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Project Summary

Electrostatic Augmentation of Fabric Filtration: Reverse-Air Pilot Unit Experience

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This report describes a test of electrostatically augmented fabric filtration (ESFF) on a pilot-scale, reverse-air-cleaned baghouse. The pilot unit consisted of two baghouses in a parallel flow path arrangement. A slipstream from an industrial pulverized-coal boiler house was the ash source for the pilot unit. The fabric under test was a 17-oz (482-g) woven-fiber-glass fabric with a Teflon® B finish. The principal independent variables were baghouse face velocity and ESFF field strength. The main parameters monitored were particle collection, baghouse pressure drop, and electrical power requirements.

It was recognized that successful operation of a large-scale ESFF baghouse required the development of a reliable and practical electrode system. During this project, a filter bag with stainless steel electrodes woven into the fabric was developed and tested in the pilot unit. Other candidate electrode designs were also developed and tested.

Research results show that reverse-air ESFF can reduce fabric filter pressure drops and (thus) may allow increased operating face velocities. It was possible to operate the pilot unit ESFF baghouse (but not the conventional baghouse) at 2 cm/s face velocity. However, due to limits on the experiment, the maximum operating time at 2 cm/s was only a few weeks, which is insufficient to ensure long-term operation at that face velocity. The flow resistance of the collected dust is substantially reduced by the presence of the electric field. Comparison of the average baghouse drag (pressure drop/face velocity) between the ESFF and conventional baghouses showed that the ESFF baghouse drag would range from 54 to 85 percent of the conventional baghouse drag if ESFF were used on the bag for its full lifetime. Based on this and other pilot unit results, it was estimated that an ESFF baghouse operating at 2 cm/s would have an annual cost 11 percent less than that of a conventional (not electrostatically augmented) baghouse operating at 1 cm/s.

The particulate control capabilities of the ESFF baghouse were about the same as for conventional filtration; the ESFF baghouse averaged 99.7 percent efficiency, and the conventional baghouse, 99.8 percent.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Background

The use of fabric filters to remove particles from gas streams is a well-established industrial practice, and its importance is growing for electrical utility boilers. The fabric filter is roughly equivalent in price to other utility control devices and provides increased particle removal efficiency. However, fabric filter operating experience is limited, and enough questions have been raised because of unexpectedly high baghouse pressure drops to cause concern in the industry.

A concept to improve fabric filtration through the use of electric fields (electrostatic stimulation of fabric filtration, or ESFF) was developed at laboratory scale by researchers at the Textile Research Institute (TRI), Princeton, NJ, whose work was partially supported by EPA. TRI showed that the concept could significantly improve filter performance by reducing filter drag and increasing filter efficiency. In work supported by EPA, the Research Triangle Institute (RTI), Research Triangle Park, NC, and ETS, Inc., Roanoke, VA, transferred the ESFF technology to the field by successfully operating a pulse-cleaned ESFF baghouse on a slipstream from an industrial boiler.

Results of this work have been reported: in brief, the pulse-jet pilot work was highly successful. A new ESFF electrode system that was suitable to pulse-jet baghouses was developed as a replacement for the inside cage. The pulse-jet baghouse had a reduced residual pressure drop and a reduced specific dust cake resistance when compared to a conventional baghouse operated in parallel. In addition, the ESFF baghouse operated stably at higher face velocities than was possible with the conventional baghouse. Economic analysis indicated that an ESFF baghouse operated at 3 cm/s would have a 30-percent economic advantage when compared to a conventional baghouse at 2 cm/s, which is the approximate upper limit for conventional pulse-jet baghouses operating on coal-fired boilers.

The ESFF effect can best be understood as the net effect of fundamental forces on particles—either charged on uncharged—in the presence of an electric field. Although only one primary electric field is applied to the filter, that field interacts with the filter fibers and collected particles to form many localized gradients in the electric field. A particle approaching the filter is thus exposed to a complex field before it is collected. The electric field continues to have an effect on the particle after it is collected.

Several changes in the pattern of dust deposition on a filter might account for the reduced pressure drop effects observed with ESFF:

1. An increased fraction of the collected dust being deposited on or near the upstream filter surface.
2. Changes in the pattern of collection on a filter fiber; e.g., more dendritic collection and bridging.
3. Formation of a highly nonuniform dust deposit—at the scale of the electrode spacing—on the filter surface.

