Advanced Electrostatic Stimulation of Fabric Filtration

Performance and Economics

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In advanced electrostatic stimulation of fabric filtration (AESFF), a high voltage electrode is placed coaxially inside a filter bag to establish an electric field between the electrode and the bag surface. The electric field alters the dust deposition pattern within the bag, yielding a much lower pressure drop than that found in a conventional bag. Pilot plant results show that AESFF bags can operate with a rate of pressure loss that is 70 percent below that for conventional bags. The presence of the electric field also affects the aging characteristics of the AESFF bags. On the average, the AESFF bags had residual drags that were 10 percent below those of conventional bags. The results show that AESFF baghouses can yield the same pressure drop performance as conventional baghouses while operating at much higher air-to-cloth ratios. An economic analysis evaluated the capital, operating, and maintenance costs for electric utility plants ranging from 200 to 1,000 MW. For AESFF baghouses the capital cost was found to be 25 to 48 percent below that of a conventional baghouse. A lifetime cost analysis predicts a net present value for an AESFF baghouse that is 10 to 30 percent below that of a conventional baghouse.

With few exceptions, fabric filters (baghouses) have proven to be very efficient dust collectors. As a result, the emphasis of baghouse research has been on finding ways to lower the pressure loss that is the natural result of dust buildup on a fabric surface. One method of lowering the pressure loss across a dust cake is through the use of electrostatics. Numerous attempts have been made to use electrostatic effects to improve the performance of fabric filters.[1,2] These efforts have met with varying degrees of success, and several concepts have been demonstrated on both reverse-air-cleaned and pulse-cleaned pilot units.[3–5] The results of these demonstrations have shown that electrostatic enhancement can have a significant effect on pressure drop. As these techniques have only been demonstrated at the pilot plant/demonstration unit stage, utilities are reluctant to pursue this technology.

In recent years, the U.S. Environmental Protection Agency has tested a center-wire electrode configuration, called advanced electrostatic stimulation of fabric filtration, (AESFF) that produces a greater reduction in pressure loss than previously studied methods. The general concept of a center-wire electrode configuration is an outgrowth of various attempts to develop a combined electrostatic precipitator/fabric filter device.[6–9] As described by Hovis *et al.*,[10] the EPA configuration is fairly simple and is quite similar to that described by Frederick[9] (Figure 1). A high voltage is imposed on an electrode which is coaxial with the bag so that an electric field is established between the electrode and the dust/fabric surface (which serves as the ground plane). The presence of the electric field alters the dust deposition pattern and the structure of the dust cake, resulting in a reduction in the pressure drop across the bag. Laboratory results[10] showed that this design reduced the rate of pressure loss by 90 percent; this improvement is much better than that offered by any previous method of electrostatic enhancement. In addition, the hardware is simpler than that required for other methods. Encouraged by these laboratory results, EPA initiated a pilot test program in conjunction with the U.S. Navy to assess the technical and economic feasibility of this new method.

This paper provides a brief description of the pilot program, which included some novel measurement and observation techniques, the results of the pilot program, and an economic analysis of AESFF based on the pilot results. The complete details of the test program are contained in the project report.[11]

Pilot Program

A fabric filter pilot plant was designed to filter coal fly ash from a slipstream from two spreader-stoker-fired boilers. The plant was located at Cherry Point Marine Corps Air Station in Havelock, North Carolina. The boilers are rated at a maximum of 9.77 kg steam/s (77,500 lb/h). Only one boiler was on-line at any given time during the pilot plant test. The fuel for the boilers was an Eastern coal with 1 percent sulfur, 5 percent water, and a heat content of 31,600 kJ/kg (13,600 Btu/lb). The ash from the boiler had a high unburned carbon content with the result that its electrical conductivity was relatively high for a coal ash. The slipstream to the pilot plant was drawn from the outlet of a mechanical dust collector. As a result, the average measured dust load at the inlet to the baghouse was somewhat low (574 mg/Nm^3).

The pilot plant consisted of a single suction-type compartment fitted with at first six and then four woven glass bags (JP Stevens 648 fabric) 7.3 m (24 ft) long and 0.2 m (8 in.) in diameter. In the six bag arrangement, there were two rows of three bags each, with alternating AESFF and conventional bags. All of the bags were fitted with electrodes as shown in Figure 1; however, a maximum of three bags were electrified at any time. The electric field strength ranged from 1.8 to 3.5 kV/cm and averaged approximately 2.7 kV/cm. Current density ranged from 10 to 20 nA/cm^2, with most of the testing performed at 10 nA/cm^2. The gas flow was drawn at a rate of 19.8 m^3/min (700 acfm). At full load the fan could produce an average face velocity of 0.71 m/min (2.33 ft/min) for six bags. By removing two bags from service, the remaining bags would have an average face velocity of 1.06 m/min (3.5 ft/min). The unit operated on a 12-hour cycle with a cleaning period of 10 minutes at the end of each cycle. A small fan provided ambient air for reverse-air cleaning.

