EPA-600/2-76-040
February 1976

Environmental Protection Technology Series

EVALUATION OF ELECTROFLUIDIZED BED

Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

EPA-600/2-76-040
February 1976

EVALUATION OF ELECTROFLUIDIZED BED

by

K. P. Ananth and L. J. Shannon

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

Contract No. 68-02-1324, Task 13
ROAP No. 21ADL-029
Program Element No. 1AB012

EPA Project Officer: Dennis C. Drehmel

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

This report was prepared for EPA/IERL-RTP under Contract No. 68-02-1324, Task No. 13. The work was performed by Dr. K. P. Ananth, Senior Environmental Engineer, and Dr. L. J. Shannon, Assistant Director, Physical Sciences Division.

INTRODUCTION

The work presented in this report was performed by Midwest Research Institute for the Industrial Environmental Research Laboratory-RTP as Task Order No. 13 on Contract No. 68-02-1324. The aim of this investigation was to analyze and evaluate the concept of using an electrofluidized bed for the collection of fine particulates.

A literature search has been conducted as part of this investigation and it was found that the general concept is analogous to that of an electrostatic precipitator except for the electrode setup and actual mode of collection. Instead of collecting particles on stationary electrodes as in an electrostatic precipitator, the electrofluidized bed uses several, large, mobile, charged particles which function as collectors in the fluidized state.

The electrofluidized bed concept has been evaluated on a semiquantitative basis, because even though it is possible to theoretically predict the single target collection efficiency, it is not possible to model accurately the dynamics of the bed. Our evaluation is contained in the following sections and is preceded by a section on background information.

BACKGROUND

Fluidized beds have been proposed as particulate filtration media from time to time; but investigations of fluid beds as particulate control systems are quite limited. Meissner and Mickley conducted laboratory studies of sulfuric acid mist removal via fluidized beds.[1/] Collection efficiencies up to 93% were obtained in their tests. Scott and Guthrie[2/] conducted studies with fluidized beds using dioctyl phthalate droplets (0.5 to 1.1 μm). Collection efficiencies varied from 70% at high superficial velocities to 90% at low superficial velocities. Black[3,4/] has conducted one of the more detailed studies of fluid beds as particulate filters. In Black's experimental program, the effectiveness of a fluidized bed in removing particulates from an air stream was investigated at superficial gas velocities of 8.75 to 25.0 ft/min. Bed height-to-diameter ratios were varied from two to six. The aerosols chosen were ammonium chloride and tobacco smoke. Concentration of aerosol ranged from 0.03 to 8.3 mg/cu m. Filtration efficiencies of the fluidized bed in removing either ammonium chloride or tobacco particles of submicron size ranged from approximately 50 to 90% on a count basis. Lowest efficiencies were encountered at highest gas flow rates and lowest bed heights.

Jackson and coworkers have recently reported results of a study to compare directly the collection of fine particles by a bed of granules operating in both the fixed and fluidized states.[5,6/] Monodispersed aerosols of dioctyl phthalate, in sizes of 0.67 and 1.2 microns were collected in a bed of granules of porous activated alumina having a mean size of 175 microns. Bed depths of 1 to 4 in. resulted in collection efficiencies up to and exceeding 99% in the fixed state for either particle size; efficiencies dropped markedly, upon bed fluidization and with increasing gas velocity, to 70 to 80% at twice the initial fluidization velocity.

The mechanisms involved in electrostatic filtration of aerosols in fixed and fluidized granular beds were studied at the Air Cleaning Laboratory at Harvard University from 1955 to 1958.[7/] Polystyrene spheres were used as the bed media in these studies. Polystyrene granules were charged _in situ_ by means of interspersed wires in the filter matrix or were remotely charged using a vibrating cylindrical Lucite trough. The test aerosol of gentian violet microspheres was charged to 18 to 64 electron charges (positive) per particle by a spinning disc generator. A fixed bed of polystyrene granules (280 micron diameter) with a surface charge density of 0.09 esu/cm^2 had a 64% collection efficiency for atmospheric dust as compared with a 96% efficiency for a fluidized bed expanded to 120% of the original bed depth.

Zahedi and Melcher at MIT have recently proposed the use of an electrofluidized bed (EFB) for the collection of fine particulates.[8/] The EFB concept is probably an outgrowth of studies on: (1) electrically induced agglomeration between particles and (2) electrically augmented scrubbers which use charged water drops to collect oppositely charged particulates.[9-11/]

In the EFB, the collection sites are envisioned to be particles about 100 μ in size.[10/] The charge on these particles is continuously renewed by the application of an ambient electric field. The fine particles, which are to be collected on the large bed particles through the agent of the electric field, are charged prior to entering the collection volume containing the large particles. The poles of the charged large particles collect the oppositely charged fines. Melcher suggests that gas velocities of the order of 3 to 8 ft/sec be used in the EFB.[8,10/]

A schematic configuration, as presented by Melcher, is shown in Figure 1 to illustrate the general features of an EFB. Gas to be cleaned enters from below through vertical ducts and is diverted through the parallel sections of the EFB at relatively low velocity to be expelled at the top through alternate vertical ducts. Particles are removed in the fluidized bed by interaction with individual collector bodies comprising the bed material. The charging section is used to charge the particles in the gas prior to entering the EFB. Figure 2 illustrates alternate configurations for an EFB.[8/]

Based on information presented above, as well as information contained in the literature, the following evaluation of the EFB has been performed.

