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NEW TECHNOLOGY FOR THE CONTROL OF AEROSOLS FROM STATIONARY SOURCES

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NOTICE

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ABSTRACT

The Environmental Protection Agency has underway a program to develop new technologies for controlling particulate matter from stationary sources, including both electrostatically augmented fabric filtration (ESFF) and electrostatic precipitators (ESPs). The first generation ESFF system, which uses an electrostatic field parallel to the fabric surface, provides a reduction in pressure drop to about 50% of the pressure drop in conventional fabric filtration for both reverse-air and pulse-jet operation. Second generation (or Super) ESFF, which utilizes an electrostatic field perpendicular to the fabric surface, provides reductions in pressure drop to 10 to 30%. Large diameter corona electrodes in ESPs have decreased the penetration up to a factor of 4 as compared with conventional small diameter corona electrodes. Work on the multistage ESP has shown that, for high resistivity particulate matter, it is possible to construct an ESP that provides equivalent performance to a conventional ESP 4 to 5 times larger. The E-SOX technology utilizes the multistage technology to free up space within an existing ESP for sulfur dioxide removal of 60 to 90%, by injection of alkaline reagents. Improved computer modeling techniques are allowing more rapid and economical ESP designs.

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INTRODUCTION

As part of its mission the Environmental Protection Agency undertakes research to develop pollution control technology for aiding industry in meeting the requirements of the various air pollution control standards and regulations. Part of this research and development is in the area of particulate matter control technology. Out of this program has come a number of significant advances. This paper describes several in both fabric filtration and electrostatic precipitation.

FABRIC FILTRATION

Historically, fabric filtration has been used for a considerable time in industry. Fabric filtration is being applied more frequently to utility and industrial boiler particulate matter control with increasing use of low sulfur coals having high resistivity fly ashes.

In the EPA particulate program it has been concluded that, of all the parameters involved in fabric filtration design, electrostatics, when properly applied, is the dominant.

Electrostatically augmented fabric filtration (ESFF) is a technique in which an electrostatic field is established across the fabric to cause preferential deposition of the particulate matter on some areas while leaving other areas open to gas flow. The electrostatic field acting on charges upon the particles causes the selective deposition; the stronger the charge and electric field the greater is the ESFF effect. The open area causes a lowered pressure drop for the baghouse. Much of the work to date has been with the electric field parallel to the surface of the fabric. Typically the field was generated between electrodes, placed at the surface of the fabric, running the length of the bag, and placed about 2 cm apart. The electric field strength is from about 2 to 8 kV/cm. In pulse-jet operation (in which the particle matter is collected on the outside of the bags) the wire support cage is adapted for developing the electric field as shown in Figure 1 (1). Adjacent wires are insulated from each other thereby allowing the cage itself to be electrified. For reverse-air, which does not use a cage, and in which the particle matter is collected on the bag interior, stainless steel yarns have been woven into the fabric warp as shown in Figure 2. The fabric is fiberglass with a Teflon finish; the yarn is 316L stainless steel having 90 fibers each 22 m in diameter (2). The alternate yarns have the electric field developed between them, the same as in pulse-jet.

The ESFF effect has been shown for fly ashes on small EPA in-house baghouses at Research Triangle Park, NC. It has also been shown for both reverse-air and pulse-jet with the EPA 28 actual m^3/min pilot unit having 2.4 m bags on an industrial boiler at the DuPont Waynesboro, VA, facilities. An ESFF system has been operated for about 14 months, using reverse-air, at the EPA 140 actual m^3/min pilot unit at the Southwest Public Service Harrington Power Station in Amarillo, TX. At the Harrington power plant the bags were full utility size, each being 9.14 m long and 0.3 m in diameter as shown in Figure 2.

Typically, for fly ash the pressure drop across an ESFF baghouse is about 50% of the pressure drop across a conventional baghouse (1,3). This means that one can minimize the pressure drop and consequently the fan power or else decrease the number of bags and consequently the capital cost.

A series of experiments were performed on the EPA in-house baghouses for both reverse-air and pulse-jet using redispersed particulate matter from a spray drying process for sulfur dioxide capture. In spray drying, a lime slurry is injected into a chamber to react with the sulfur dioxide. The resulting mixture consists of fly ash, and reacted and unreacted lime. For spray drying by-product particulate matter, the pressure drop was reduced by about a factor of 4 to 6 as compared to conventional filtration. Figure 3 is a pressure vs time trace which shows dramatically the effects of turning the field on. At the start, with the power off, the pressure drop was continuing to rise and would have eventually gone off the chart if continued. The pressure drop started to respond immediately to turning on the field.

The ESFF effect that has been discussed is based upon the action of an electric field upon particulate matter containing only natural charge. No corona for charging the particles was generated. The measured natural charge on typical fly ash is about 0.1 to 0.2 μC/g; for spray drying by-product some of the measured charges were as high as 1.68 μC/g. The difference in the pressure drop reduction for spray drying material as compared to fly ash accounts for some of the improvement. The remainder is due to the ability for developing a stronger electric field with this material as a result of lower operating temperatures and higher moisture levels. Varying the electic field has also been seen to affect the pressure drop reduction. The ESFF effect improves with increasing electric field and decreases with lowered electric field.

Work is underway on techniques in ESFF for simultaneously increasing the field strength and increasing the charge on the particles. There is good indication that by doing this it would be possible to achieve pressure drop reduction for most particulate matter that will equal that which was achieved with spray drying material.

Charging of particles occurs when a corona current is caused to flow across the gas stream containing the particles. Conventional ESFF, in which the electrodes and resultant electric field are parallel to the surface of the fabric, is not conducive to generation of a corona discharge or increasing the field strength; the filtration fabric would rapidly break down from the corona formed on its surface. The need to charge the particles and to increase the field strength has led to a second generation ESFF which has been termed "Super ESFF." In Super ESFF a strong electric field, with corona discharge, is developed perpendicular to the fabric rather than parallel. Super ESFF has been applied to both reverse-air and pulse-jet filtration.

In reverse-air Super ESFF the electrical field is developed between an axially located wire, extending the length of the bag, and the interior surface of the fabric filtration bag which is made electrically conductive by one of several means (See Figure 4). The electrical field between the axial wire and the grounded conductive fabric is sufficently strong so that the wire goes into corona, and the particles entering the bottom of the bag, containing some natural charge, are given additional charge by the corona current. In normal fabric filtration the particles follow the gas streamlines and consequently tend to deposit themselves evenly on the bag's interior. Under the influence of the electric field the charged particles leave the gas streamlines and tend to be selectively deposited on the lower portion of the bag. This leaves the upper portion of the bag with little or no particle matter upon the surface. Consequently the majority of the gas flows out through the upper portion of the bag which provides a significantly decreased pressure drop.

