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論　　文

A Program to Develop Engineering Data for Fabric Filtration with Integral Particle Charging and Collection in a Combined Electric and Flow Field

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The application of electrostatics to fabric filtration in the form of integral particle charging and collection in a combined electric and flow field causes the particle deposition to be dominated by the electrostatic precipitation (ESP) effect rather than the porous flow collection. A program was undertaken to develop engineering design data for this new technology. A mathematical model was developed to predict the nonuniform deposition of the particulate matter and the relative pressure drop that would result from it. The model predicts both the nonuniform deposition and relative pressure drop with reasonable accuracy. Also investigated as part of the program was the use of pulse energization to equalize the corona currents among a number of electrified bags powered by one electrical power supply. Energization of the bags decreased the penetration of particles larger than 0.8 μm; the trend suggested that it should also be possible to decrease the penetration of particles smaller than 0.8 μm.

1. Introduction

Fabric filtration is one of the principal technologies for the removal of particulate matter from gas streams. Other technologies include electrostatic precipitators, scrubbers, inertial devices, and filtration by nonfabric media.

The specific interest in this work is the application of fabric filtration to the cleaning of high-volume gases from the steam-electric utilities and other industries. For these applications the fabric is set up in the form of bags. Gas flow is arranged so that it flows either from the inside of the bags-out or in the opposite direction, from the outside of the bags-in. The dust is collected either on the inside or the outside of the bag, depending on the direction or flow. For the steam-electric generating industry, inside-to-outside flow is predominant. The work reported here will be for inside-to-outside flow filtration.

The fabric filtration bags are cleaned on a cyclic basis by reversing the gas flow, mechanical shaking, or some combination of both.

During the filtration cycle the pressure drop across the filter media rises. The pressure drop limits operation and is one of the major factors that results in increased operating or capital costs.[1] Considerable efforts have been undertaken in reducing these costs.[2] One of the most promising approaches is the application of electrostatics to the filtration process.

Work has been done in the laboratory and in pilot units in either precharging the particulate matter prior to collection[3-8] or collecting the particles in an electric field.[9-13] The reported work shows interesting reductions in pressure drop. Limited work on collection of charged particles showed that a nonuniform dust deposition would result in a potential for even further reductions in pressure drop.[14-16]

A practical fabric filtration system in which particle charging and collection was first made integral with the bag is shown in Fig. 1.

This system was operated in a small laboratory baghouse,[17] in an EPA pilot unit with a spreader-stoker boiler,[18,19] and on an EPA pilot unit at the Southwestern Public Service Company in Amarillo, TX.[20]

The system of fabric filtration with integral

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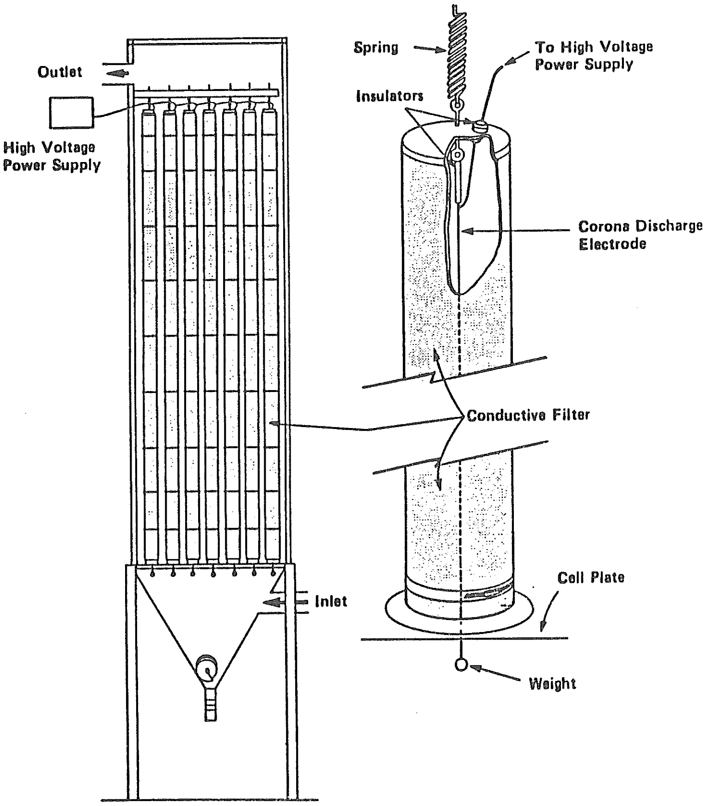

