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EVALUATION OF ELECTRIC FIELD FABRIC FILTRATION

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EVALUATION OF ELECTRIC FIELD FABRIC FILTRATION

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INTRODUCTION

The work presented in this report was performed by Midwest Research Institute for the Industrial Environmental Research Laboratory-RTP as Task No. 12 on Contract No. 68-02-1324. The objective was to evaluate the use of electric fields in fabric filters as a means of controlling fine particulate emissions from industrial sources.

Particles are normally brought to the surface of a fiber by diffusion and convection as well as by the effect of the flow field of the gas and retained on the individual fibers comprising the filter by surface forces. The magnitude of electrical forces compared to other forces that can be applied to particulates suggests that improvement in aerosol filtration should occur when electric fields are present in fabric filters. The static charges on most naturally occurring aerosols may also play a role in the collection and retention of the particles.

The following sections of this report present a discussion of theoretical studies of electrified filters, a review of experimental studies of model filter systems, and conclusions.

THEORETICAL ASPECTS OF ELECTRIFIED FABRIC FILTERS

External fields, internal fields, and electrets have been studied in conjunction with fiber filter systems. Each of these possibilities is reviewed separately.

EXTERNAL ELECTROSTATIC FIELDS

If a filter is placed in an initially homogeneous electric field, the fibers will be polarized to produce an inhomogeneous electric field near the fiber surface. Neutral particles entering the filter will be polarized by the external field and will therefore interact with the field around the fiber. Any net charge on the particles will also interact with the local field.

Zebel,[1/] Kazutaka and Koichi,[2/] and Rao, et al.,[3/] among others have theoretically studied the problem of the deposition of aerosol particles from an air stream in a homogeneous electrical field. A general theory for deposition upon an isolated, uncharged cylinder in an electrical field when the particles are charged or uncharged has been formulated by Zebel. The isolated fiber used by Zebel gives a good representation of an individual fiber in a model filter with widely and regularly spaced fibers. In such a model filter, a uniform external electric field will produce uniform polarization in fibers and particles alike, which is not the case with densely packed filters.

Kazutaka and Koichi developed theoretical equations to estimate the collection efficiency of an isolated fiber in an external field and then utilized a logarithmic expression to relate single fiber efficiency to the overall collection efficiency of a fiber filter.[2/] These authors also developed a semi-empirical equation to account for the interference effect of neighboring fibers in a random two dimensional arrangement of fibers. Kazutaka and Koichi present calculations which show a very significant increase in collection efficiency of single fibers in the presence of an electric field.[2/]

Rao et al.[3/] extended Zebel's theory by including the effect of the closeness of fibers on the deposition of charged particles by use of a three cylinder model. Rao et al. assumed potential flow in their model and corrected the velocity and electrostatic potentials by the method of images when the distance between the cylinders is small.

The single-cylinder model of Zebel significantly over estimates the deposition of particles in low-porosity filters because of the neglect of the interaction of neighboring fibers. The three-cylinder model proposed by Rao et al. predicts that the deposition on a given fiber will decrease as the porosity of the filter decreases--a result more in agreement with experimental observations.

The preceding models all predict that electric fields should enhance the collection efficiency of fabric filters. However, these models, as well as those for conventional fabric filters, are of limited use in assessing the probable performance of an actual filter in an industrial application. The relatively limited utility results because the models do not accurately represent the complex structure of a filter and incorporate the assumption that the filters are sufficiently clean for no deposition to take place on previously deposited particles. The latter assumption is a serious limitation with regard to industrial fabric filter systems. A layer of deposited particles, called the filter cake, forms part of the filtering media in an industrial fabric filter. The filter cake can cause important changes in the filtering characteristics. Deposited particles do not, as a rule, distribute themselves evenly over the surface of the fibers, but build-up chain aggregates which act themselves as very fine fibers and may collect particles more effectively than the material of which the filter is made.

Theoretical models of fabric filtration also fail to adequately incorporate important engineering parameters which markedly influence the performance of fabric filters. The air-to-cloth ratio, cleaning mechanism, temperature, humidity, weave pattern, fabric weight, gas flow rate and filter fabric "surface" characteristics appear to be the most important engineering parameters. The filter fabric "surface" is defined as that region of the fabric which, in successive loading and cleaning cycles, has a significant influence on deposition and removal characteristics. Theoretical models of fabric filters also generally do not consider the electrical, geometric, adhesive and mechanical properties of the filter fabric "surface" despite the fact that the interface between the dust and fabric "surface" is, perhaps, the most important facet of the entire fabric filter system.