Pulse-jet Super ESFF requires that the electric field be perpendicular to the external surface of the fabric filtration bag, which is the surface upon which the particle matter collects. This is accomplished by developing the electric field between corona discharge wires, placed parallel between the fabric filtration bags, and the wire anti-collapse cages inside of the bags; the cages in turn are grounded (see Figure 5). The strongest electric field is established in the area directly between the wire and the grounded support cage. It is in this area that the maximum amount of particle matter is selectively deposited. The fabric filtration bag surfaces between these areas of maximum deposit provide the low flow resistance for the majority of the gas which results in the lowered pressure drop across the bags.

The reverse-air Super ESFF has been operated in a small single-bag baghouse with bags 1.07 m in length and 0.13 m and 0.2 m in diameter. The pressure drop ranged from about 10 to 30% of the pressure drop of conventional reverse-air filtration. The range is a function of particle matter resistivity and gas temperature. Lower temperatures allow higher field strengths. Lower resistivities allow higher corona currents. With high field strength at a temperature of about 70°C and maximum charge (such as experienced with spray dryer conditions) the pressure drop is lowest. At higher temperatures of about 150°C, as experienced under the gas cleaning conditions of steam-electric utilities, especially with high resistivity particle matter, the pressure drop was at the higher end of the range.

In a larger reverse-air Super ESFF pilot unit having 0.2 m diameter bags, 7.47 m in length, operating on a stoker-fired boiler at 150°C, the average pressure drop was about 25% of the pressure drop being achieved with conventional fabric filtration. The fly ash from this stoker-fired boiler had a very low electrical resistivity due to about 30% unburned carbon contained within it.

Performance from reverse-air Super ESFF appears to offer a significant improvement over the original ESFF concept described previously, and offers an even greater improvement over conventional reverse-air filtration. This again will allow either a more significant reduction in operating costs due to the need for less fan power, or less capital costs due to the need for even fewer filter bags as compared to conventional ESFF.

A small amount of work has been done on pulse-jet Super ESFF. A nine bag ambient temperature baghouse having bags 1.22 m in length and 0.13 m in diameter was electrified. Difficulty in stabilizing the resistivity of the particle matter made a quantitative determination of the pressure drop reduction unfeasible. However, the data qualitatively indicates that the pressure drop reduction is significantly improved over the conventional pulse-jet ESFF previously described. Pulse-jet Super ESFF shows considerable potential, and additional work is scheduled.

ELECTROSTATIC PRECIPITATORS

EPA's electrostatic precipitator (ESP) research has concentrated on improving performance and operation, decreasing size and cost, upgrading performance for operation with desulfurization systems, integrating sulfur dioxide control into the ESP, and developing performance and cost models.

Historically, for operation with low resistivity particle matter, ESPs have been designed for high corona currents. Even with these high corona currents the absence of a back corona problem allows achievement of high electric field strength. As a consequence, the ESPs operated well, and the particles were easily charged and collected. High corona currents were achieved by use of small diameter discharge wires (approximately 0.3 cm) or use of electrodes with a multiplicity of discrete discharge points. Where the allowable useful current is limited by high resistivity, the low corona onset voltage and fairly steep voltage/current relationship result in both a decreased electric field strength and low corona current for charging. The combination of low current density and electric field produced by conventional discharge electrodes requires that a high specific collector area (SCA) be provided to meet emission standards. The SCA is defined as the ratio of the volumetric flow rate of gas to the collector plate area.

Experimental studies at the EPA 840 actual m^3/min field pilot unit at TVA's Bull Run Power Plant and the in-house 28 actual m^3/min pilot ESP have shown that the use of larger diameter, smooth-surface electrodes (approximately 1 cm in diameter) can provide a significant improvement in ESP performance--especially when high resistivity particle matter is collected. The large diameter electrodes allow operation at high field strengths and useful current densities for particle charging. As can be seen from Table 1, the large diameter wires reduce the penetration for high resistivity particle matter (2×10^{12} ohm-cm) by a factor of 4, and the penetration for moderate resistivity (8×10^{10} ohm-cm) particle matter resistivity by a factor of 1.25. Economic analysis has shown that the large diameter wire technology is applicable in both new and retrofit situations when the particle matter resistivity is greater than about 8 x 10^{10} ohm-cm. The application of this technology is being further pursued.

In conventional ESPs particle charging and collection take place in the same electrical section. It has been found that, for the higher resistivity particle matter, separation and optimization of the charging and collection steps can lead to significant improvements in performance.

A number of precharger techniques have been worked upon including the trielectrode (4), cold-pipe (5), and charged droplet. One of the most promising is the cold-pipe precharger shown in Figure 6. It consists of discharge wires interspersed with grounded pipes through which cooling water flows. The purpose of the cooling water is not to cool the gas stream but to cool the dust layer that forms on the pipes. Cooling the dust layer decreases the resistivity, thereby allowing high field strength and current which puts high charge levels on the particles. The direction of gas flow for the front view of the cold-pipe precharger, which is on the left side of the figure, is perpendicular into the paper; for the side view the gas flow is from left to right.

Combining the cold-pipe precharger with wire-plate collectors using large diameter wires provides an even further improvement in performance. Large diameter wires in the collector sections allow development of high field strengths and also provide sufficient corona current to clamp the particle layer to the plates, thereby minimizing non-rapping reentrainment. Figure 7 shows the multistage ESP which consists of collector sections each of which is preceded by a cold-pipe precharger. With high resistivity particulate matter a multistage ESP will give the same collection efficiency as a conventional ESP operating with relatively low currents and fields and having 4 or 5 times the collecting plate area. Operation of the multistage ESP with the cold-pipe precharger and large diameter wires in the collector sections has been done on the EPA in-house 28 actual m^3/min ESP and on the EPA 425 actual m^3/min ESP at Colorado Public Service's Valmont Power Station.

Multistaging, when retrofitted to an ESP that is working well and is in compliance with the particulate matter regulations, will have more capacity than is actually needed. This suggests that some portion of the ESP internals can be removed. This freed up space, fitted with suitable nozzles, can be used for removal of sulfur dioxide from a flue gas by injecting droplets of an alkaline reagent.

This system, which has been named E-SOX, for the removal of sulfur dioxide along with the particulate matter in an ESP, is shown schematically in Figure 8. The alkali reagent shown being used here is a high calcium lime that has been slaked and slurried by techniques that have been developed for conventional spray drying flue gas desulfurization. E-SOX is discussed in considerably greater detail elsewhere (6), (7).