The test program called for a prolonged side-by-side comparison of conventional and AESFF filtration. The bags operating as conventional filters served as experimental controls to permit assessment of the effectiveness of AESFF. Certain constraints affected the design of the experiments. First, there was only a single baghouse module available for use in the test program. Second, the host site for the pilot plant was only available for one year, after which the pilot plant had to be removed. Third, the pilot plant could not be continuously manned. These constraints were not overly restrictive, since the focus of the pilot program was to demonstrate the feasibility of advanced ESFF and not to try to optimize the design or operation. Nevertheless, some novel techniques were required to ensure the successful completion of the project. In order to deal with the first two constraints, individual bag flow monitors (IBFMs) were used to permit simultaneous operation of two different types of filtration (i.e., standard, non-enhanced filtration and AESFF) in a single compartment. An IBFM is simply a calibrated orifice plate placed at the inlet of the bag on top of the compartment tubesheet. Pressure taps located on the upstream and downstream sides of each orifice plate provide a mechanism for measuring the orifice pressure drop. Data on the pressure drop, temperature of the gas, and calibration allow the flow into each bag to be calculated. The greatest advantage of testing the AESFF and conventional bags in a single compartment is that the different bags were exposed to identical conditions, providing increased confidence in the comparison of the results for the two sets of bags. The only disadvantage to this technique is the additional analysis required to understand the data. The details of the data analysis will be outlined below.

The other major hurdle to be faced was the requirement that the pilot plant operate unattended for extended periods of time. While it was not difficult to design the baghouse itself for unattended operation, there was the problem of data collection. The limited amount of time available for the use of the test site meant that mistakes would be costly in terms of lost operating time. In other words, it was essential to have a means to check up on the plant on a daily basis and to inspect the data as it was collected. To meet these requirements, off-the-shelf hardware and software were assembled into a data collection system that would automatically collect and store the data on a microcomputer and permit remote access to the stored data. This system was a great asset to the test program since it eliminated the cost of labor for data collection and since the automatic storage of data in magnetic form eliminated the possibility of errors that would accompany manual entry of the data into a computer. A complete description of the data collection program is given by Viner *et al.*[12]

The only data that were not collected automatically were the inlet dust loading readings. This was measured on two occasions by standard EPA Method 5 techniques. It was assumed that the dust load was constant over time. Although this is a tenuous assumption, the importance can be minimized by calculating relative (as opposed to absolute) values.

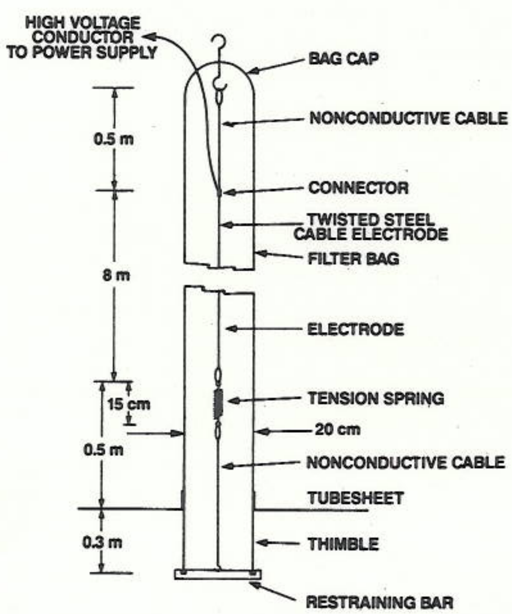

Figure 1. A prototype electrode design for implementation of advanced ESFF.

Data Analysis

A commonly accepted model of pressure drop behavior in fabric filters holds that the drag across a filter increases linearly with the dust load on the filter, expressed as:

$$S(t) = \frac{\Delta P_{\text{dust/fabric}}}{V(t)} = S_e + K_2 W(t - t_{\text{clean}}) \quad (1)$$

where $S(t)$ = the drag across the filter at time t (kPa·min/m)
$\Delta P_{\text{dust/fabric}}$ = the pressure loss across the dust/filter (kPa)
$V(t)$ = the filtration velocity at time t (m/min)
S_e = the effective residual drag (kPa·min/m)
K_2 = the specific resistance of the dust (N·min/g·m)

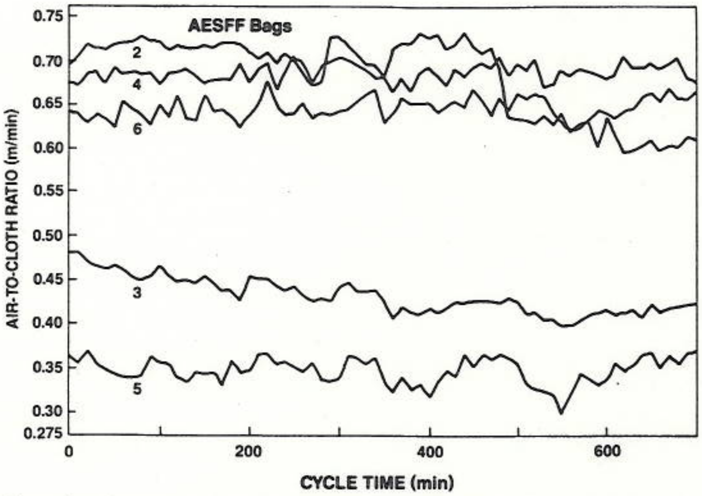

Figure 2. Average air-to-cloth ratios for each bag during one filtration cycle.