In summary, although theoretical models predict that external electrical fields will enhance the collection efficiencies of fabric filters, it is not clear whether the predicted increased performance can actually be achieved in industrial systems. Experimental investigations of actual systems will be required to answer this question. Available experimental data are analyzed in a later section of this report.

INTERNAL FIELDS WITH POTENTIAL APPLIED TO THE FILTER ELEMENT

Walkenhorst has studied the filtration of dust by filter systems utilizing internal electric fields with potential applied to the filter elements.[4] The specific configuration investigated by Walkenhorst consisted of a filter composed of an array of individual wires arranged in a lattice. The filter consists of parallel thin wires with well-insulated surfaces and the basic concept is that the deposition of particles in these filters results from electrical forces. The polarity of the two sets of wires is periodically reversed, with the period depending on the amount of dust retained in the filter and the charge which it carries.

Walkenhorst discusses some of the theoretical aspects of these filters, but does not develop a model--preferring to test the concept with experimental models. The results of his experimental work is discussed in a later section of this report.

ELECTRETS

Electrets are devices which have a "frozen-in" effective charge. As a consequence, electrets are the electrostatic analog of permanent magnets since an electrical field is produced without the application of external potentials. This field can be stable for long periods of time. If a filter is constructed from fibers of an electret, inhomogeneous electric fields will occur around each fiber. It is then possible to obtain electrical enhancement of aerosol filtration without applying external fields or potentials.

Ziekman has investigated electrets, both theoretically and experimentally.[5] His theoretical work was based on a model of a high-porosity system shown in Figure 1. The filter model consists of parallel cylinders at equal distances (d). The electric field in the neighborhood of the cylinder in the center is calculated by superposition of the components of the electric field from the nine individual cylinders shown in Figure 1. Contributions of other cylinders were neglected. The calculated electric field is thought to be representative of the electric field in the neighborhood of an arbitrarily chosen fiber in the filter. The flow field was computed by the Kuwabara-Happel stream function which is based on a system of parallel cylinders located at random, with the direction of the flow being perpendicular to the axes of the cylinders:

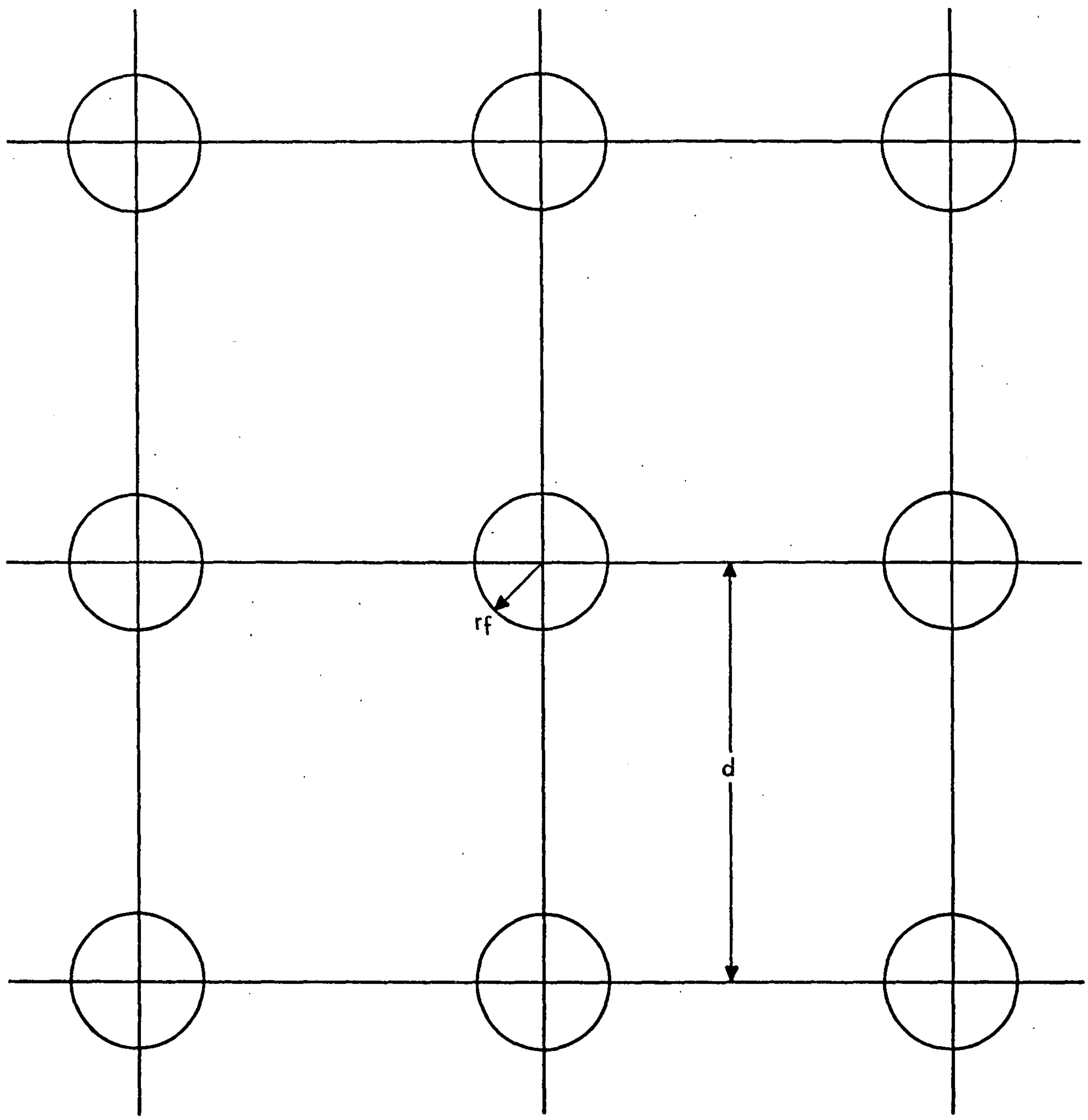

Figure 1. Ziekman's model of a high-porosity filter system

$$\Psi = \frac{v_o r \sin\theta}{2\left(\frac{1}{2}\ \ln\beta + K\right)} \left\{1 - (r_f/r)^2 - 2\ \ln\ (r/r_f)\right\}$$

where K = 0.75 according to Kuwabara,[6] and K = 0.50 according to Happel,[7]

$\beta = 1 - \epsilon$, where ϵ is the porosity,

r = polar coordinate,

r_f = radius fiber,

v_o = undisturbed flow velocity (flow at infinity).

Computer calculations performed by Ziekman demonstrated clearly the increased single filter particle collection efficiency in comparison to the efficiency of nonelectrified fibers. Maximum collection efficiency was predicted for highly charged particles. The collection efficiency enhancement was also predicted to be maximized in the lower Reynolds number region.

Ziekman's theory can be used to calculate single fiber efficiencies by calculating limiting particle trajectories which result in collection. From the single fiber efficiencies, total filter efficiencies may be calculated. It must be emphasized, however, that efficiencies calculated in this way are initial values of the collection efficiency. Efficiencies decrease as the filter becomes loaded with aerosol due to a continuous reduction of the filter's polarization by charge carrying aerosol particles.

EXPERIMENTAL STUDIES OF ELECTRIFIED FILTERS

Many investigators[4,5,8] have reported data from experiments utilizing models which incorporated one or more wires or fibers, oriented perpendicular to the gas stream. Various methods for charging either the aerosol, the filter area, or both were used. Gas velocity (particle velocity) and type and size of aerosol also varied. Typical examples of such systems are those reported by Kirsch[8] and Walkenhorst.[4]

This experimentation has provided valuable reinforcement and refinement of the basic theory as discussed previously. All studies indicate substantially reduced penetration (increased collection efficiency) for filters with applied external fields. However, in almost every case, the models were quite simple, monodisperse areosols were used and aerosol concentration was low. Exceptions are some parts of the work of Walkenhorst[4] and Kirsch.[8] The principal results of previous experimental work are reviewed next.