The E-SOX system has been evaluated on the in-house 28 actual m^3/min ESP using two-fluid nozzles for the alkali reagent injections. The sulfur dioxide removal results are shown in Figure 9. Two reagents were used -- sodium carbonate solution and lime slurry. With the sodium carbonate inlet concentrations of 15 and 30% by weight and at flow rates ranging from 26 to 75 liters per hour, the sulfur dioxide removal ranged, for an inlet concentration of 1200 to 1500 ppm, from about 50 to almost 90%, with 2 seconds of residence time. With a slurried lime injection, whose concentration was 7 and 15% by weight, SO_2 removal ranged from about 40 to almost 60%. Maximum sulfur dioxide was removed at the higher injection rates. The removal was not found to be highly sensitive to reagent concentration. For the lime experiments the maximum stoichiometry of calcium to sulfur was about 1.8 based upon inlet sulfur dioxide. In both cases the injected droplets were completely dried in considerably less than 2 seconds, and the deposits on the ESP were removed by normal rapping. In this series of experiments no attempt was made to optimize the sulfur dioxide removal. In a typical ESP retrofit, enough of the internals could be removed to obtain 2 seconds of residence time. The remainder of the ESP can be multistaged not only to regain original particulate collection performance but also to capture the injected reagent.

The costs of E-SOX have not been fully worked out. However, it is expected that the process should be among the lowest cost of the various flue gas desulfurization techniques. The use of an existing ESP makes it unnecessary to add equipment, such as a spray drying chamber, for sulfur dioxide capture; the lime system is the same as is required for some of the other processes. One advantage of E-SOX is that the injection of a large quantity of droplets lowers the gas temperature and volume which causes a reduction in particle resistivity and an increase in SCA. The E-SOX project is expected to be moved onto a larger pilot unit using actual flue gas as the next stage in its development.

E-SOX, if successfully developed, would be a low-cost retrofit for reducing emissions of sulfur dioxide from coal-fired power plants. This is significant for several reasons: first, coal-fired power plants with ESP particulate control technology represent the largest source category for sulfur dioxide emissions in the U.S.; and second, the high cost of controlling sulfur dioxide with existing technology is a major issue to be considered in air pollution policy analysis. It would be especially useful for those situations in which there is not room for retrofit of a spray drying flue gas desulfurization chamber.

OTHER ACTIVITIES

In addition to the work just described, EPA has a strong program in modeling and fundamentals. The purpose of the modeling/fundamentals program is to provide design and performance models, for the particulate control devices, which are based on a sound understanding of the underlying physics of the particulate collection process. The ESP work has resulted in a com- computer model that is in widespread application by vendors, users, and researchers (8), especially for utility applications. Work is underway to improve the ESP model in the areas of effects of electrode geometry, electrical conditions, and space charge. There is also interest in applying the ESP model to industrial sources in addition to utilities. A new modelling technique computes the voltage and current for several common electrode geometries. The results are presented both numerically and as a video display of the electric field and the current distribution. The ability to display the electrode geometry, electric fields, and current distribution allows the designer to make changes and immediately determine the effect of the changes on ESP performance. Work is currently underway to extend and verify the model capabilities to all electrode shapes and to also allow changes in collector geometry.

The program has produced a useful model for fabric filters. The current version of the model does not include electrostatic effects. However, work is underway to introduce the effects of application of ESFF into the fabric filtration models. A major effort is underway to extend the usefulness of these models to the control of particulate matter from various industrial sources in addition to utilities.

There is additional work being done in fugitive particle control involving the development of engineering design information for hoods used for collection of particles and fume. Operation and maintenance manuals are being developed for ESPs and baghouses. Finally, research is being done to develop technology to decrease the emissions of condensible aerosols.

CONCLUSION

This paper has presented an overview of the key projects of the EPA particulate technology R&D program, which may be of interest to industry. Work will be continuing in the areas that include ESPs, electrostatically augmented fabric filtration, and control of fugitive emissions. Discussion of specific problems in particulate matter control that may make use of these technology areas, would be welcomed.

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Table 1. COMPARISON OF LARGE AND SMALL DIAMETER DISCHARGE ELECTRODES

Resistivity, ohm-cm	8×10^{10}	2×10^{12}
Electric field ratio (E_L/E_S)	1.60	1.19
Current density ratio (j_L/j_S)	0.41	0.69
Power ratio (P_L/P_S)	0.55	0.81
Overall migration velocity ratio (w_L/w_S)	1.12	1.33
Penetration ratio (Pt_L/Pt_S)	0.80	0.25

NOTE: Subscript L refers to large diameter electrode, and subscript S refers to small diameter electrode.