An increased fraction of the dust being deposited near the upstream surface of the filter has been observed in laboratory studies of ESFF. Collection in the less dense surface region, which is enhanced by the electric field, leads to reduced pressure drop for a given quantity of dust and reduces the amount of dust that penetrates the fabric.

Changes in the pattern of dust deposition on fibers have been observed by a number of researchers. In general, the presence of an electric field leads to increased dendritic particle collection.

If electrostatic forces cause the formation of a dust deposit with a nonuniform areal mass density, a reduction in pressure drop should result. This will be true, for instance, if coulombic forces cause most of the dust to collect in the immediate region of the electrodes, leaving reduced deposits on the rest of the filter. Highly nonuniform deposits have been observed with redispersed fly ash in a laboratory ESFF filter.

Stabilization of the deposited dust layer by the electric field has also been studied as a possible ESFF mechanism. It is postulated that the initial dust cake formation in an ESFF filter is quite porous due to the electical gradient forces, and that the electric field prevents the collapse of this porous cake as the pressure drop across the filter increases. In ordinary filtration, this porous structure is assumed to collapse somewhat as the cake mass and pressure drop increase.

Purpose of Program

The main purpose of this research program was to develop reverse-air-ESFF. The work centered on the ESFF pilot unit and included electrode and electrical system development as well as pilot unit tests. The emphasis was on realistic field operation to provide pressure drop, particle removal, and system cost information that ultimately could be used in an economic analysis of ESFF.

Pilot Unit and Operating Experience

The primary operating mode during the ESFF pilot unit test program was parallel operation of a conventional (control) baghouse and an electrostatically augmented (ESFF) baghouse. Boiler and coal variations in an operating boiler were expected to be too large for successful comparative testing to be done serially in time in a single baghouse. Testing was done serially (field on/field off) during portions of the test program only to allow different tests to be undertaken at the same time.

The pilot unit was operated on a slipstream from an industrial pulverized-coal boiler house. The coal fed to the boilers was highly variable: sulfur content ranged from 0.6 to 2.9 percent (average about 1.3 percent), and ash content from 6 to 27 percent (average about 13 percent).

Figure 1 is a diagram of the pilot unit. The pilot plant capacity was about 9 m^3/min (300 ft^3/min) in each baghouse; average inlet mass loading was about 0.7 g/m^3 (0.3 gr/scf). The inlet temperature was about 150° C (300° F). The baghouses were normally operated with three bags, each 20.3 cm (8 in.) in diameter and 244 cm (8 ft) long. The electrical hardware consisted of high-volatage DC power supplies, current and voltage instrumentation, and the ESFF electrodes. Operation was 24 hours each day while testing was in progress.

A program goal was to develop ESFF electrodes, and considerable effort was expended during the program to improve the electrode system. Two categories of electrodes were considered: (1) electrodes that are separate from the filter fabric and must be mounted close to the filter to function, and (2) electrodes that are integral to the filter fabric.

During the pulse-jet program, a special pulse-jet cage was developed in which alternate cage rods were electrically connected together but electrically isolated from all nearest neighbor rods. The electric field was thus formed between the long vertical rods of the cage. This electrode design was well suited to a pulse-jet baghouse, because a cage was needed to support the bag even in conventional operation. The cage/electrode was not very different form conventional cages and was estimated to be only slightly more expensive.

The conversion of the pilot unit from pulse-jet to reverse-air cleaning required a different approach to electrode design. The reverse-air baghouse had the dirty gas inside the bag, rather than outside. Collapse of the bag during cleaning could not be hindered or cleaning would suffer drastically. The cage-type electrode was not a desirable choice, and the conversion from pulse-jet to reverse-air operation was accompanied by the start of a program to develop an electrode system integral to a reverse-air bag. While this electrode development program was in progress, cage-type electrode systems such as that shown in Figure 2 were used at the pilot plant.