$W(t - t_{clean})$ = the mass of dust deposited per filter area (since the most recent cleaning at time t_{clean}) (kg/m^2).

In a conventional baghouse, the pressure loss from one side of the dust/fabric surface to the other is equal to the tubesheet pressure drop. In this study, the tubesheet pressure drop is the sum of two pressure drops: the pressure loss through the dust/fabric depth and the pressure loss due to the IBFM orifice plate at the inlet to the bag; that is,

$$\Delta P_{tubesheet} = \Delta P_{orifice} + \Delta P_{dust/fabric} \quad (2)$$

The IBFM pressure drop is usually small, [less than 0.1 kPa (0.4 in. H_2O)] however, it must be taken into account. By measuring both the tubesheet pressure drop and the IBFM orifice pressure drop, the dust/fabric pressure drop can be obtained by difference.

The purpose of the IBFM orifice plate is to permit the determination of the flow into individual bags. The average face velocity across the bag surface is the ratio of the bag flow to the bag surface area; that is,

$$V(t) = \frac{k \cdot \sqrt{\Delta P_{orifice} \cdot T}}{A} \quad (3)$$

where k = a calibration constant characteristic of the orifice plate [$m^3/min\ (kPa\ °K)^{1/2}$]

T = the temperature of the gas passing through the orifice (K)

A = the active filtration surface area of the bag (m^2).

By measuring the orifice pressure drop and the gas temperature, the average filtration velocity through a bag of area A can be calculated. This information can then be used to determine the rate of dust accumulation on a filter bag. The cumulative dust load is found by integration:

$$W(t - t_{clean}) = C_i \int_{t_{clean}}^{t} V(t)dt \quad (4)$$

where C_i = dust concentration at the inlet of the filter (kg/m^3).

When expressed in terms of drag, as in Equation 1, the dust/fabric pressure drop is seen to be a function of the residual drag of a filter (S_e) and the specific dust resistance (K_2). The filter drag (S) and dust load (W) at any time (t) can be calculated from the measured gas flowrate, and the values of S_e and K_2 can be determined for each bag by linear regression of the drag-dust load data. Given values of K_2 and S_e, one can calculate pressure drop for a system operating at different conditions (e.g., filtration velocities, dust loads). In particular, one can predict the pressure drop performance of conventional and AESFF baghouses operating under identical conditions.

Pilot Plant Results

The pilot plant was brought on-line in May 1985 with a total of six bags, three of which were electrified. For the sake of clarity, the AESFF bags will be referred to as bags 2, 4, and 6 (i.e., the "even" bags). The conventional bags were numbered 1, 3, and 5 (i.e., the "odd" bags). The first test was to see if the electric field had any effect on the distribution of flow between AESFF and conventional bags. The information on individual bag flows can be obtained from the IBFM orifice data. An example of this data (in terms of bag flow per unit area) is shown in Figure 2. There are two sets of curves shown in the figure. The upper set of curves corresponds to three even (i.e., AESFF) bags, and the lower set of curves corresponds to two of the odd (i.e., conventional) bags. The data shown in the figure are from early in the test program and, although it is a bit noisy, it shows a clear distinction between the AESFF and conventional bags. The important feature of the data is the much higher flow through the AESFF bags, indicative of a lower flow resistance. In this case, the AESFF bags are carrying roughly 70 percent more flow than the conventional bags. The gap between the velocity curves of the two odd bags is largely due to differences in drag characteristics of the new bags. This discrepancy eventually disappeared. The noise in the data was due to prob-

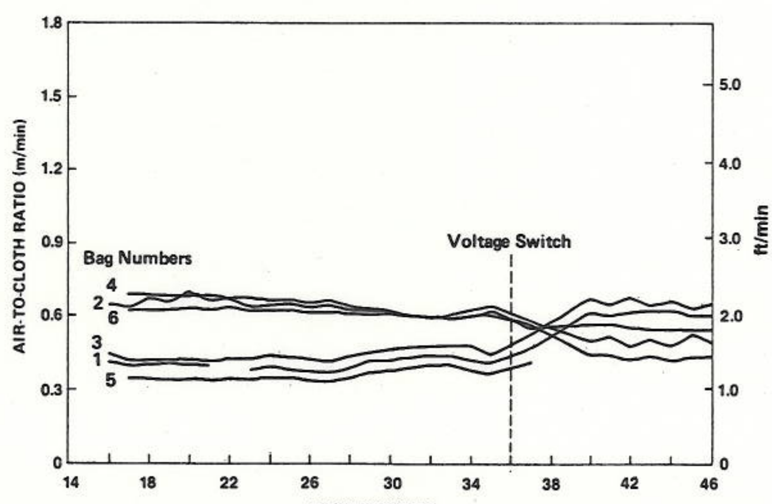

Figure 3. Individual bag-flow data (cycle average air-to-cloth ratio) when the voltage was switched.