Fig. 1 Fabric filtration with integral particle charging and collection in a combined electric and flow field.

particle charging and collection in a combined electric and flow field showed high potential for providing a very low pressure drop. However, there did not exist an engineering design methodology for the technology. Neither had any of the previous work on the application of electrostatics to fabric filtration reported engineering design methodologies.

2. Objectives of the Program

To help achieve acceptance by the user community of fabric filtration with integral particle charging and collection in a combined electric and flow field, the need for solutions to several technical issues had been identified. These were:

- The development of an engineering methodology or model to provide design certainty to the prospective user
- The use of conventional fabrics instead of more complex and expensive conductive fabrics
- The equalization of currents among a number of bags operated with one power supply
- The penetration of particle matter through an electrified bag.

A program was undertaken to address these technical issues.

3. Approach

The development of a mathematical engineering design model required that the nonuniform dust layer deposition be quantified as a function of varying the electrical conditions—voltage and current within a bag. Also needed was the effect of nonuniform deposition on the gas flow as a function of position in the baghouses. An experimental program was undertaken in the Particulate Technology Laboratory of EPA's Air and Energy Engineering Research Laboratory at Research Triangle Park, NC.

The experimental program made use of a small single-bag laboratory pilot unit arranged as in Fig. 2. The small baghouse was capable of operating between ambient and 200°C; the mois-

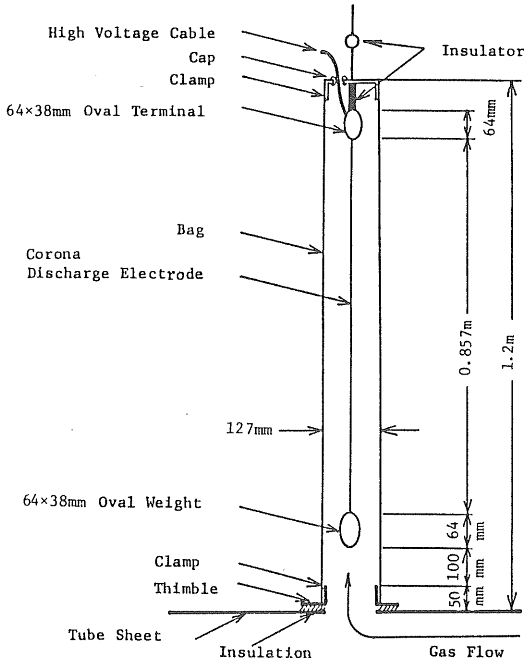

Fig. 2 Single-bag experimental setup for fabric filtration with integral particle charging and collection in a combined electric and flow field.

ture level could be adjusted by the addition of steam. The voltage could be adjusted by varying the DC power supply output. The voltage-current relationship could be varied somewhat by changing the corona discharge electrode diameter.

The dust layer properties—areal density, thickness, and flow resistance or drag and its reciprocal (the face velocity per unit of pressure)—were measured on the bag after completion of a test run. This was facilitated by having a seam, running in the axial direction of the bag, to allow the bag to be removed, opened, and laid out flat on the measuring table.

Two types of fabric bags were used. The first was of typical fabric filtration fiberglass material finished with Teflon B, representing conventional porous filter media. The second was fabricated of the same Teflon B finished fiberglass material, modified by stainless steel yarns woven into it at the time the fabric was woven. The stainless steel yarns improved the electrical conductivity of the poorly conductive fiberglass. In operation the bags were grounded through a metering circuit to measure the corona current. Negative corona was used because of the tendency of ESPs to spark at lower voltage with positive corona.