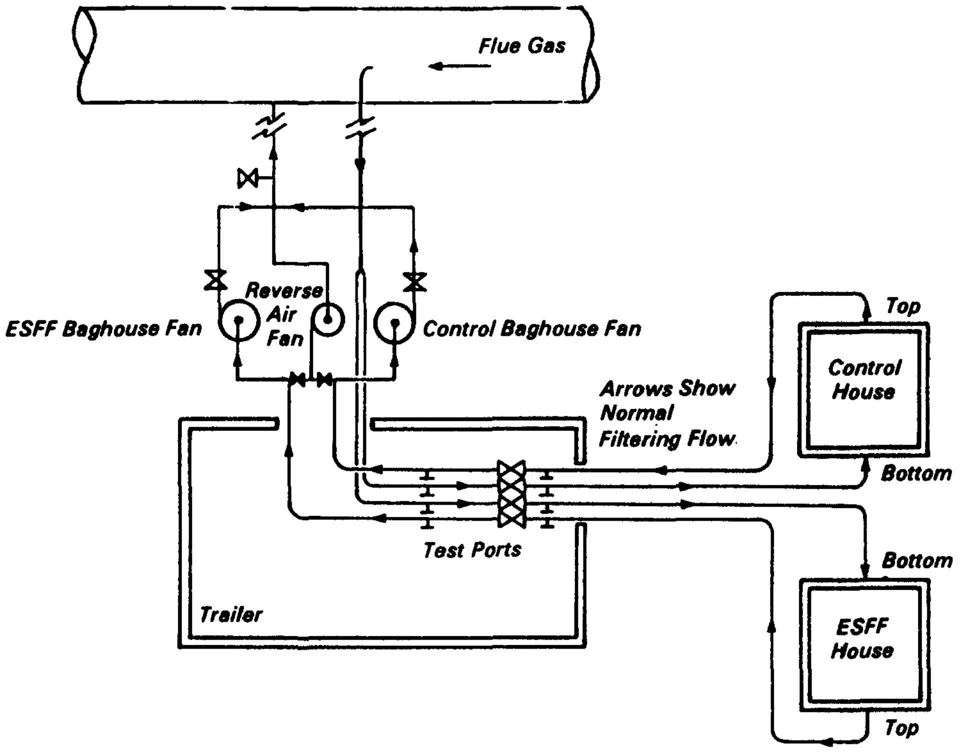

Figure 1. *ESFF pilot unit.*

Electrodes integral to the bag fabric were developed in three directions, more or less concurrently: (1) printed ESFF electrodes, (2) sewn-on ESFF electrodes, and (3) ESFF electrodes woven into the filter fabric.

The concept of using printed electrodes in the ESFF application was pursued: they were found to produce a suitable ESFF effect when applied to a polyester felt. However, the formulation used was not suitable for high-temperature flue gas service. No suitable compounds were identified, and active research on the concept was stopped until a suitable material becomes available.

Sewn-on electrodes were studied and actually put to use at the pilot unit. The major anticipated disadvantages were the large amount of hand labor required to make the bags and the number of pinholes made by the stitching. Bags were constructed and were found to give a satisfactory ESFF effect but to have above-average particle penetration.

Electrodes woven into the fabric were the object of considerable study. A test run was first made with three electrode materials—a stainless steel fiber yarn, a carbon yarn, and a stainless steel/nylon blend. Despite being the most difficult to weave of the test yarns, the stainless steel yarn became the electrode of choice because of its durability.

Sufficient fabric was made for pilot plant use, with the multifilament stainless steel yarns woven in the warp direction at 2-cm spacing. Bags were constructed from the woven electrode fabric, and the performance of the woven electrode bag at the pilot unit was essentially the same as that of the other reverse-air electrodes.

Results

The primary measure of the ESFF effect is the reduction of pressure drop at various baghouse operating conditions. Both the residual pressure drop and the final pressure drop of the ESFF bags were reduced in comparison with conventional technology. ESFF and conventional technology are compared here, on the basis of average drag.

For much of the ESFF test program, baghouse parameters were deliberately varied so that relatively long-term performance at a fixed face velocity could not be evaluated. This is not a departure from normal baghouse operation: baghouse load swings are commonplace. Both the ESFF and conventional baghouse average drags show a gradual increase in average drag over the first 2 months of operation, followed by operation with no overall changes but large variation about the apparent mean. Based on these results, data analysis has been limited to data collected at about the same time from bags of about the same age and history.