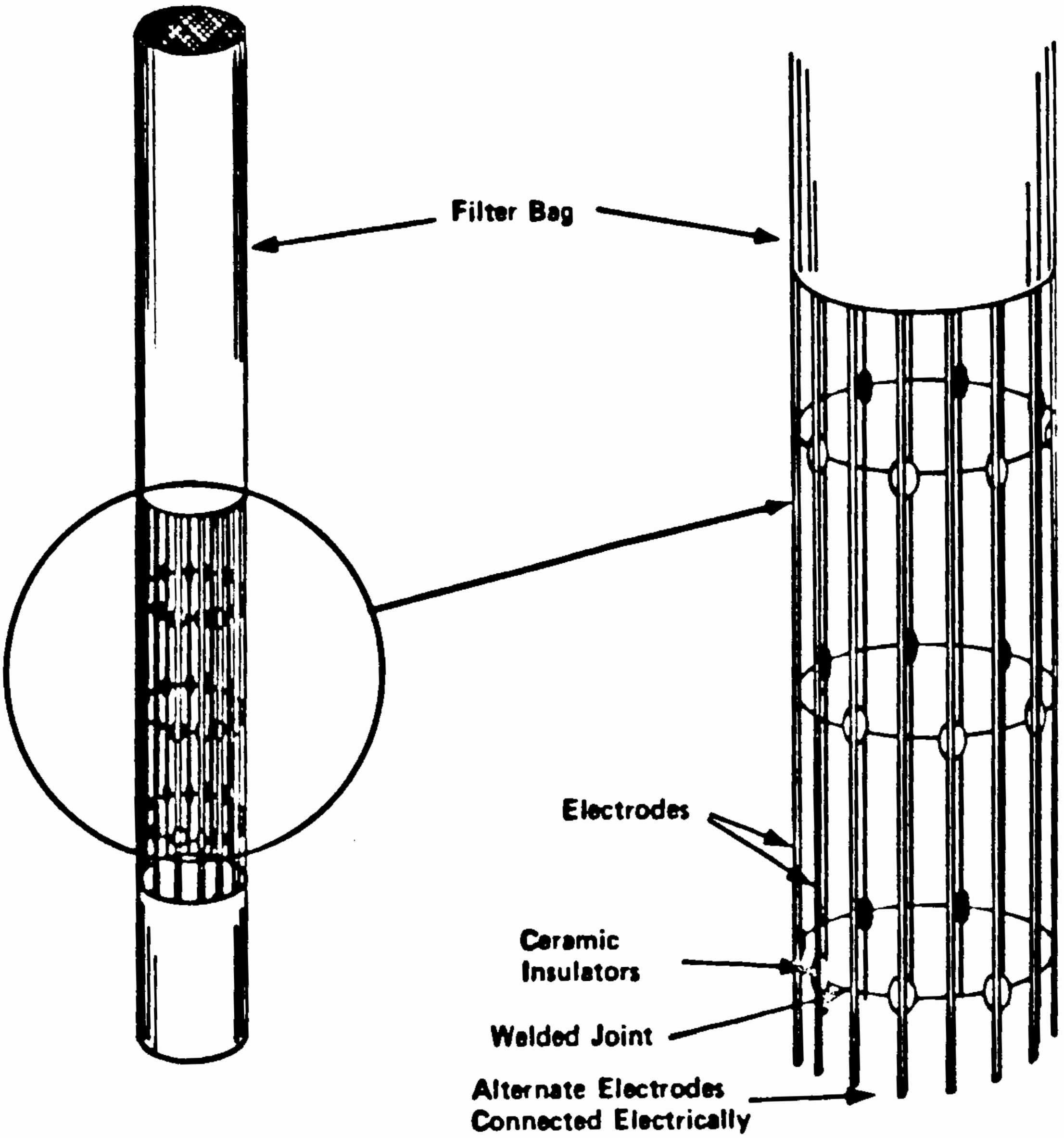

Figure 1. Pulse-Jet ESFF Electrode/Bag Assembly

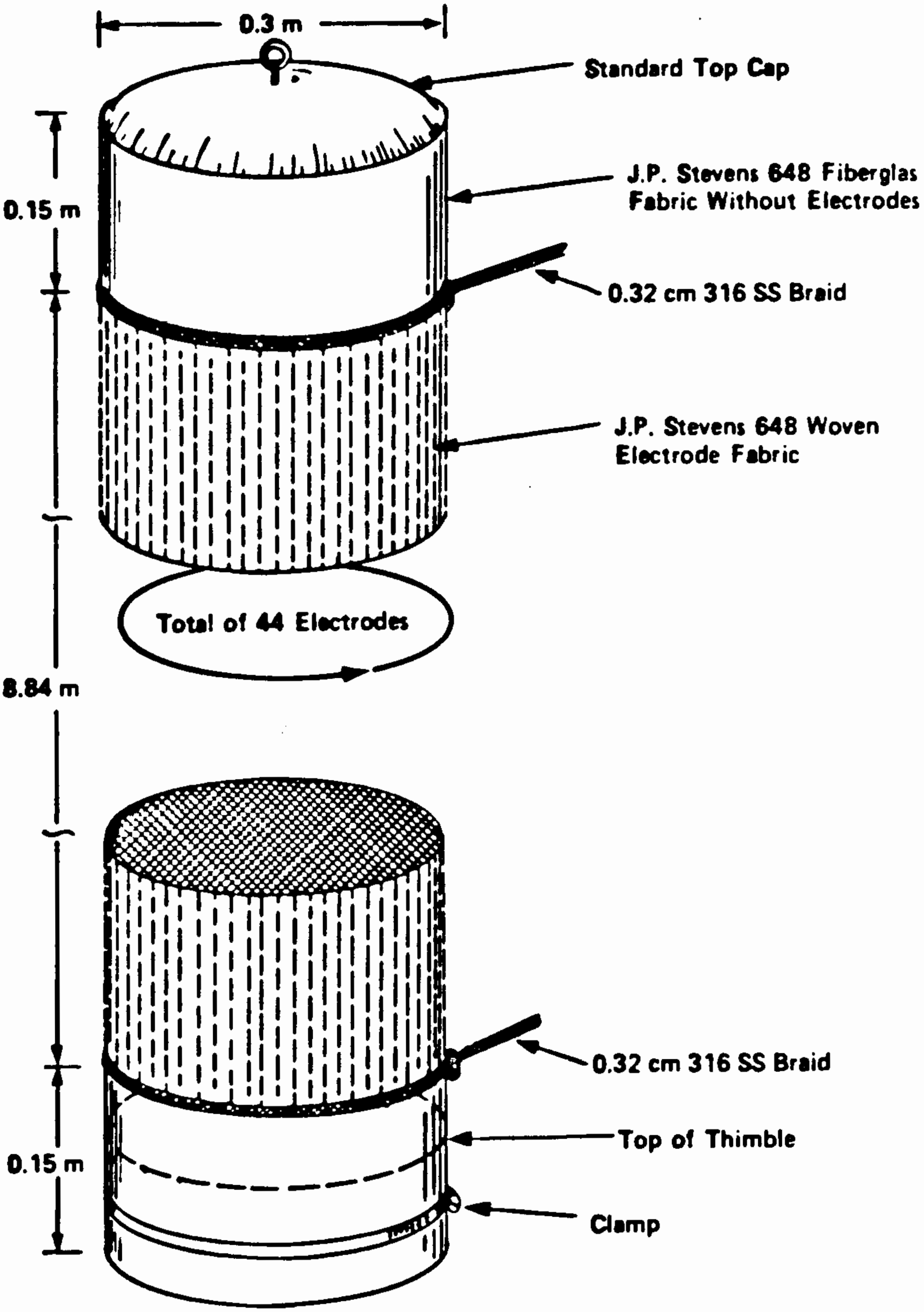

Figure 2. Reverse-Air Woven-In