The particulate matter that was used had been obtained, after collection in a baghouse, at the Harrington Power Station of Southwestern Public Service Company (SWPS), in Amarillo, TX. The coal burned there is a low sulfur western coal from the Powder River Basin in Gillette, WY. The flyash when redispersed had a geometric mean diameter of 3.3 μm and a geometric standard deviation of 2.9.

To gain further insight into the behavior of the "poorly conductive" fabric that had not been modified by metallic conductors woven into it, a bag was set up as shown in Fig. 3, with wire probes stitched into it. When energized with corona, an electrostatic voltmeter was used to determine the effect of surface charge. The electrical resistance between probes was measured using a DC power supply and current meter.

The approach to mitigate the maldistribution of current in a multibag array was to apply pulse energization. It has been reported that pulse energization provides more uniform current dis-

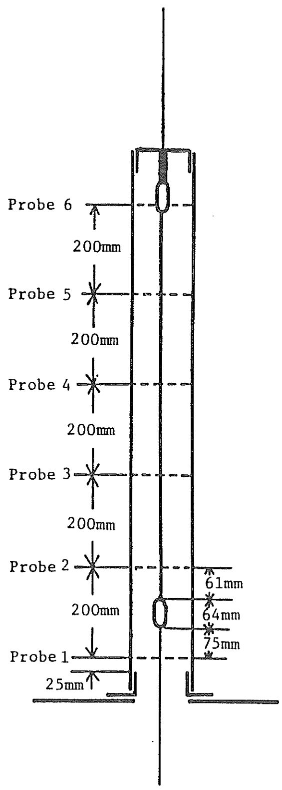

Fig. 3 Experimental setup for measurement of surface charge with poorly conductive bag.