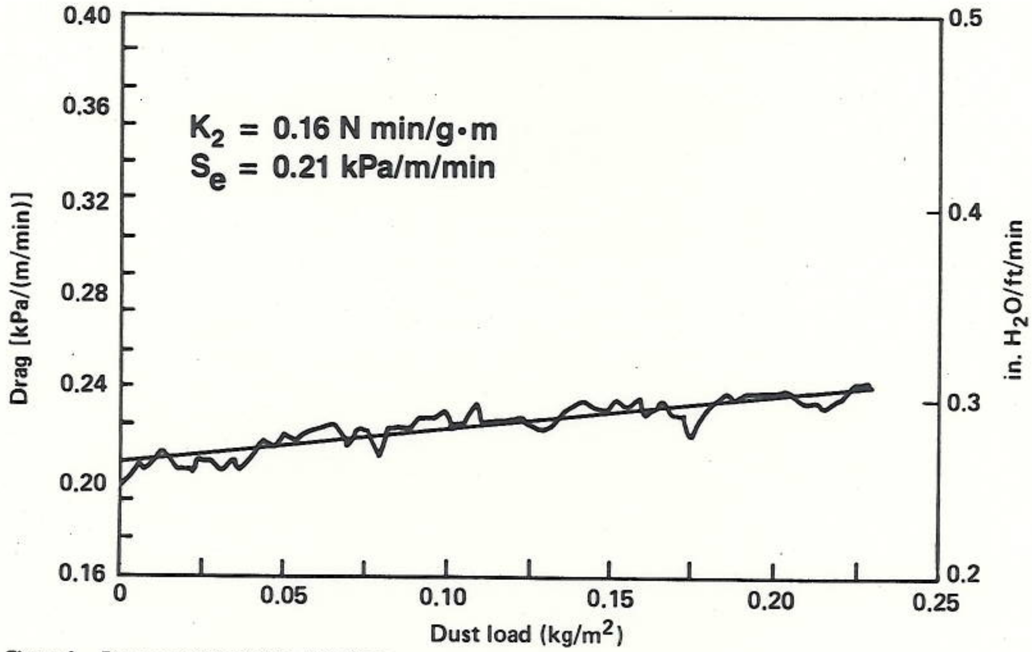

Figure 4. Drag correlation for the AESFF bag.

lems of water condensation in the IBFM pressure lines. The data for bag 1 were lost during this cycle because of this problem, which was later corrected.

To condense the data from Figure 2, the cycle average air-to-cloth ratio (i.e., average volumetric flowrate divided by total bag area) was computed for each bag during each filtration interval, yielding a single value indicative of the bag performance for that cycle. A plot of the cycle average air-to-cloth ratios for several cycles early in the test program are shown in Figure 3. Once again, the upper set of curves corresponds to the even (AESFF) bags and the lower set of curves to the odd (conventional) bags. The data for cycles 15 through 35 show a clear and consistent differentiation of flow toward the AESFF bags. However, it was not certain that AESFF was the cause of that flow differentiation. Therefore, at the outset of cycle 36 the voltage was switched from the even bags to the odd bags. Thus, the bags that formerly were AESFF bags were now conventional bags and vice versa. Within a few cycles, the flow curves had crossed as shown for cycles 36 to 40. As time went on, this difference became more pronounced. As a result, it was concluded that the flow differentiation was clearly a function of the voltage applied to the electrodes in the AESFF bags.

The flow differentiation seen in the figures is convincing evidence of the existence of an AESFF effect. However, further analysis is required to obtain a quantitative assessment of the effect of AESFF on pressure drop. Specifically, the parameters S_e and K_2 that appear in Equation 1 had to be determined. The inlet dust concentration and instantaneous air-to-cloth ratio were integrated over time as shown in Equation 4 to yield the cumulative areal dust density (W) as a function of time. Equation 2 was rearranged to yield the dust/fabric pressure drop as a function of time based on the recorded tubesheet and IBFM pressure drops. Individual bag drags were then computed as the ratio of the dust/fabric pressure drop to the bag face velocity. Examples of the results of these calculations are shown in Figures 4 and 5 in which the drag of a bag is plotted as a function of the corresponding dust load on that bag. The straight line that passes through the data in each figure is the regression fit to the data. There are two important features to note in these figures. First, the straight lines provide a good fit to the data, indicating that the assumption of a linear relationship between drag and dust load (i.e., Equation 1) is reasonable. Second, the slopes (i.e., K_2 values) of the two lines are quite different; that is, the drag for an AESFF bag rises much more slowly than that of a conventional bag. There is also a slight difference in the intercepts of the two lines, indicating that the conventional bag has a slightly higher residual drag than the AESFF bag. When the data from every cycle were analyzed in the same manner, the differences between the K_2 and S_e values for the AESFF and conven-

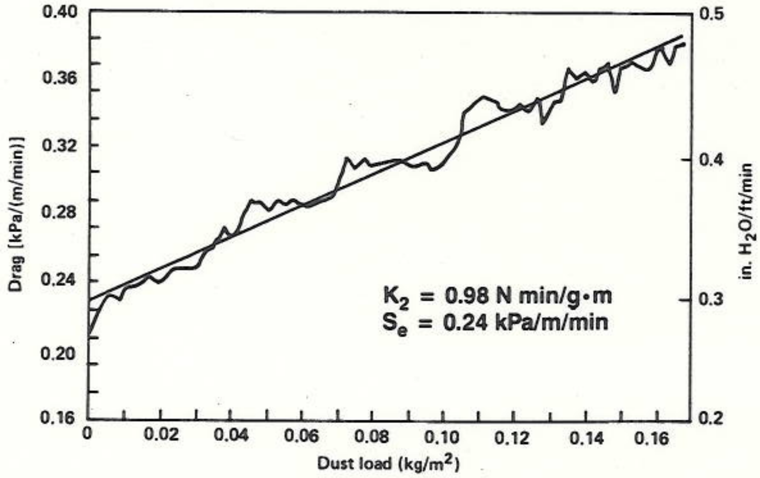

Figure 5. Drag correlation for the conventional bag.

