrate the system durability over a meaningful time frame. During the tests, ash samples are collected from the bulk gas stream at the exit of the agglomeration chamber, between the two cyclones, and also from the discharge pipe of the final cyclone. The main dependent variables of interest are the mass mean particle size and size distribution of the ash before and after the agglomeration process, and the cyclone collection efficiency of the unagglomerated and agglomerated particulate streams.

Seven independent variables have been identified for the parametric testing. These are: 1) frequency of the sound generator, 2) ash residence time within the agglomeration chamber, 3) ash loading in the bulk gas stream, 4) operating system pressure, 5) agglomeration chamber temperature, 6) particle size distribution of the fly ash, and 7) ash type. The testing is performed using a statistical experimental design approach. First, a two-level fractional factorial design is used to obtain basic information about each independent test variable. Next, a three-level response surface design is used to determine optimum operation conditions.

The high frequency agglomeration tests (1000-3000 Hz) are currently being performed and will be followed by the low frequency agglomeration tests (150-600 Hz). The system durability test, a 200-hour continuous duration test will be performed at the optimum operation condition determined from the parametric testing.

High Frequency Test Results

Pulse combustor testing began with the 1000 Hz Schmidt tube type combustor. The single burner is shown in Figure 3. Once this sound source had been characterized, the 2000 Hz and 3000 Hz T-burners were tested. The 3000 Hz generator is shown in Figure 4. Measuring the sound intensity with four microphones, shows that it does not drop off significantly down the length of the agglomeration chamber. Typical sound pressure level data is shown in Figure 5 for microphone 1. The 1000 Hz Schmidt tube achieved the goal of 160 dB in the agglomeration chamber. Both the 2000 and 3000 Hz combustors were unable to achieve sufficient acoustic intensity.

The noise in the frequency spectra below approximately 300 Hz is due to flow and combustion noise produced by the preheat combustor of the agglomeration chamber (note, the preheat combustor was not fired during which sound pressure level data for the T-burners was taken).