The data in Tables 1 and 2 were selected from the overall data pool to provide the clearest available constrasts between ESFF and conventional baghouse operation. Table 1 compares the average drag in the ESFF baghouse and that in the conventional baghouse for the two baghouses operating in parallel. The bags in both baghouses were constructed of the same material and were of the same age. Each data pair compares bags with about 1 month of use, and each is an average over 3 or more days' operation. Table 1 shows that the average drag for a baghouse operated as an ESFF baghouse continuously could be expected to be 65 to 70 percent of the drag in a conventional baghouse.

The data in Table 2 are much like those in Table 1. The bags were about 1-month old and of the same fabric. In Table 2, however, the comparisons are between periods of field-on and -off operation in the same baghouse; i.e., the bags were operated with an ESFF field for a period of time and then the field was turned off for a period of several days. In some cases the field was then turned on again. The ratio of drags averages 0.9, compared to the ratio of 0.65 to 0.70 found for the data in Table 1.

This comparison of Tables 1 and 2 indicates that applying the ESFF field continuously is decidely more advantageous than turning the field on and off.

The effects of electric field strength and face velocity on drag were investigated during the three test periods. Data from these tests are given in Figure 3. Data include both parallel baghouse operation and field-on/-off operation. Most data points are averages of 2 to 4 days of operation. There is clear dependence of average drag on field strength at all face velocities tested, as well as significant dependence of average drag on face velocity. Halving the face velocity at any field strength reduced the average drag by 25 to 50 percent.

Over the entire pilot unit test program, the bag currents averaged about 130 μA/bag, or about 0.7 W/m^2 at an applied voltage of 5.4 kV. The monthly average currents ranged from 13 to 420 μA per bag, which is about 0.07 to 2.5 W/m^2.

ESFF performance was not related to bag current if the electric field was kept on the bag. Sooty particles from oil firing and acid condensation during low tem-