tional bags were of similar magnitude. Overall, the AESFF bags yielded K_2 values that were 30 percent to 80 percent less than the K_2 values for the conventional bags. On the average, the reduction was 70 percent. The differences between the residual drag values (S_e) were much smaller, ranging from a 36 percent reduction for new bags to a 10 percent reduction for older, more "seasoned" bags. Since the overall bag drag is a function of S_e and K_2, the results in the figures show that the importance of the electric field in an AESFF bag is largely in the modification of the K_2 value, with residual bag drag a significant (but secondary) factor.

Considerable effort has been invested in understanding how AESFF affects pressure drop performance. Laboratory measurements[13] have shown that one of the ways in which AESFF affects performance is by altering the dust deposition pattern within the bag. It appears that a large fraction of the dust that enters the bag is collected along the lower half of the bag surface. It can be easily shown that a filter with a non-uniformly deposited dust layer will have a significantly lower drag than a filter with a uniform dust layer. A numerical model of an AESFF filter[14] that treats the filter as a porous-wall electrostatic precipitator accurately predicts this non-uniform distribution pattern and the resultant reduction in pressure drop. If the dust layer is unevenly distributed on the bag surface, then the K_2 values calculated from the pilot plant data are actually "apparent" values, since it was implicitly assumed in the analysis that the dust is evenly distributed on the bags.

It seems clear that AESFF alters the pattern of dust deposition on the bag but there may be another aspect of AESFF performance. Laboratory studies[15] have shown that dust cakes collected in the presence of an electric field have strikingly different structures than those collected without an electric field. Dust cakes collected with an electric field have dendritic structures that produce a very porous dust cake. Since the porous structure and non-uniform distribution phenomena are both products of the electric field, it is impossible to assign a specific degree of "AESFF enhancement" to one or the other. However, the evidence suggests that the non-uniform distribution phenomenon is the dominant factor in reducing the rate of pressure loss in an AESFF bag.

At first glance, the pilot plant results suggest that AESFF has only a small effect on the residual drag (S_e) of the bags. This should not be considered a firm conclusion since the baghouse was equipped with new bags at the start of the test program. In an operating baghouse, the residual drag increases with bag age as dust penetrates deeply into the fabric structure. The AESFF test program did not last long enough for the bags to attain the high residual drag typical of full scale baghouses (i.e., the bags behaved as though new throughout the test program). Therefore, the pilot program data on S_e should be considered as significant but incomplete. In pilot studies[16] of parallel field ESFF, electrostatically enhanced bags operated for extended periods with residual drags that had half the residual drag of conventional bags filtering the same dust. It is not clear how to translate those results to the case of AESFF; however, it seems reasonable to expect that the residual drag would be reduced to a greater extent than shown in the pilot plant results. For example, for certain dust/fabric

Table I. Detailed costs of conventional and AESFF baghouses for a 500-MW power plant.

	Conventional	Case 1	Case 2
Capital costs			
Gas flow rate (m³/min)	56,630	56,630	56,630
Air-to-cloth ratio (m/min)	0.61	0.98	1.63
Total cloth area (m²)	92,900	58,100	35,100
Number of bags	10610	6631	4004
Collector and supports	$9,330,000	$6,120,000	$3,930,000
Ducting and supports	$1,260,000	$1,260,000	$1,260,000
Ash removal system	$1,140,000	$842,000	$629,000
Insulation	$2,600,000	$1,750,000	$1,150,000
ID fan	$497,000	$398,000	$442,000
Miscellaneous	$6,420,000	$4,570,000	$3,200,000
Total field cost	$21,247,000	$14,940,000	$10,611,000
Engineering	$4,249,400	$2,988,000	$2,122,200
Contingency	$4,249,400	$2,988,000	$2,122,200
Total baghouse cost	$29,745,800	$20,916,000	$14,855,400
ESFF hardware	$0	$852,083	$514,514
Engineering	$0	$170,416	$102,902
Contingency	$0	$170,416	$102,902
Installed cost	$0	$1,192,915	$720,318
Turnkey cost	$29,745,800	$22,108,915	$15,575,718
ESFF % of total	0	5.4	4.6
Operating and maintenance costs			
Fixed operating costs	$121,000	$121,000	$121,000
Variable operating costs	$335,000	$354,000	$287,000
Electrode replacement	$0	$170,416	$102,902
AESFF electricity	$0	$241,447	$145,779
Cost of electricity	$970,000	$889,000	$836,000
Total O&M cost	$1,426,000	$1,775,863	$1,492,681
Net present value	$42,483,517	$37,971,777	$28,909,062