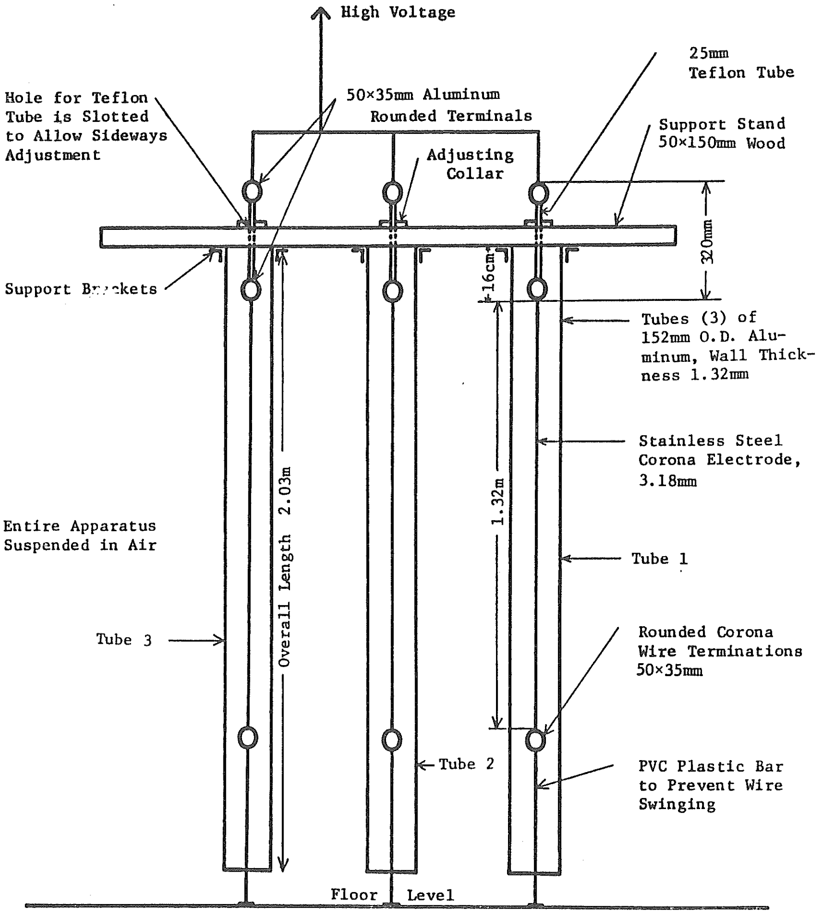

Fig. 4 Experimental setup for determining effects of pulse energization on maldistribution of corona current.

tribution than does DC energization.[21-23] The experimental apparatus of Fig. 4 was used with both DC and pulses superimposed on the DC to evaluate the approach. The apparatus was arranged so that the effect of pulse energization could also be evaluated.

The effect of particle penetration through a fabric filter of integral particle charging and collection in a combined electric and flow field was evaluated in a five-bag, ambient temperature laboratory baghouse. Each bag was 2.4 m long and 0.125 m in diameter.

4. Results

It was confirmed that integral particle charging and collection in a combined electric and flow field did indeed cause a nonuniform deposit of particulate matter on the porous fabric filter. This is seen in Fig. 5, as a typical set of test data; both the density and dust layer thickness decrease from the bottom of the bag to the top. The drag, which is the resistance to flow, also decreases from bottom to top. This is consistent for all the tests. The mass density of the dust layer, which is calculated from the areal density and thickness, shows no correlation with electrical conditions or position in bag. Of special significance is the variation of face velocity depending on position in bag. Typical plots shown in Fig. 6 suggest that the variation in face velocity with position is reasonably linear. This allowed the gas flow to be defined for a bag.

With the gas flow defined, the mathematical model for the nonuniform deposition was developed. For the j length increment it is:

$$N_{j-1}[1-(1-H_j)G_j-(1-G_j)H_j]=N_j \quad (1)$$

In which N_{j-1} is the quantity of particulate matter

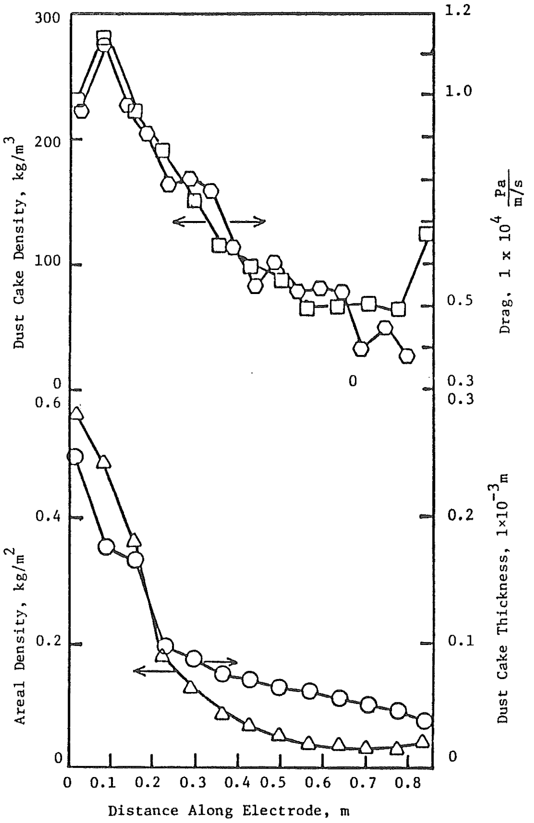

Fig. 5 Typical set of test results for non-uniform deposition.