Electrode ESFF Bags

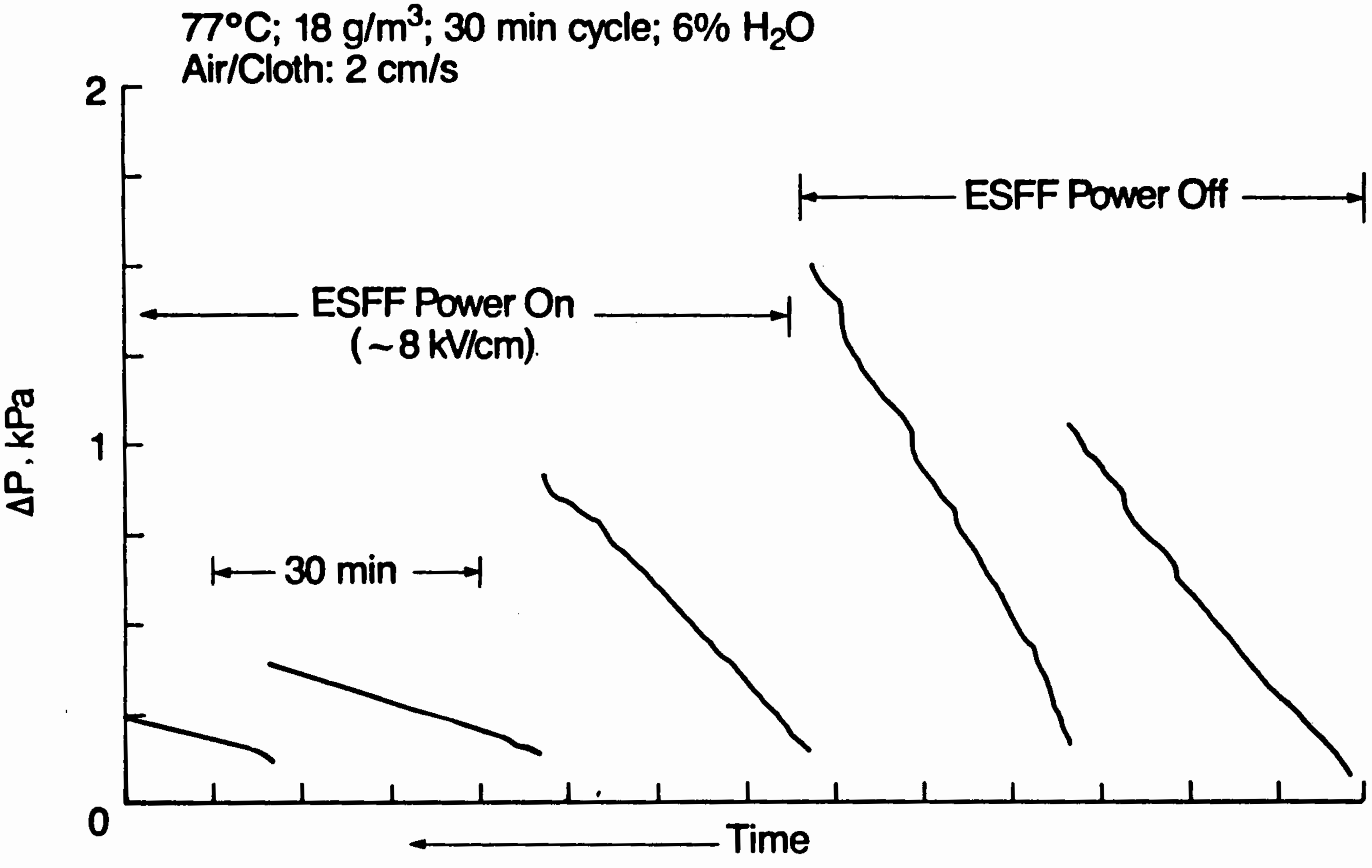

Figure 3. Effect of Turning ESFF Field On

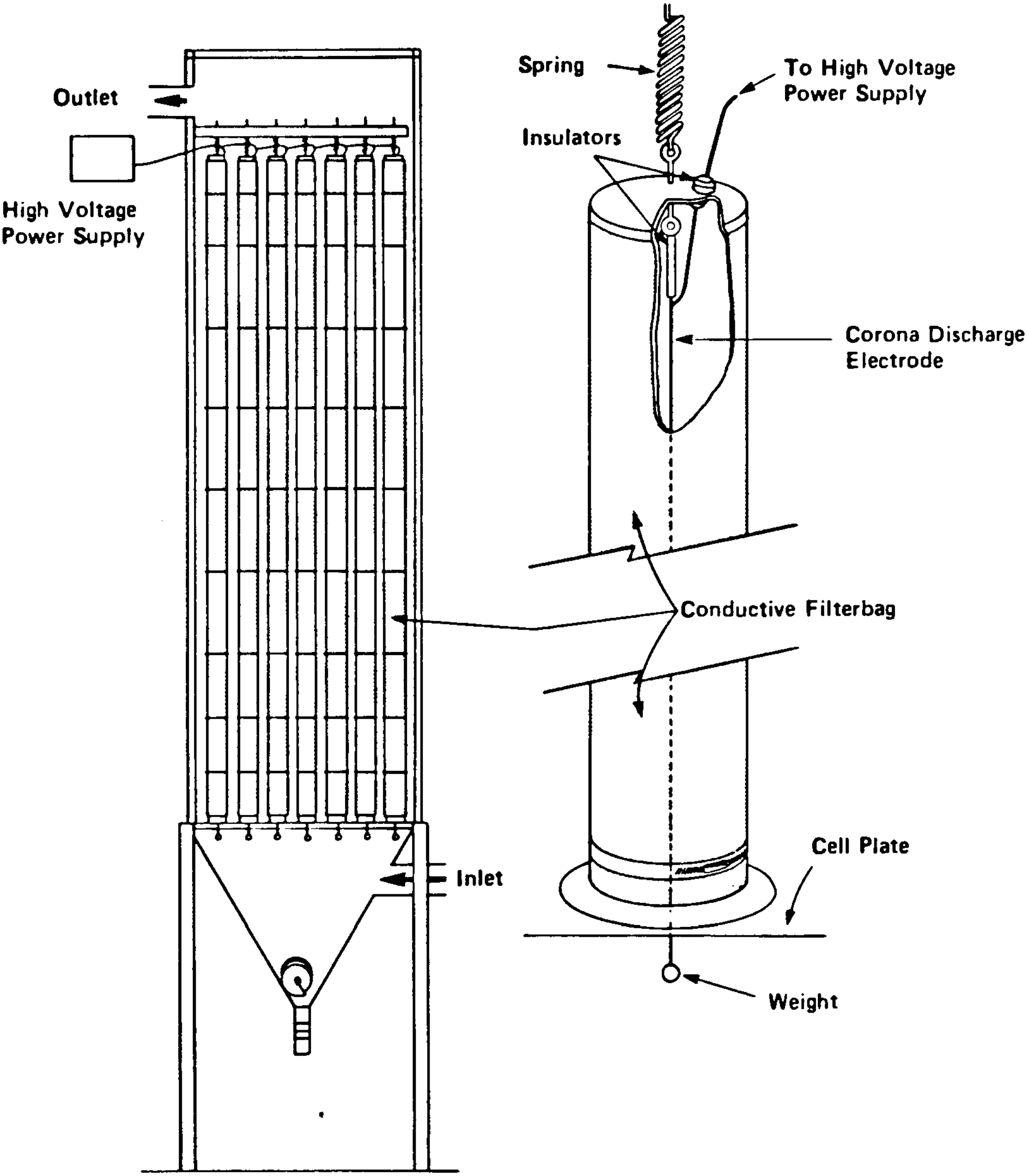