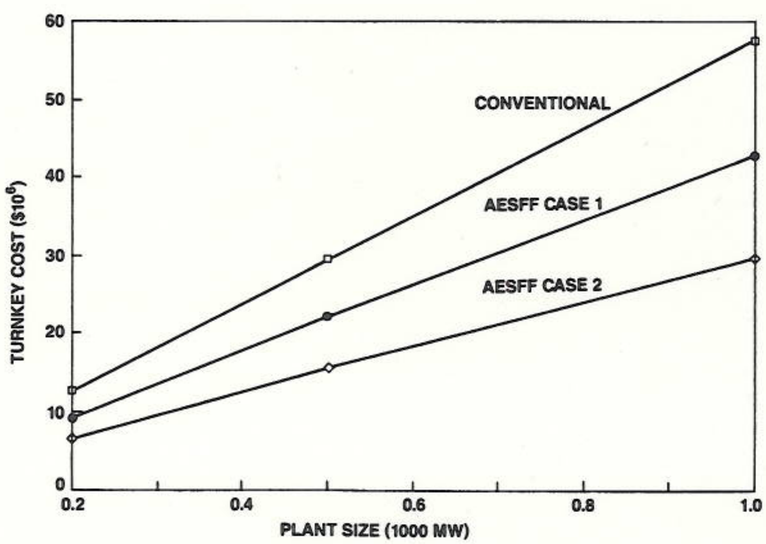

Figure 6. A comparison of capital costs for equivalent baghouses.

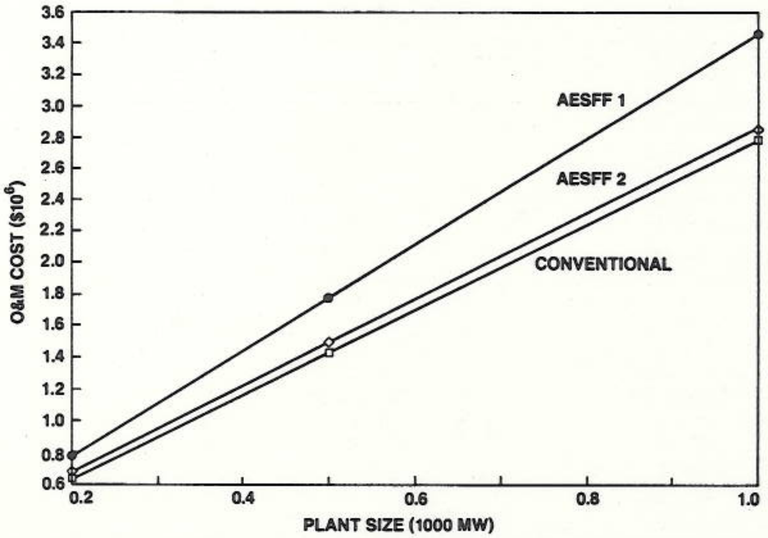

Figure 7. Annual operating and maintenance costs for conventional and AESFF baghouses.

combinations, an AESFF bag may operate with half the residual drag of conventional filters.

Economics

It is clear from the laboratory and pilot results that AESFF is technically feasible. The goal of economic analysis is to determine whether or not AESFF is economically feasible.

The discussion of the pilot plant results focused on the ability of AESFF bags to operate with a lower pressure drop than conventional bags. While there may be instances where an electric utility is interested in using AESFF on a retrofit basis to reduce high operating costs, the real economic benefit of AESFF will be in the construction of smaller baghouses that operate with pressure drops similar to those currently found in conventional baghouses. That is, an AESFF baghouse would be designed to operate with tubesheet pressure drops currently found in conventional baghouses: typically 0.75 to 1.5 kPa (3 to 6 in. H_2O). An AESFF baghouse, however, would operate at a much higher face velocity than a conventional baghouse, resulting in a much smaller baghouse. The reduction in baghouse size would be accompanied by a reduction in capital cost for the baghouse; however, the AESFF design would require electrical hardware not found in conventional baghouses. Similarly, if an AESFF and a conventional baghouse were operated at the same average pressure drop, one would expect an AESFF baghouse to have a higher operating cost due to the additional cost of electricity to power the electrodes. A rigorous analysis is required to sort out these opposing factors and determine the economic feasibility of AESFF.

The goal of baghouse design is to build the smallest baghouse possible while maintaining acceptable pressure drop performance. For the purposes of this analysis, Equation 1 will provide an adequate description of baghouse pressure drop performance. For a given specific dust resistance (K_2) and residual drag (S_e), the cycle average pressure drop at any face velocity can be calculated by substituting an average dust load (W_{ave}) for the instantaneous dust load [$W(t)$]. For the coal fly ash that is produced in electric utilities, a typical K_2 value is 1 kPa/[(kg/m^2)(m/min)] {6 in. H_2O/[(lb/ft^2) (ft/min)]}. Typical S_e values are on the order of 1.23 kPa/m/min (1.5 in. H_2O/ft/min) and the average amount of dust per unit area of bag surface (i.e., W_{ave}) during a filtration cycle is on the order of 1.2 kg/m^2 (0.25 lb/ft^2). At a face velocity of 0.61 m/min (2 ft/min), Equation 1 predicts an average pressure drop of 1.5 kPa (6 in. H_2O) for a conventional baghouse.