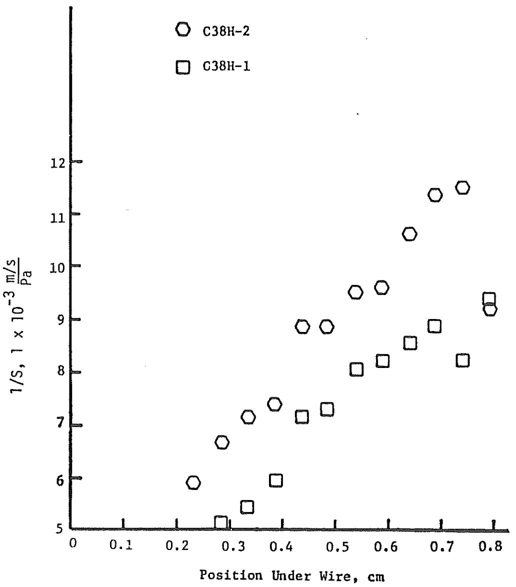

Fig. 6 Typical plots of face velocity per unit of pressure showing linear relationship to position under wire.

entering the j length increment, N_j is the quantity of uncollected particles leaving the j length increment, G_j is the porous flow collection, and H_j is the ESP collection. The need to divide the bag into increments is caused by two collection mechanisms—collection due to the porous flow by the term $(1-H_j)G_j$, and collection due to the ESP effect by the term $(1-G_j)H_j$.

In Eq. (1) the porous flow collection is

$$G_j=\frac{(v_{j-1}-v_j)}{v_{j-1}} \tag{2}$$

in which v_{j-1} is the velocity of the gas entering increment j, and v_j is the velocity of the gas existing the increment. The ESP collection is

$$H_j=\sum_{i=1}^{m}[1-\exp(-\overline{\mathrm{SCA}}_j\cdot w_{ji})] \tag{3}$$

in which $\overline{\mathrm{SCA}}_j$ is the average specific collector area for the j increment, w_{ji} is the electrical migration velocity for the j length increment, and i is the particle size increment. $\overline{\mathrm{SCA}}_j$ increases in each succeeding increment due to gas loss through the porous walls of the bag. Figure 7 shows a typical prediction of nonuniform deposition.

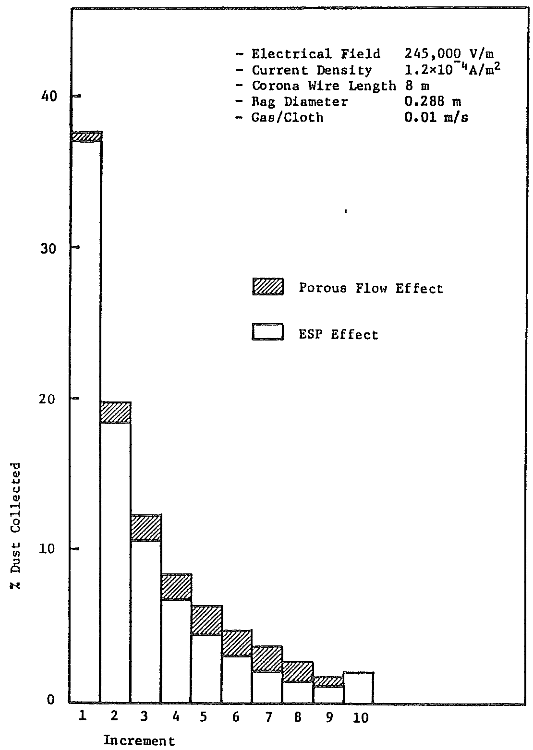

Fig. 7 Mathematical prediction of nonuniform deposition for SWPS pilot unit electrical conditions.

Note that Eq. (3) is the Deutsch-Anderson relationship for turbulent flow, which is the flow regime for practical size fabric filtration bags. For the Deutsch-Anderson equation it is necessary to divide the particle size into m small size increments each of which can be considered to have a single electrical migration velocity.