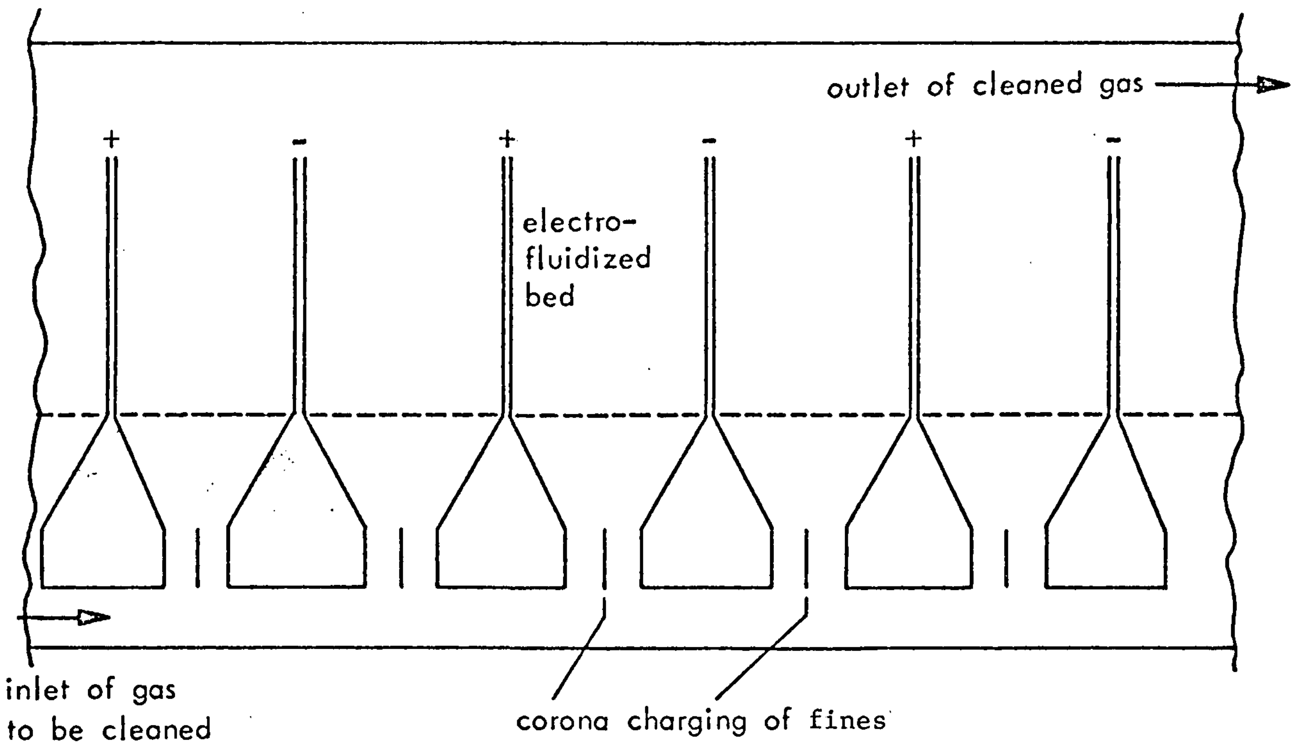

Figure 1. Possible configuration for electrofluidized bed.