To obtain a reasonable comparison of conventional and AESFF baghouses, the size of an AESFF baghouse was determined that will maintain the same average pressure drop. The data from the AESFF pilot plant showed that, on the average, the apparent K_2 values were 70 percent less than those of the conventional bags and that the residual drags were roughly 10 percent less than those of the conventional bags. These results were obtained without any effort to optimize the design or performance of the AESFF bags. Over short periods, the AESFF bags operated with apparent K_2 values that were just 10 percent of the corresponding conventional values. Therefore, it is not unreasonable to assume that an AESFF bag could operate with an apparent K_2 value that is one-fourth of the K_2 value for conventional bags. That is, one could reasonably design an AESFF baghouse on the basis of an apparent K_2 value of 0.25 kPa/[(kg/m^2)(m/min)] {1.5 in. H_2O/[(lb/ft^2)(ft/min)]}; however, the data on residual drag are less conclusive. Therefore, two cases were considered in the economic analysis. Case 1 assumed that AESFF has no effect on residual drag: the value of S_e was taken as 1.23 kPa/m/min. Case 2 was based on the assumption that AESFF bags would operate with half the residual drag of conventional bags (0.62 kPa/m/min). Given these param-

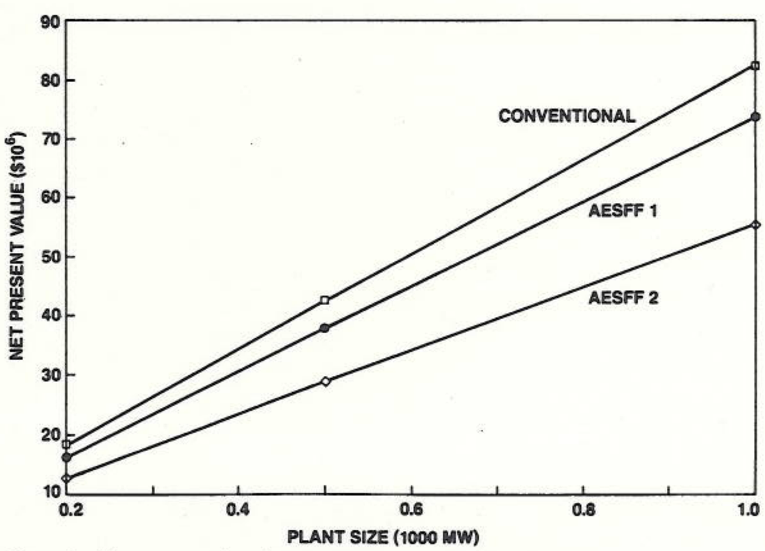

Figure 8. Net present values for conventional and AESFF baghouses.

eters and the average dust load described above, Equation 1 can be rearranged to find the face velocity that would yield the same average pressure drop as a conventional baghouse (i.e., 1.5 kPa). For Case 1, the face velocity is found to be 0.98 m/min (3.2 ft/min). For Case 2, the face velocity is 1.63 m/min (5.3 ft/min). (Note that the assumption of the same average dust load implies more frequent cleaning of the bags.)

Given the size of a baghouse, a scale factor method can be used to estimate the capital cost within 25 percent. Viner and Ensor[17] used this method to develop empirical equations for the cost of components of conventional baghouse systems. However, the scale factor technique cannot be applied to novel hardware such as AESFF electrodes and power supplies. Pilot plant experience provided guidance for the estimation of electrode cost. Power supply costs were estimated by comparing AESFF power requirements with those of electrostatic precipitators. The prorated cost of an assembled electrode and power supply was estimated to be $128.50 per bag.

On the basis of the estimation methods outlined above, costs were estimated for baghouses operating on three different sizes of electric utility plants: 200, 500, and 1000 MW. Capital (turnkey) costs, operation and maintenance costs, and net present value were all calculated. The results of the capital cost calculations are shown in Figure 6. For the AESFF Case 1 baghouses, the turnkey costs are 25 percent below those of equivalent conventional baghouses. For the AESFF Case 2 baghouses, the turnkey costs are 48 percent below those of equivalent conventional baghouses. A detailed breakdown of costs for a 500 MW plant is shown in Table I. The costs in the table show that part of the cost reduction results from the fact that smaller baghouses require less auxiliary equipment (e.g., insulation). For both Cases 1 and 2, the cost of AESFF hardware (including installation) amounts to approximately 5 percent of the total turnkey cost.

The results shown in Figure 6 indicate an estimated savings of $16/kW for a baghouse designed with specifications of AESFF Case 1 and $29/kW for a baghouse designed with specifications of AESFF Case 2. These estimated savings are a direct result of the smaller size of the AESFF baghouses. Clearly, these estimates show the reduced capital costs easily offset the additional cost of the AESFF hardware.