EXTERNAL FIELDS

Little data were found which directly compared differences in penetration through a "real" fibrous filter operated with and without an applied external field. Kirsch[8] did investigate these effects directly using a polymer fiber "real" filter. The Kirsch experiments used a fiber filter with fiber diameter of 25 μm, α (volume fraction) = 0.029, H (thickness) = 1.1 cm. Gas velocities ranged from 4.4 cm/sec to 27.6 cm/sec. Field intensity, when used, was varied from 0.91 to 11.5 Kv/cm. Monodisperse aerosol diameters were 0.12 μm to 3 μm, with standard deviation less than 1.05 in all cases. Particle concentrations were less than 10^4 and $10^5/cm^3$ for $D_p \sim 3$ μm and < 1 μm, respectively. The duration of the test runs "did not exceed a few minutes so that secondary effects of particle deposition could not influence the results."

Table 1 is a partial reproduction of the Kirsch data with additions. N_0 is inlet particle concentration, N_1 is outlet particle concentration in the absence of an electrical field, N_2 is outlet concentration with application of the electrical field. For fine particles (D_p = 0.12 μm), represented by experiments 33 through 36 inclusive, it can be seen that there

Table 1. PERFORMANCE OF "REAL" FILTERS IN THE ABSENCE AND PRESENCE OF EXTERNAL ELECTRIC FIELDS [8/]

Exp	U cm/sec	r, Nm	N_1/N_0	N_2/N_{0_1}	N_2/N_0*	E, Kv/cm
29	4.4	1.50	0.77	0.55	0.42	0.91
29a	4.4	1.50	0.77	0.08	0.062	2.27
30	10.0	1.33	0.83	0.17	0.14	2.8
30a	10.0	1.33	0.83	0.001	0.0008	10.8
31	18.8	1.33	0.86	0.27	0.23	2.72
31a	18.8	1.33	0.86	0.0055	0.0047	10.0
32	26.6	1.1	0.87	0.45	0.39	2.72
32a	26.6	1.1	0.87	0.025	0.022	11.5
33	6.4	0.06	0.87	0.93	0.81	2.3
33a	6.4	0.06	0.87	0.53	0.46	10.9
34	14.6	0.06	0.92	0.96	0.88	3.6
34a	14.6	0.06	0.92	0.72	0.66	10.2
35	21.0	0.06	0.93	0.92	0.86	4.3
35a	21.0	0.06	0.93	0.81	0.75	10.0
36	27.6	0.06	0.94	0.94	0.88	4.1
36a	27.6	0.06	0.94	0.81	0.76	10.2

* Where $N_2/N_0 = N_1/N_0 \times N_2/N_1$

is little increased collection due to imposition of low strength field. The effect is less than 10% improvement at the four particle velocities investigated. This is graphically illustrated in Figure 2. When a much higher field intensity (2-4 times) is used, improvement is quite significant at low particle velocities and decreases as high flow velocities are reached, although at 27.6 cm/sec the effect is still noticeable (Figure 3).

Dennis et al.,[9/] Silverman et al.,[10/] and Whitby[11/] have investigated electrically assisted filters which are commercially available for use on atmospheric dusts. The general experiences reported in these references are (1) electrification improves collection efficiency for very light loadings of submicron aerosols; and (2) penetration of fine aerosols is relatively high (40-50%), depending on the flow velocities and porosity of the filter media.

INTERNAL FIELDS

Walkenhorst conducted experimental studies on filters consisting of arrays of insulated wire 0.08 mm in diameter (0.5 mm apart). Potentials of 600-1,000 volts were applied to the wires, with the polarity reversed at frequent intervals to reduce the effect of the polarization of the collected dusts. Typical results are shown in Figures 4 and 5 for coal and quartz dusts at different relative humidities and gas stream velocities. Experiments on coal dust were conducted at 34% and 95% relative humidity, 600 volts were applied to the filter, and the polarity was reversed every 10 sec (Figure 4). At a flow velocity of 10 cm/sec and low relative humidity, the penetration of particles in the size range of 0.4-1.0 μm was 5% or less. With increasing flow velocity, penetration increased significantly reaching 65% at 0.4 μm and 25% at 1.0 μm for a velocity of 80 cm/sec.

Figure 5 presents the results for quartz dust. The results are similar to those with coal dust, with collection efficiency somewhat less than for coal dust.

The pressure drop at 10 cm/sec was less than 0.001 in. of water. Electric power consumption would be expected to be very low.

ELECTRETS

Ziekman investigated filters formed from electret fibers which were initially approximately 23 μm in diameter. These filters showed a penetration for 0.72 μm di-octylphtalate aerosols of less than 1% (compared to 80-90% for comparable "unelectrified" filters) at a pressure drop of less than 0.04 in. of water and flow velocity of approximately 1.25 ft/sec. However, the penetration of the filter increases with particulate loading, as shown in Figure 6.