Figure 4. Super ESFF Reverse-Air Configuration

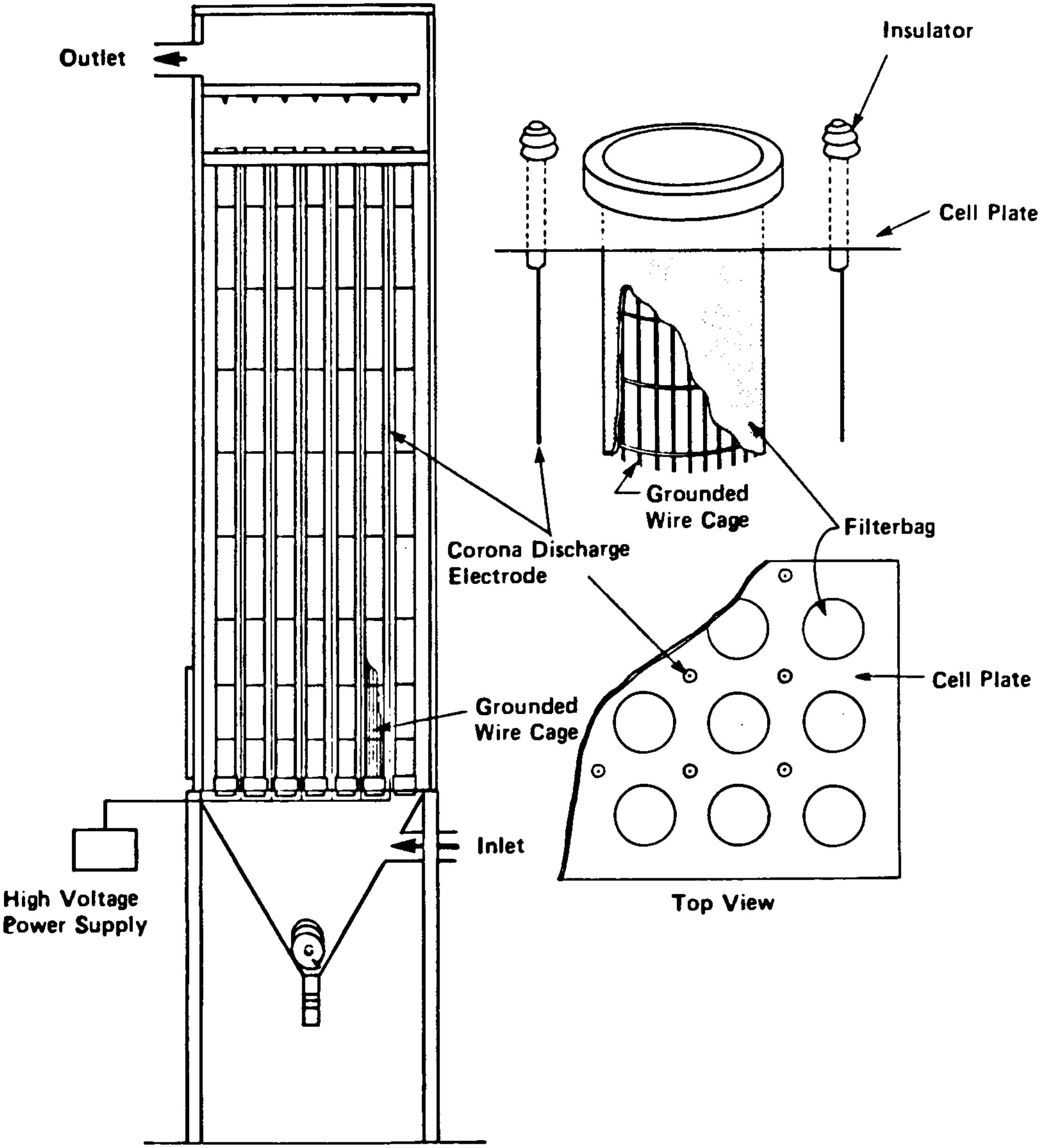

Figure 5. Super ESFF Pulse-Jet Configuration

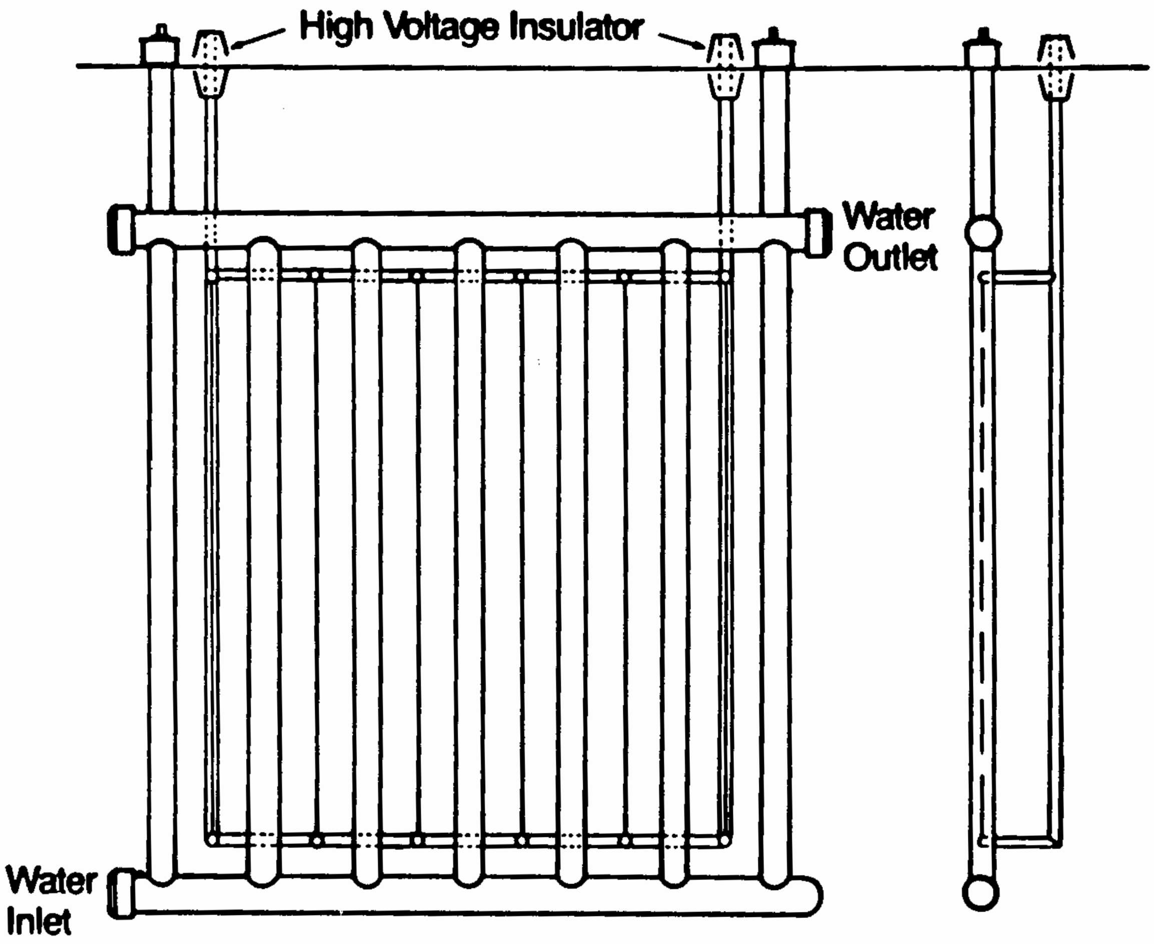