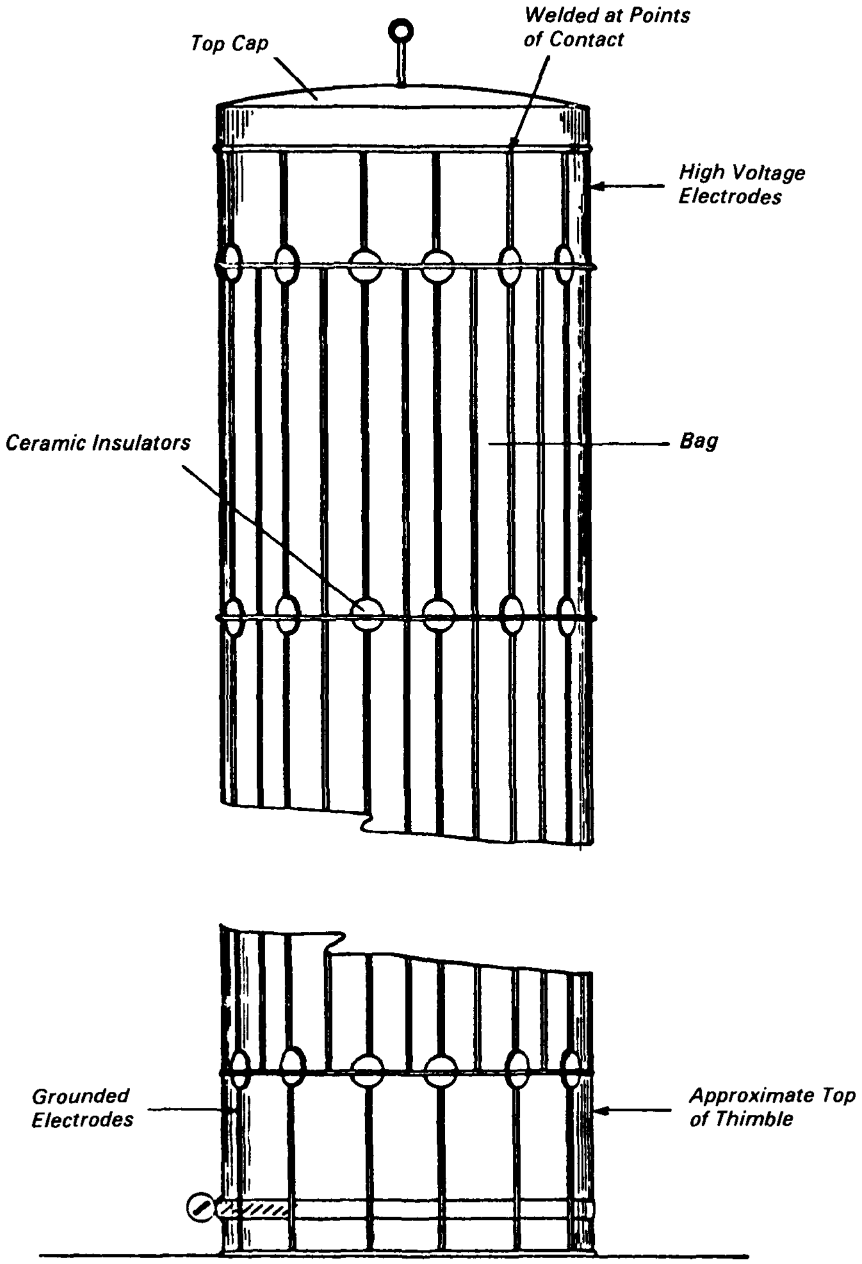

Figure 2. *Reverse-air "RIGID" cage.*

perature caused high currents and reduced the power supply voltage. Under these conditions, there was no ESFF field on the bag, and no ESFF effect. Generally, the bags recovered without special efforts to clean them.

The particle removal capabilities of the ESFF and conventional baghouses were very similar: the ESFF baghouse averaged 99.7 percent efficiency, and the conventional baghouse, 99.8 percent. This difference is not significant at the 90-percent level for the data collected.

A modified baghouse cost model was applied to a 500-MW power plant for both conventional fabric filtration and ESFF. Costs were estimated for both at face velocities of 1 and 2 cm/s. Conventional fabric filters are nomally not capable of operation at 2 cm/s; whether an ESFF filter can operate at that gas rate remains uncertain. The pilot unit was operated at 2 cm/s without difficulty, but the maximum operating time was only a few weeks. The design pressure drops used in the model for the ESFF and conventional baghouses were based on pilot unit experience. Based on pilot unit experience, the ESFF bags are expected to cost two to four times as much as conventional bags; this range is used in the ESFF cost estimates.

The cost estimates provided by the model for 1- and 2-cm/s face velocities and ESFF bag costs of two, three, and four times conventional bag costs of $7/m^2$ are given in Table 3. For example, at 1 cm/s, an ESFF baghouse has increased turnkey capital cost when compared to conventional technology, increased variable operating costs (dominated by bag replacement cost), and reduced total electrical cost (because of reduced pressure drop). Overall, the ESFF baghouse would be expected to cost between $400,000 and $1,200,000 more than a conventional baghouse operating at the same face velocity.

Operating an ESFF baghouse at an increased face velocity appears to be an attractive alternative. An ESFF baghouse at 2 cm/s, using bags costing three times conventional bags, has an annual cost of $3,430,000. Experience at the pilot unit suggests that this is reasonable. The bag cost estimate may be excessive for a full-scale production operation. A conventional unit at a normal and achievable 1 cm/s, controlling the same gas stream, has an annual cost of $3,840,000, giving the ESFF baghouse an 11-percent cost advantage; at a bag cost of twice conventional bag cost, the advantage is 18 percent.

The comparisons above show that the ability to operate an ESFF baghouse at increased face velocities is the single most important variable in the economic analysis; ESFF bag cost is also critical.

Conclusions

ESFF, utilizing an electric field parallel to the fabric surface (with no particle charging), has been applied successfully at pilot scale on a reverse-air baghouse.

The integral woven-in electrode developed during this program is a reliable way to produce an electric field parallel to the fabric surface and has potential for commercial development.

At any given face velocity, the pilot ESFF baghouse had a reduced residual pressure drop and a reduced rate of pressure drop increase, compared to the pilot conventional baghouse.

Particulate mass emissions from the ESFF baghouse were not significantly different from conventional baghouse emissions.