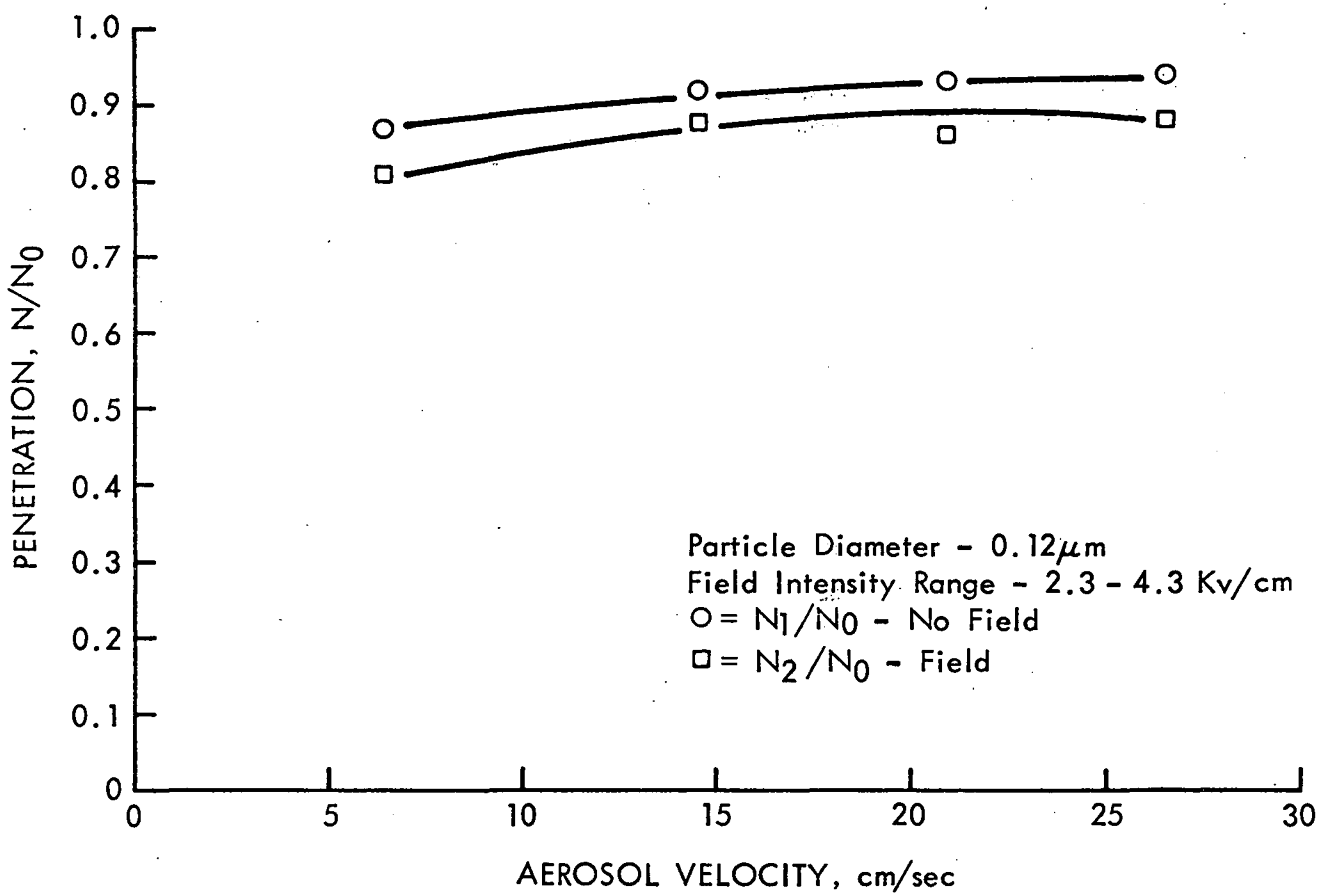

Figure 2. Performance of "real" filter in the absence and presence of external electric field