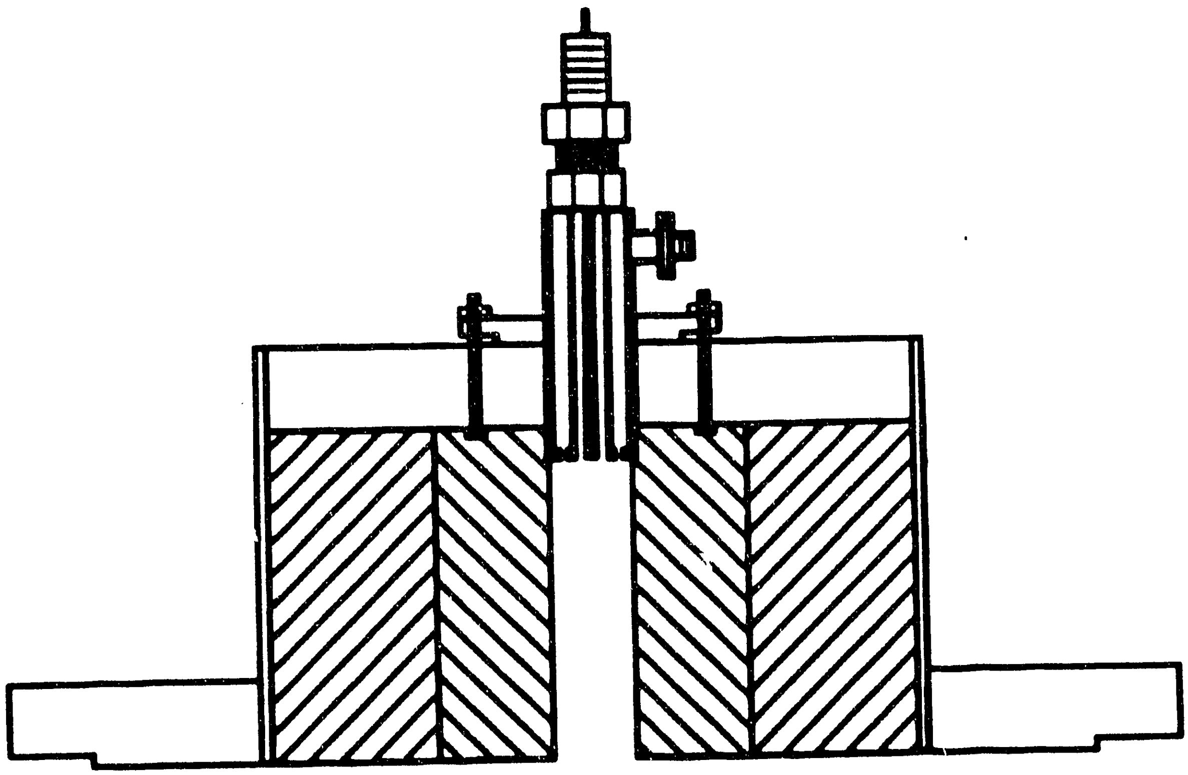

Figure 3. MTCI 1000 Hz Generator

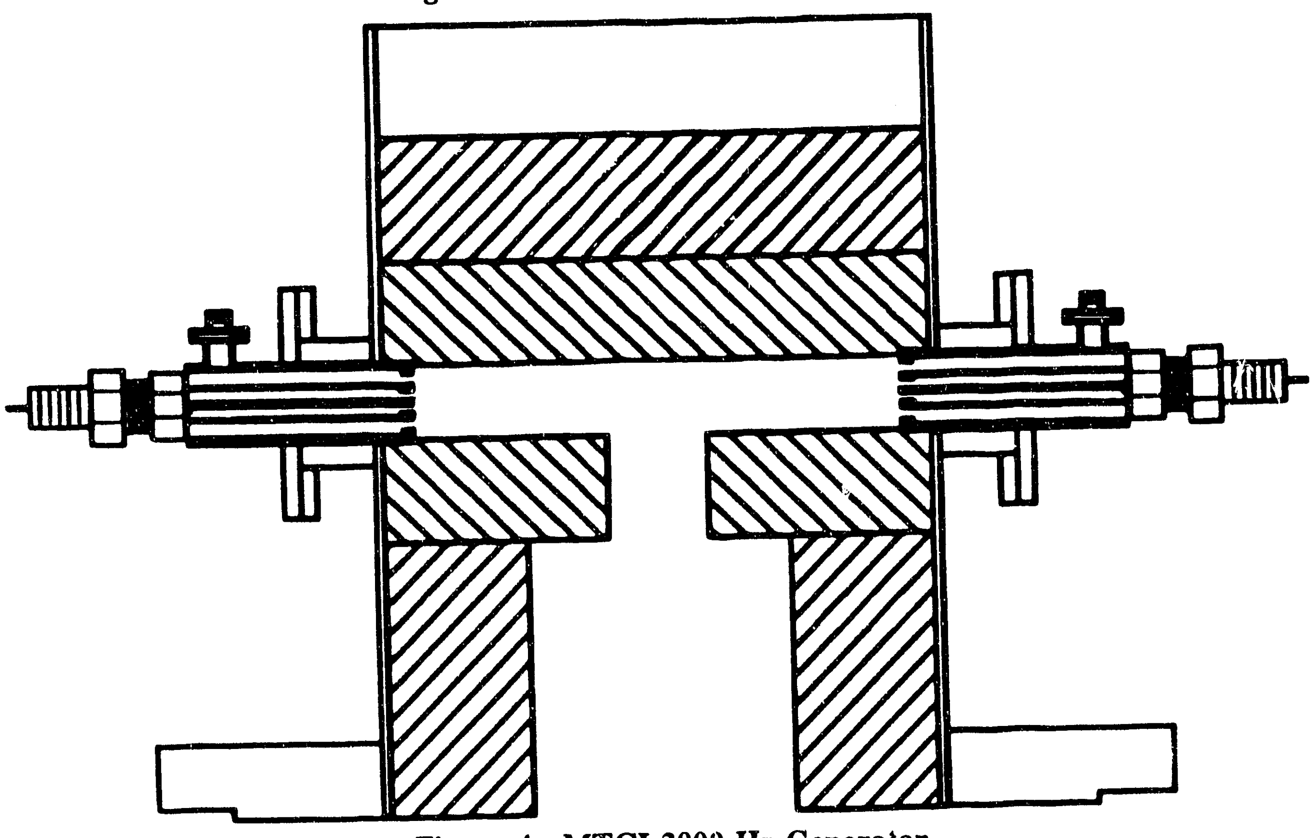

Figure 4. MTCI 3000 Hz Generator

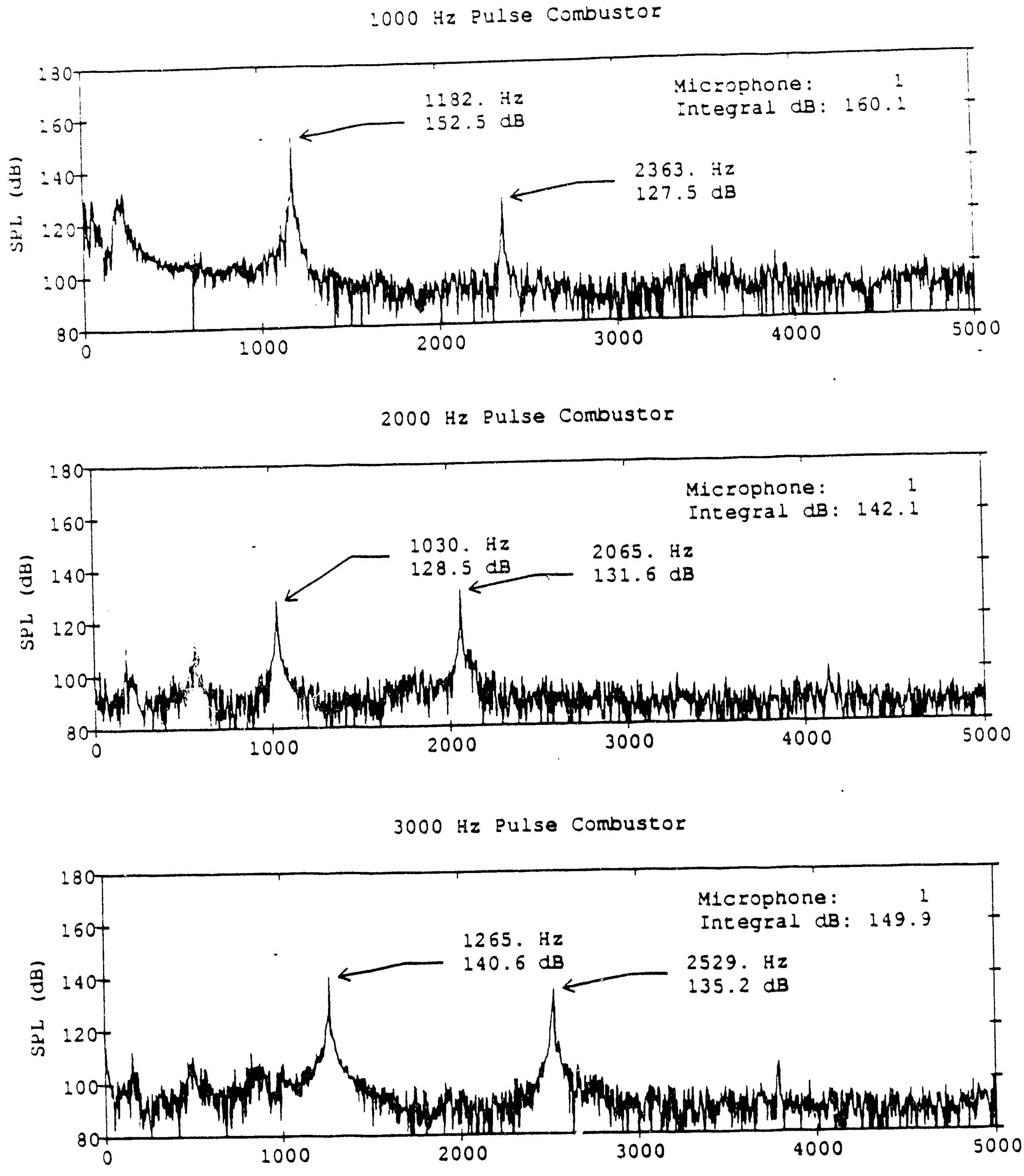

Figure 5. Sound Pressure Level Data For 1000, 2000, and 3000 Hz Pulse Combustors From Microphone 1

Pulse combustor performance is not influenced significantly by firing rate or pressure over the operating ranges tested in this facility. Increasing and decreasing both parameters has had no significant effect on the pulsations. With the existing facility, there is no control over the sound intensity of the pulse combustors. The frequency can be altered by changing pulse combustors.