Operation of a reverse-air ESFF baghouse at above conventional face veloci-

Table 1. *Drag Comparisons Over Similar Operating Periods (Comparison of Two Baghouses, ~1-Month-Old Bags, Field-On South Baghouse, Field-Off North Baghouse)*

Inclusive Julian date, day.year	*Field strength, kV/cm*	*Face velocity, cm/s*	*Mean of average drags, kPa·s/cm*	*Ratio of field on/ off drags*	*Difference of field on/ off drags, kPa·s/cm*
148.81-151.81	*3.9*	*2.0*	*0.40*	*0.54*	*0.34*
148.81-151.81	*0*	*2.0*	*0.74*		
191.81-196.81	*3.6*	*1.5*	*0.56*	*0.66*	*0.29*
191.81-196.81	*0*	*1.5*	*0.85*		
25.82-31.82	*4.0*	*2.0*	*0.76*	*0.85*	*0.13*
25.82-31.82	*0*	*2.0*	*0.89*		
Overall mean				*0.68*	*0.25*

Table 2. *Drag Comparisons Over Similar Operating Periods (Same Baghouse, Bags, Electrodes, ~1-Month-Old Bags, Sequential Field On/Off Periods)*

Inclusive Julian date, day.year	*Field strength, kV/cm*	*Face velocity, cm/s*	*Mean of average drags, kPa·s/cm*	*Ratio of field on/ off drags*	*Difference of field on/ off drags, kPa·s/cm*
Standard bags, rigid electrodes					
246.82-249.82	*2.8-3.8*	*1.25*	*1.44*		
256.82-260.82	*3.8*	*1.25*	*1.49 1.46*	*0.89*	*0.18*
250.82-254.82	*0*	*1.25*	*1.64*		
Standard bags, rigid electrodes					
269.82-273.82	*3.8*	*1.4*	*1.30*	*0.84*	*0.25*
274.82-278.82	*0*	*1.4*	*1.55*		
Sewn spiral electrode bags					
343.82-349.82	*2.2*	*1.5*	*1.16*	*0.92*	*0.10*
350.82-356.82	*0*	*1.5*	*1.26*		
Sewn spiral electrode bags					
362.82-363.82	*2.4*	*1.5*	*1.48*	*0.94*	*0.10*
364.82-365.82	*0*	*1.5*	*1.58*		
Overall mean				*0.90*	*0.16*

ties was not clearly demonstrated during this program.

The average drag of both the conventional and ESFF baghouses increased as the face velocity was increased. The average drag decreased as the field strength was increased for all face velocities.

The current requried by the ESFF baghouse did not depend on field strength or dust cake thickness within normal operating ranges.

An ESFF baghouse operating at 2 cm/s, using bags costing three times the cost of conventional bags, was estimated to have an annual cost 11 percent below a conventional baghouse at 1 cm/s. Bag cost and ESFF face velocity are the most important parameters in the economic comparison of ESFF with conventional operation.

Recommendations

Undertaking reverse-air ESFF with relatively full-scale bags with sufficient operating time would allow evaluation of long-term effects and benefits. Extended operation (a year or so) under field conditions should provide conclusive evidence concerning the design face velocity allowable for ESFF baghouses.

An improved theoretical understanding of the electrical effects in filters would be helpful. Currently, generalizations from data are not possible. Variations in the inlet to the pilot unit made detailed study of many operational parameters difficult. Results of further laboratory-scale work, particularly at boiler temperatures, could lead to further model development.

Modeling and onsite testing in various environments could extend the applicability of ESFF over a range of dusts and conditions.