Although these results are impressive, they do not provide a complete picture of AESFF economics. One must also consider the cost of operation and maintenance (O&M), which depends on a number of factors. One obvious difference between a conventional baghouse and an AESFF baghouse is the higher electricity penalty of an AESFF baghouse. Another factor that must be taken into consideration is the cost of replacing broken AESFF electrodes. Experience with wire electrodes in electrostatic precipitators (ESPs) indicates that electrodes fail as a result of electrical, mechanical, and thermal stresses. According to Oglesby and Nichols,[18] weighted-wire electrodes fail more often than the rigid electrodes. The problem with weighted wire electrodes is two-fold. First, the mechanical stress associated with the swinging of the electrode is similar to cold-working of the wire, which reduces the mechanical strength. Secondly, a swinging electrode is more likely to produce electrical arcing, which can produce rapid erosion of the electrode. Although rigidly mounted electrodes are also subject to the problem of arcing, they are less susceptible to the problems of mechanical failure and arcing due to motion of the electrode. Based on these considerations, the AESFF electrodes are expected to have a relatively long life. First, they are rigidly mounted, rather than free hanging, as in the weighted-wire design. Consequently, they will be less susceptible to mechanical stresses. Secondly, the resistivity of the bag/fabric surface is higher than that of a metallic ESP collector plate with the result that charge cannot become concentrated rapidly in a small area. The net result is that arcing is less likely to occur between a wire and a fabric bag than between a wire and plate. In properly designed and erected precipitators, electrode failures are as low as one or two per year[18] and conventional wisdom holds that average electrode life ranges from 5 to 10 years. Therefore, for the purposes of this study, it is assumed that the mean electrode life in an AESFF bag will be 5 years.

Another difference in O&M costs between conventional and AESFF bags is in the cost and frequency of bag replacement. In the pilot study, an electric field was established between the high voltage center electrode and the relatively conductive layer of ash on the bag surface. In an electric utility application the ash layer will not be nearly as conductive, so the bag must be made conductive to serve as the electrical path to the grounded tubesheet. Spivey *et al.*[19] reported on a successful technique for weaving small diameter wires into bag fabric. Alternatively, it may be possible to identify a conductive coating that can be applied to the bag surface. For the purposes of this study, it was assumed that AESFF bags would cost 50 percent more than conventional bags.

Another factor influencing bag-related operating costs is the frequency of bag replacement. Chapman and coworkers[20] proposed an empirical formula relating bag life to the average face velocity through the bag. On the basis that a reverse-air cleaned bag operating at a face velocity of 0.61 m/min (2 ft/min) has a lifetime of 4 years, the life of a bag with a higher face velocity can be estimated as:

$$L_b = 4.0\,(0.61/V_b)^{0.6} \qquad (5)$$

where L_b is the life of a bag (in years) whose average face velocity is V_b (m/min).

When the various factors affecting operation and maintenance cost are taken into consideration, the results shown in Figure 7 are obtained. The conventional baghouse is predicted to have the lowest O&M costs. A baghouse designed and operated according to the AESFF Case 1 specifications has the highest O&M costs because the additional cost of the items cited above cannot be offset by the fact that there are fewer bags to be maintained. A baghouse designed and operated according to AESFF Case 2 specifications would have O&M costs only slightly higher than those of a conventional baghouse. That is, at a sufficiently high face velocity, the higher cost of the bags and higher frequency of bag replacement are nearly offset by the fact that there are fewer bags.

The complete picture of estimated AESFF economics is based on a life cycle analysis that incorporates both the capital and O&M costs. One type of life cycle analysis is based on the net present value (NPV). This is the sum of all present and future costs expressed in terms of current dollar value (here taken to be June 1985). Assuming that the capital cost is a one-time payment and the O&M costs are recurring annual costs, and assuming an average discount rate of 10 percent over a baghouse life of 20 years, one can calculate the cumulative uniform series factor. The product of the cumulative uniform series factor and the annual O&M cost is the lifetime O&M cost in terms of current dollars. The sum of the capital cost and the lifetime O&M cost is the NPV. The results of this calculation are plotted in Figure 8. Estimated lifetime cost savings range from $1.9 million for AESFF Case 1 (at 200 MW) to as much as $27.2 million for AESFF Case 2 (at 1,000 MW). For an AESFF Case 1 baghouse, this amounts to lifetime savings of 10 percent. For AESFF Case 2, the estimated savings are over 30 percent.

Summary

A pilot plant was constructed to evaluate the technical feasibility of

AESFF. Conventional and electrified filter bags were operated in a single compartment, and bag flow monitors were used to collect data on individual bag performance. A sophisticated data collection system permitted unattended operation of the system for extended periods. There was never any sparking at the voltage and current levels tested, and the bags never suffered any ill effects as a result of the electric field. The side-by-side comparison of conventional and AESFF filtration showed that AESFF has a significant effect on the rate of pressure loss in a filter bag. Laboratory observations and model calculations indicate that the reduction in pressure loss is largely due to non-uniform dust deposition within the bag.

An economic analysis of AESFF based on pilot plant performance indicates that an AESFF baghouse will have an estimated lifetime cost that is at least 10 percent less than the lifetime cost of an equivalent conventional baghouse. If it is found that electrostatic enhancement improves bag cleaning characteristics (i.e., lowers residual drag), then estimated lifetime cost savings may be as high as 30 percent.

As with any new technology, there is room for improvement in AESFF. In addition, there are questions yet to be answered about the applicability of AESFF to systems with high-resistivity dust. Although it is feasible to increase the electrical conductivity of fabric bags, it is not known how such systems would perform when a thick layer of resistive dust is deposited on the surface. Undoubtedly, the design will evolve as more is learned about electrode performance and maintenance requirements. However, both the promising results obtained in the laboratory and field work and the very favorable economic analysis presented here provide a strong incentive to continue developing this technology.

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