By assuming that the dust layer porous flow properties are constant, the drag (resistance to flow) is proportional to the amount of dust deposited in each increment. As seen in Fig. 7, there is a predicted deposition for each increment. The pressure drop from the inside to the outside of the bag causes the flow resistance of each of the increments to be in parallel. Therefore, using parallel resistance relationships, the relative pressure drop prediction is

$$\frac{\Delta P_{\mathrm{n}}}{\Delta P_{\mathrm{u}}}=\frac{S_{\mathrm{n}}}{S_{\mathrm{u}}}=l\left(\sum_{j=1}^{l}\frac{1}{W_j}\right)^{-1}\Big/W_i \qquad (4)$$

in which P is the relative pressure drop, S is the average drag, W is the areal density in increment j, and l is the number of bag increments. The subscripts n and u denote nonuniform and uniform deposition, respectively.

Derivations of Eqs. (1), (2), (3), and (4) and the relationships for v_j, $\overline{\mathrm{SCA}}_j$, and w_{ji} have been reported elsewhere.[24]

Predictions using the mathematical model are presented in Figs. 7 and 8. Figure 7 is based on the electrical conditions of the EPA pilot plant at Southwestern Public Service Company. Figure 8 is based on the electrical conditions of the pilot baghouse on the spreader-stoker boiler. The electrical conditions of the two baghouses were reasonably similar in respect to electric field and current density. The spreader-stoker unit had more coarse particles and fewer fines than did the SWPS unit. The geometric mean diameter was 18.4 vs 3.3 μm and the geometric standard deviation was 5.2 vs 2.9.

The computed relative pressure drop at SWPS is 0.44. This compares to a measured relative pressure drop of 0.43.[20] The computed relative pressure drop for the spreader-stoker unit is 0.22, which compares to a measured relative pressure drop of 0.20 to 0.30.[19] The difference in both the computed and measured performance is due mainly to the particle size difference. Similar differences in performance would be experienced with an ESP for different particle size distributions.

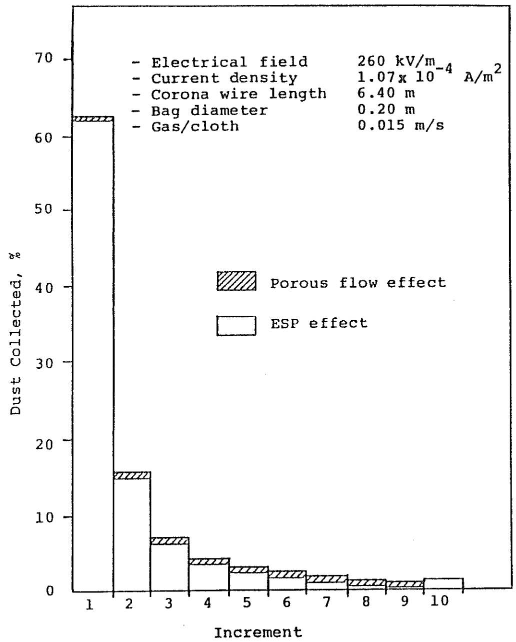

Fig. 8 Mathematical prediction of nonuniform deposition for spreader-stoker pilot unit electrical conditions.

The single "poorly conductive" bag (Fig. 3) with the stitched-in surface charge probes showed high surface charge when operated with the axial corona discharge wire energized.[24] Voltages indicated by the zero-current drain electrostatic voltmeter ranged from 4.8 to 16.0 kV with 35 kV applied to the corona discharge wire. The temperature and moisture conditions were changed for the various tests, resulting in variations in the corona current for the same electric field. Other measurements indicated that there was high resistance in the axial direction which would hinder drain-off of the charge. The results of this work suggest that, if poorly conductive bags are used, there will be high surface charges present which would tend to suppress corona and effectively decrease the field.