Several agglomeration tests have been performed during which ash is injected into the 3 second residence time port. One successful comparison sample was taken in which ash samples were collected both with and without sound. The particle size distributions for the samples collected from Tests 47, 48, and 49, and measured with the Andersen Cyclade, are presented in Figure 6. The mass fraction of ash less than approximately 10 microns was 7.2% in Test 47, when the pulse combustor was tuned in. This mass fraction increased to 12.2% and 10.9% respectively in the two "no sound" tests. Further testing is required to determine whether the reduction in the small micron mass fraction with the operating, acoustic sound source is truly significant.

FUTURE WORK

Experimental testing in the subpilot-scale agglomeration test rig will be completed in early 1993. Comparisons between the test data and predictions made by an acoustic agglomeration computer model will also be made. The Phase III Commercial Assessment will be started prior to completion of all experimental testing in order to provide sufficient time to complete the assessment.

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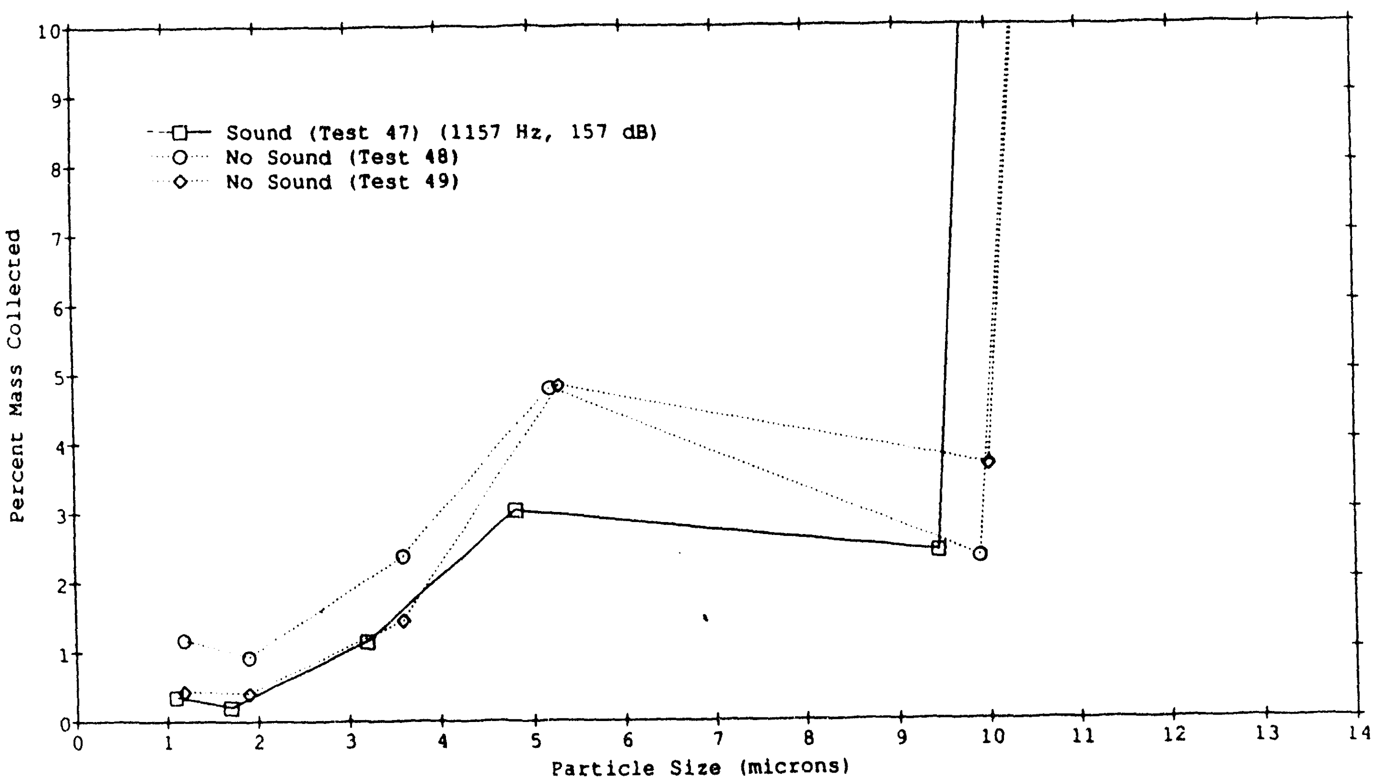

Figure 6. Particle Size Distribution Data From Tests 47, 48, and 49

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