Figure 6. Cold-Pipe Precharger

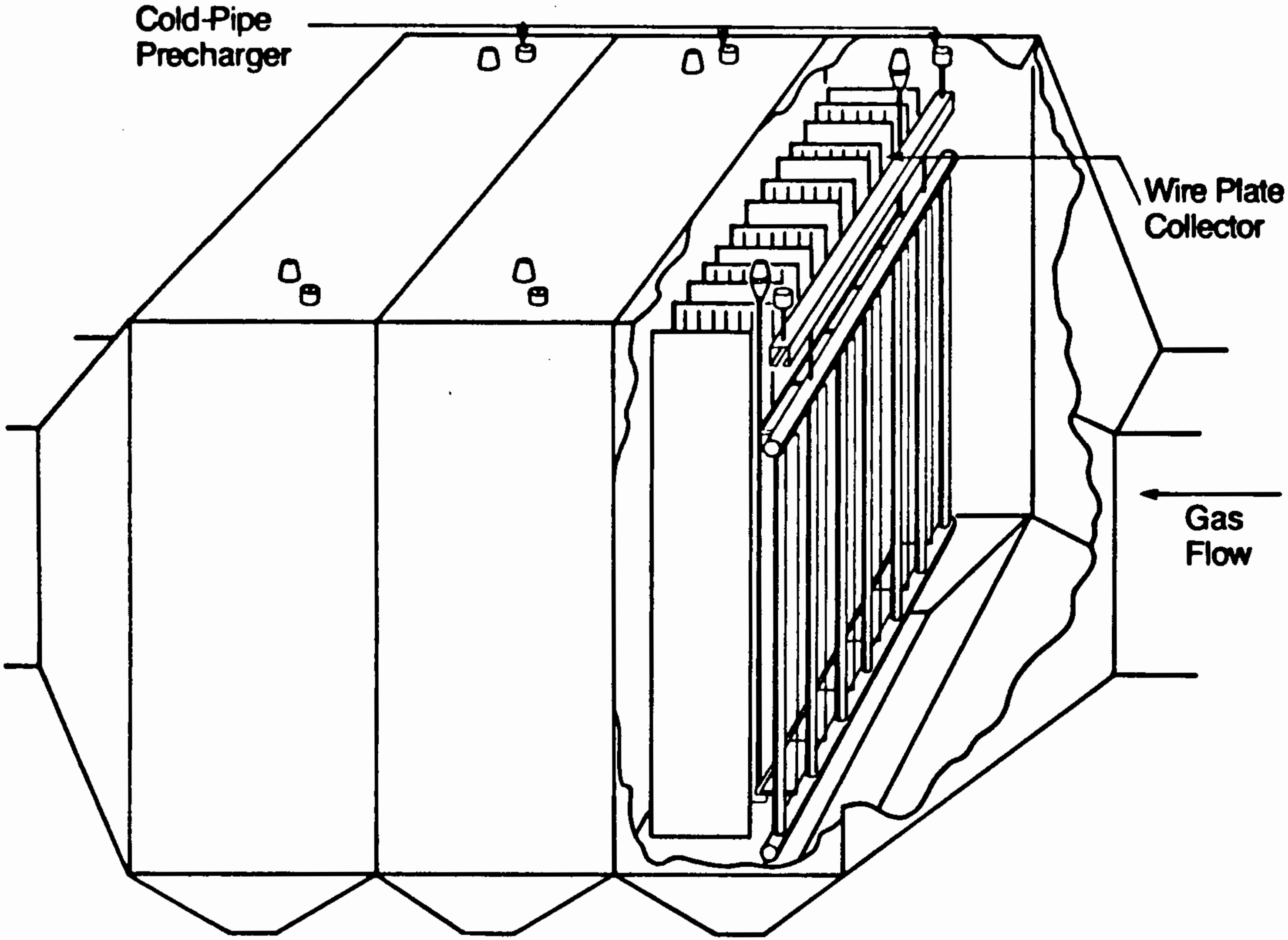

Figure 7. Multistage Electrostatic Precipitator

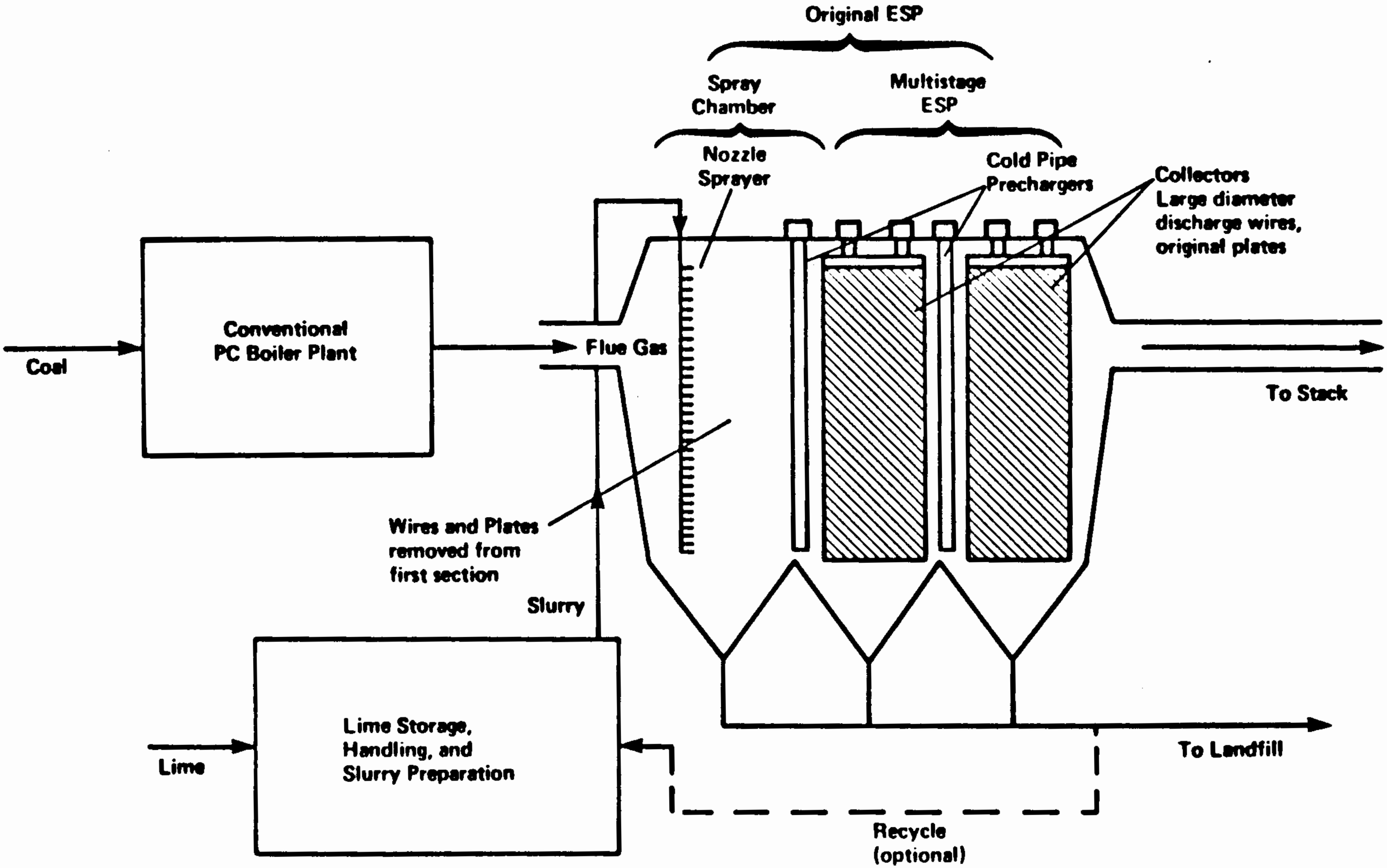