The results of the test on particle penetration are shown in Fig. 9.[24] For this test the bags were clean at the start; as the test proceeded, penetration continued to decrease until (at the end) only particles <0.8 μm had penetration greater than in conventional nonelectrified filtration. In inside-to-outside flow filtration, the filtration media is the residual dust layer rather than the fabric. For this test the residual dust layer had not been allowed to build up. The

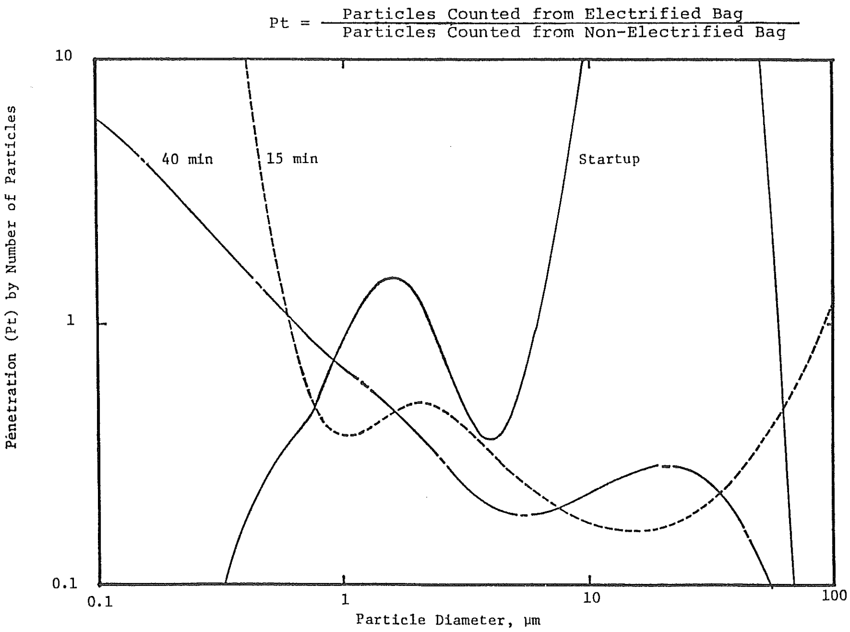

Fig. 9 Comparison of penetration for fabric filtration with integral electric field and particle charging to conventional filtration (both started with clean bags).

results suggest that, in normal practice in which a residual dust layer forms and remains intact, penetration will decrease in the submicron particle size range.

5. Conclusions

The application of integral particle charging and collection in a combined electric and flow field has the potential to significantly change and improve fabric filtration. It does this by lowering the pressure drop thereby either saving fan power or else by reducing the baghouse size for the same fan power.

It has been shown that the application to fabric filtration of integral particle charging and collection in a combined electric and flow field changes the particle deposition and gas flow as compared to conventional filtration. The migration velocities imparted to the particles are generally much higher than the face velocities within the bag; therefore, they dominate the particle movement and cause a nonuniform particle distribution.

A mathematical engineering design model and methodology have been developed for baghouse fabric filtration with integral particle charging and collection in a combined electric and flow field. The model predicts with reasonable accuracy the nonuniform dust deposition that has been observed in the laboratory. The model predicts, at least qualitatively if not somewhat quantitatively, the relative pressure drop that should be achieved as a function of varying the electrical conditions applied to the electrified fabric filtration baghouse.

The predictive mathematical engineering design model assumed ideal electrical conditions; e.g., uniform corona distribution and no back corona. It is expected that the larger fabric filtration bags, that are used in commercial applications, will be less sensitive to local nonuniform electrical conditions than laboratory size bags such as were used in the test program. Pulse energization, or one of the lower-cost semi-pulsing techniques should be considered, along with a microprocessor controller, for maintaining good electrical conditions. Pulse energization was also found to be useful for providing uniform current distribution in the tuft corona region of negative corona, even with slight misalignment present.

Fabric filtration bags using conventional fabric that has not had its electrical conductivity increased could be used if the resistivity of the particle matter were sufficiently low. For higher resistivity particle matter the electrical conductivity of the filtration fabric would have to be increased.

Starting with a clean bag, particles $<0.8\ \mu m$

have a greater penetration with electrified filtration bags, on a number of particles basis, than with conventional filtration bags. The trend is for the penetration to decrease as the particulate or dust layer builds up in the bag.

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