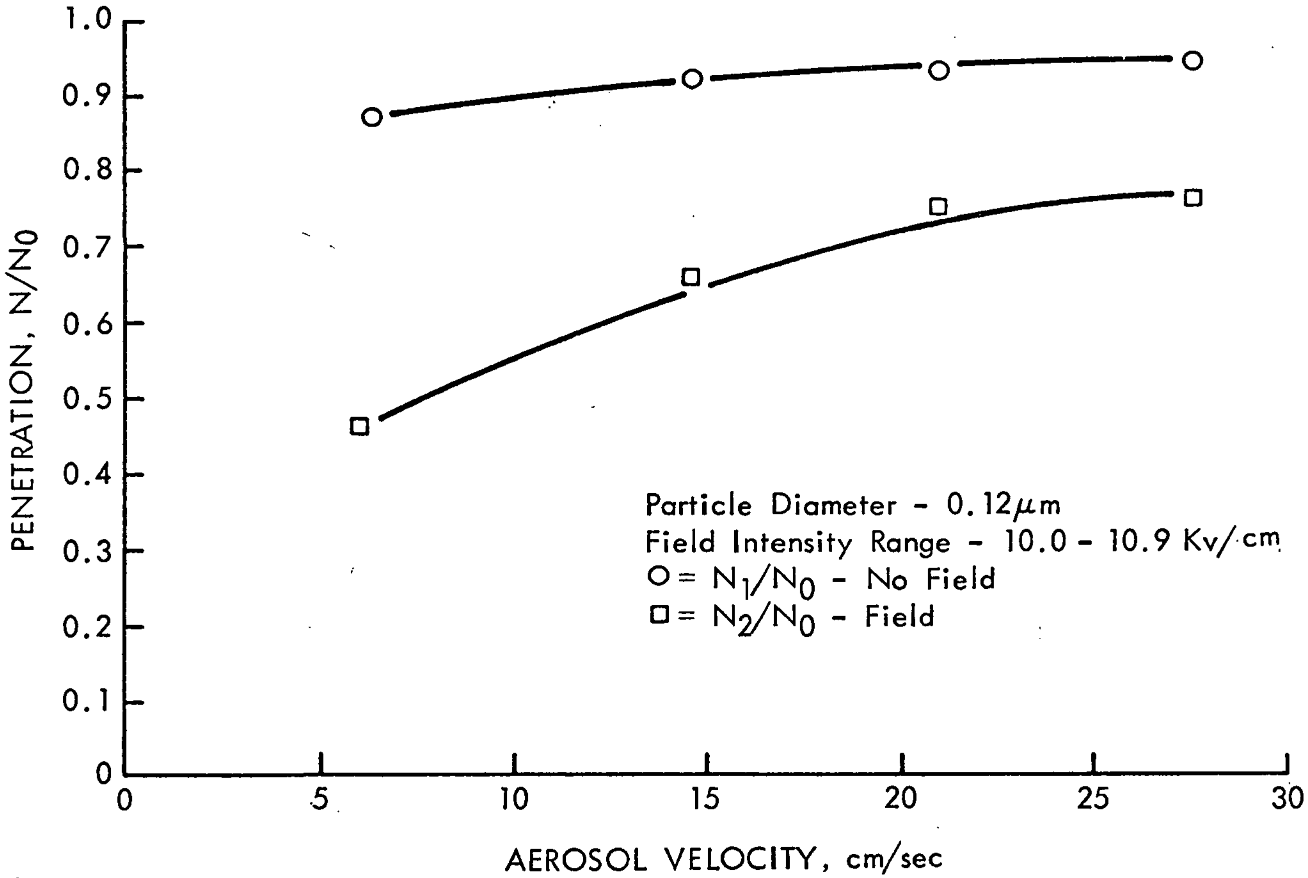

Figure 3. Performance of "real" filter in the absence and presence of external electric field