Figure 8. Schematic of E-SOX Process

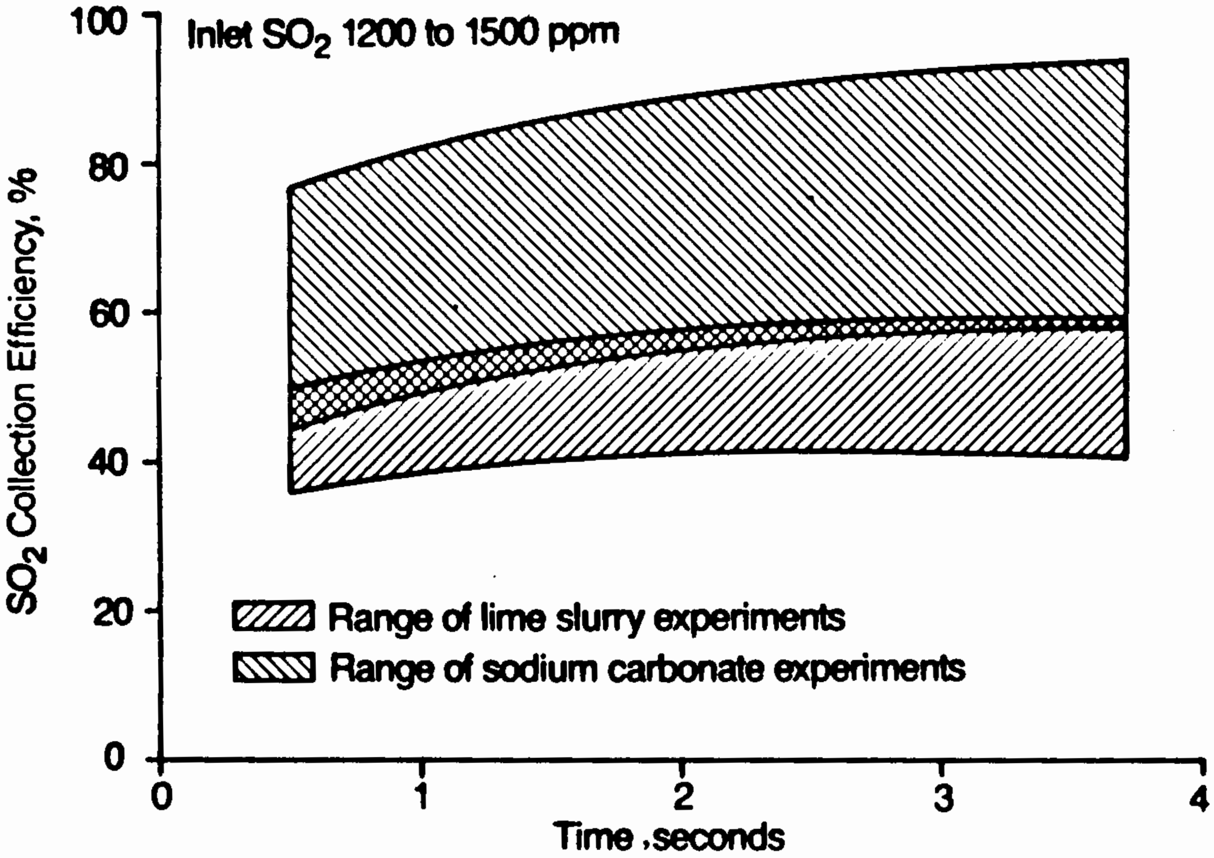

Figure 9. E-SOX Data for Sodium Carbonate and Lime Slurry Experiments