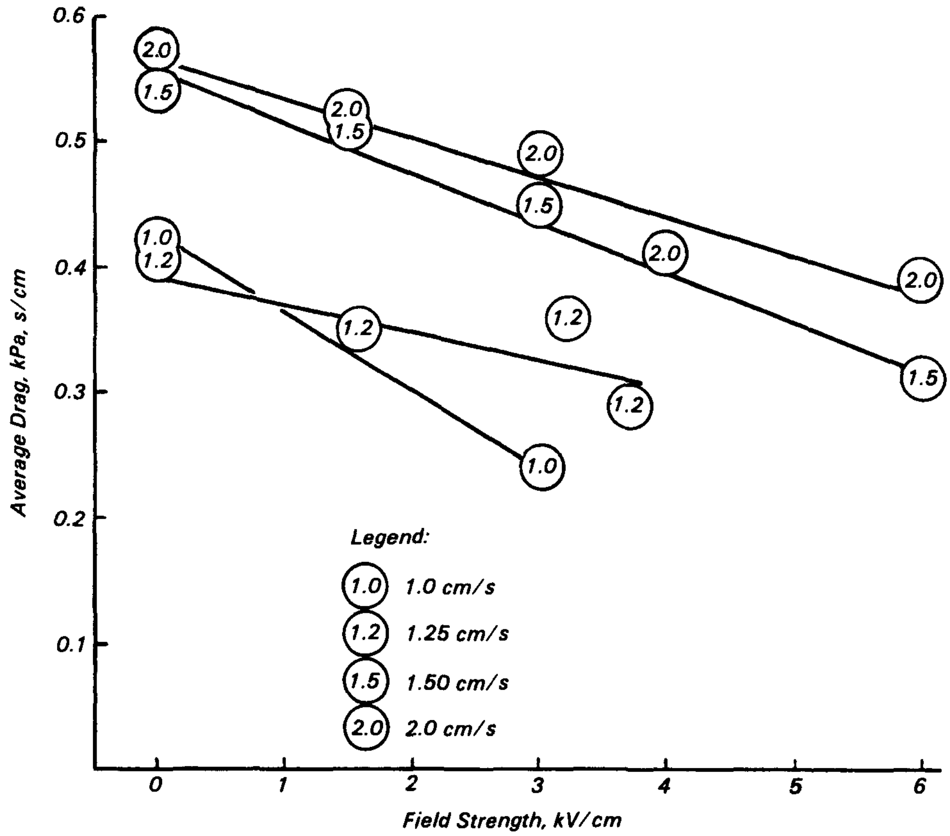

Figure 3. *Drag as a function of field strength and face velocity.*

Table 3. *ESFF Versus Conventional Baghouse Cost*

	Cost (10^6 $)							
	Face velocity = 1 cm/s				Face velocity = 2 cm/s			
Baghouse description: Bag cost:	Conv. $7/m^2	ESFF $14/m^2	ESFF $21/m^2	ESFF $28/m^2	Conv. $7/m^2	ESFF $14/m^2	ESFF $21/m^2	ESFF $28/m^2
ESFF hardware	0	0.62	1.02	1.43	0	0.31	0.51	0.71
Collector and supports	5.85	5.86	5.86	5.86	3.64	3.65	3.65	3.65
Ducting and supports	0.87	0.87	0.87	0.87	0.86	0.87	0.87	0.87
Ash removal system	0.62	0.62	0.62	0.62	0.61	0.61	0.61	0.61
Insulation	1.60	1.60	1.60	1.60	1.10	1.10	1.10	1.10
Ash pond	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14
ID fan	0.08	0.04	0.04	0.04	0.22	0.13	0.13	0.13
Miscellaneous	4.01	4.01	4.01	4.01	2.74	2.75	2.75	2.75
Total field cost	14.2	14.8	15.2	15.6	10.3	10.6	10.8	11.0
Engineering	2.83	2.95	3.03	3.11	2.06	2.11	2.15	2.19
Contingency	2.83	2.95	3.03	3.11	2.06	2.11	2.15	2.19
Turnkey cost	19.9	20.7	21.2	21.8	14.4	14.8	15.1	15.3
Fixed operating costs	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Variable operating costs	0.39	0.69	1.00	1.30	0.30	0.52	0.74	0.97
Cost of electricity	0.18	0.15	0.15	0.15	0.24	0.18	0.18	0.18
Annual capital cost	3.17	3.30	3.39	3.48	2.31	2.36	2.41	2.45
Total annual cost	3.84	4.24	4.64	5.03	2.95	3.16	3.43	3.70

Basis: 500-MW boiler, 720 am^3/s; conventional average pressure drop of 1.12 kPa at 2 cm/s, 0.42 kPa at 1 cm/s; ESFF pressure drop of 0.65 kPa at 2 cm/s, 0.19 kPa at 1 cm/s; interest rate of 15%/yr.

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The complete report, entitled "Electrostatic Augmentation of Fabric Filtration: Reverse-Air Pilot Unit Experience," (Order No. PB 84-230 002; Cost: $14.50, subject to change) will be available only from:

National Technical Information Service
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