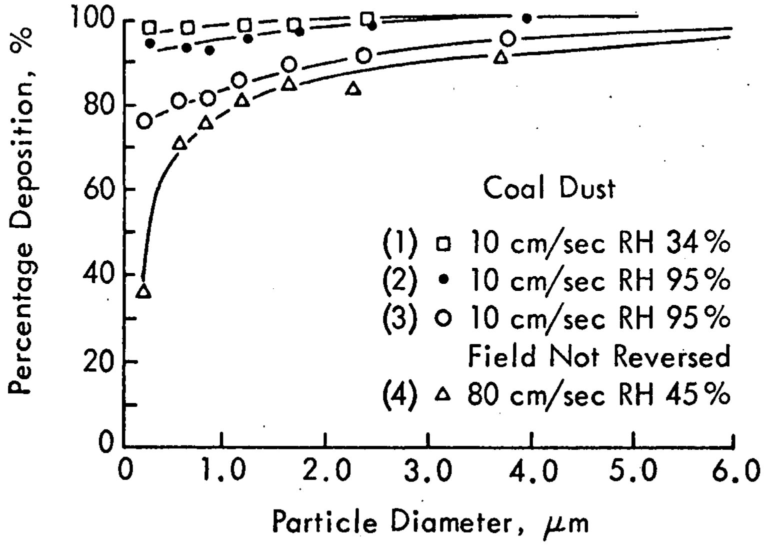

Figure 4. Collection efficiency of wire grid filters with coal dust

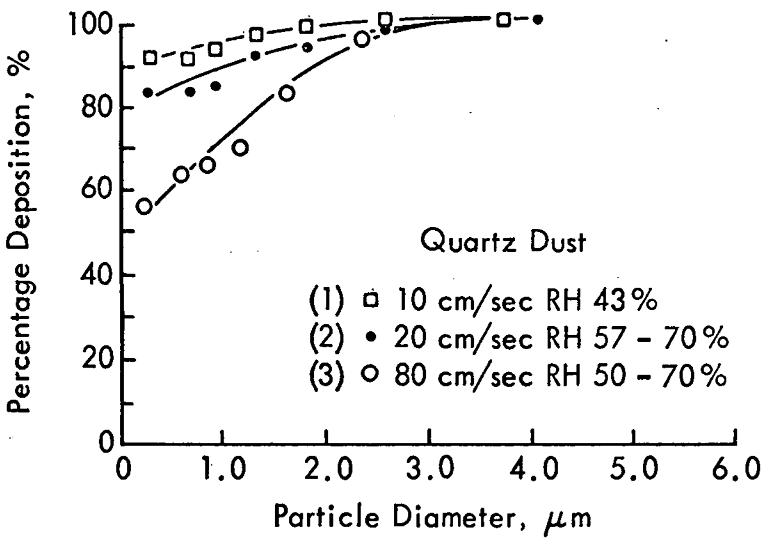

Figure 5. Collection of wire grid filters with quartz dust

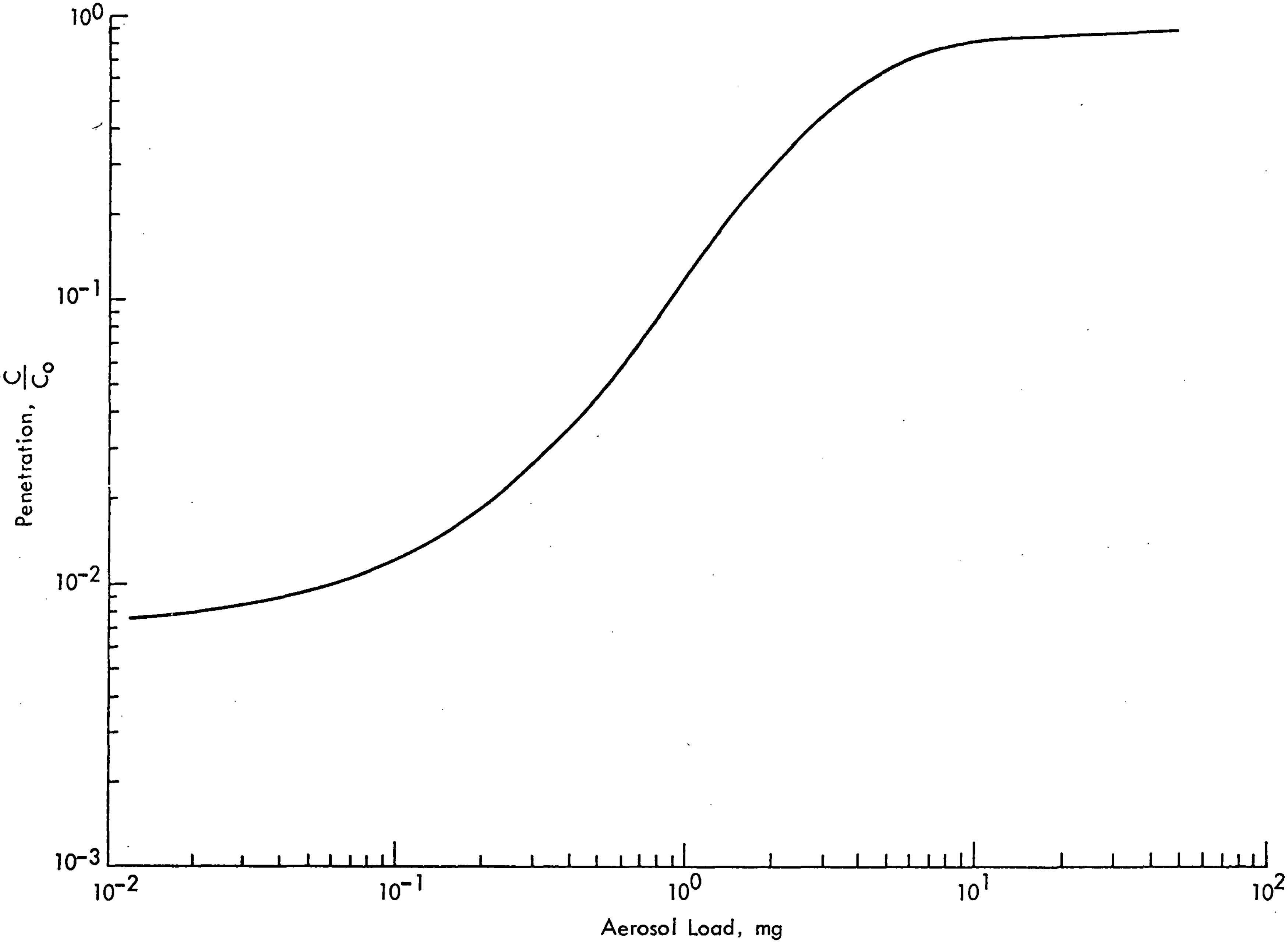

Figure 6. Pentration versus load for electret filter

This is the result of the cancellation of the electric field of the electret by the collected polarized aerosol particles. The data shown in Figure 6 were taken with a filter 3 cm in diameter. Consequently, for a maximum penetration of 1%, at a particulate loading of 1 grain/ft^3, only about 0.2 ft^3 of gas/ft^2 of filter could be treated before regeneration or replacement of the filter.

CONCLUSIONS

Available theoretical and experimental information indicates that electric fields can improve the collection efficiency of fabric filters. However, the lack of adequate data on filter systems suitable for industrial applications precludes a firm judgement on the potential usefulness of an electrified filter for industrial applications. Some intuitive statements of advantages and disadvantages can be proposed.

It may be possible to utilize a system composed of a conventional bag filter with an electrification addition. The field would be applied intermittently, e.g., just after cleaning, to maintain uniformly low penetration during the period of cake repair. The same combination operated continuously might have a positive benefit in reducing penetration of fine particles. The system might also combat reentrainment of collected particles, however deposited, due to electrostatic adhesion.

Another possibility involves usage of a more porous filter media in an electrified filter system to increase capacity, operate at lower pressure drop, or allow control of difficult sources. The economics and reliability of such a device is speculative.

Nearly all of the test work to date involved short-term effects. The test regimes were constructed to minimize or eliminate the other important filtration mechanisms. Further testing would be needed to document any improvement in collection efficiency when these other mechanisms are in operation, particularly with respect to fine particulates.

Nearly all tests utilized extremely low concentrations of aerosol. Consequently, for a short test-run the deposition on the filter was light. Little information is available on the incremental effect due to electrostatic benefication when a more normal filter cake is present.

No studies investigated cleaning mechanisms, possible difficulties in cleaning, or penetration increase during cleaning. Cleaning of an electrified filter or an electrostatically assisted system will probably be more difficult than merely reversing polarity or turning off the field. There are some reservations, as well, when one considers introduction of an electrified filter into industries which collect dust having an explosive or fire hazard.

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16. ABSTRACT

The report gives results of an evaluation of the potential usefulness of electrified fabric filters for industrial gas cleaning. Available theoretical and experimental information indicates that electric fields can improve the collection efficiency of fabric filters. However, the lack of an adequate data base on filter systems, representative of those used on industrial applications, precluded a firm judgment on whether electrified fabric filters will be adaptable to and useful for the control of emissions from industrial sources.

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