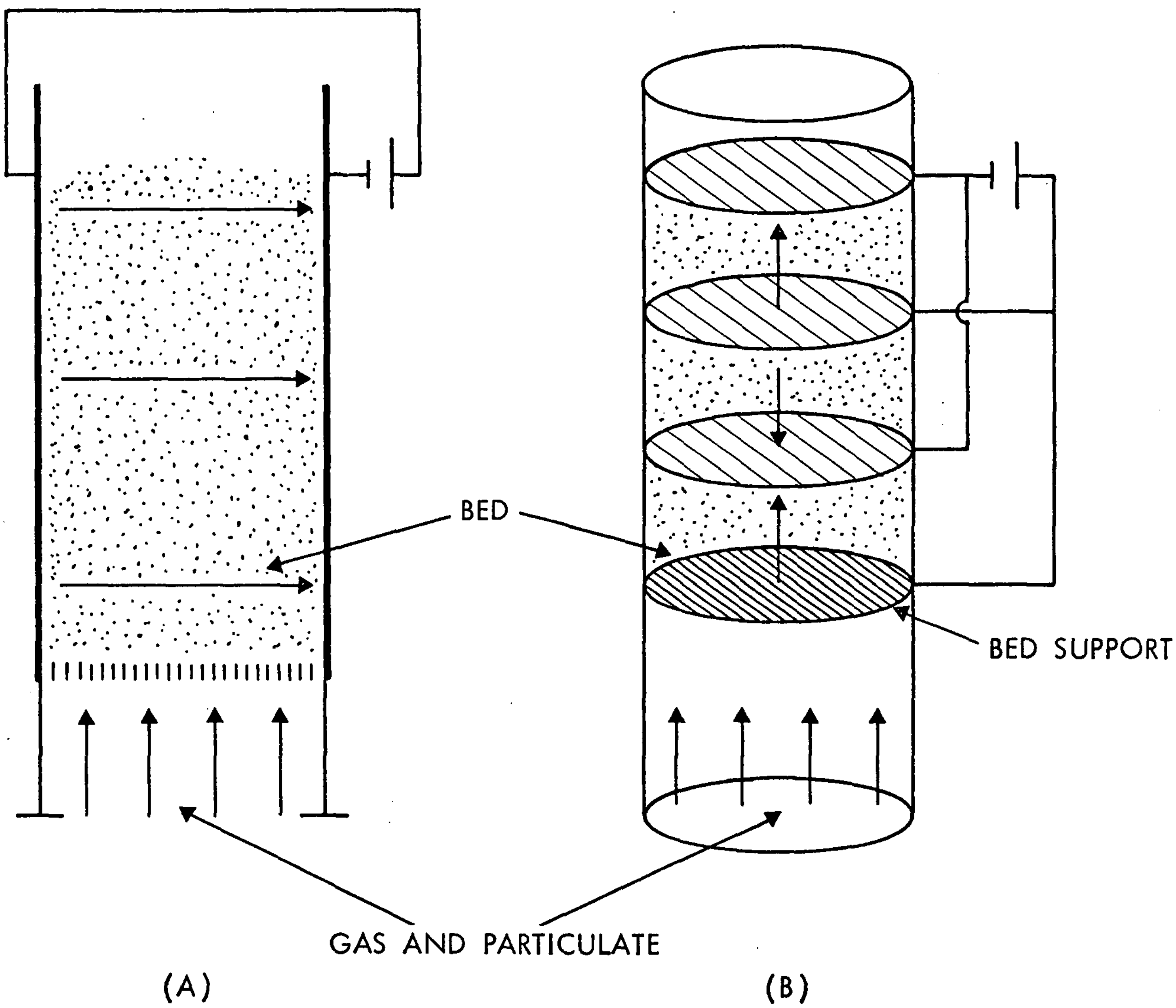

Figure 2. Alternate configurations for an electrofluidized bed--
(A) cross-flow; (B) co-flow.

TECHNICAL EVALUATION

The development of a model of a fluid bed as a particulate control device is hampered by many of the difficulties involved in modelling a fabric filter system (i.e., interference effects of neighboring particles, variation of collector body surface characteristics with time, interaction of collector mechanisms). A further complication arises because the precise behavior of a mass of fluidized solids is difficult to define and is strongly dependent upon the particle size of the bed material.

Extensive effort to model a fluid bed was deemed to be outside the scope of this evaluation, and a simple model of a fluid bed acting as a particulate collecting device was developed in order to define some of the characteristics of such a collection system.

MODEL OF FLUID BED

The fluid bed was assumed to be composed of an array of collector bodies with diameter D_c and interference effects of bed collector bodies were assumed negligible. Utilizing the concept of single target efficiencies, the following expression can be written for the number of particles removed from an aerosol stream as it traverses an element of the bed of length dL

$$-\frac{dn}{n} = \eta_T N_{eff} \frac{\pi D_c^2}{4} dL \qquad (1)$$

where N_{eff} = number of effective collector bodies per unit volume of bed,

D_c = diameter of collector body,

dL = incremental length of the bed,

n = number of particulates per unit volume at entrance to bed element,

η_T = overall single particle target efficiency.

The number of effective collector bodies (N_{eff}) is used in Eq. (1) rather than the total number of collector bodies (N_{TOT}) in order to make allowance for the actual behavior of a mass of solids fluidized by a gas. Under conditions for fluidization some of the gas travels through the bed between individual bed particles, but much of it travels through in "bubbles" or pockets and experiences minimal contact with the bed particles. In the bed itself the bed particles move in distinct aggregates which are lifted by the bubbles or which move aside to let the bubbles pass.[7] The total number of bed particles will not be involved in aerosol collection; hence, the need to use the term N_{eff} rather than N_{TOT}.

Integration of Eq. (1) within appropriate limits results in:

$$-\int_{n_i}^{n_o} \frac{dn}{n} = \int_0^L \eta_T \, N_{eff} \, \frac{\pi D_c^2}{4} \, dL \tag{2}$$

or

$$\frac{n_o}{n_i} = \exp\left[-\eta_T \, N_{eff} \, \frac{\pi D_c^2}{4} \, L\right] \; . \tag{3}$$

By defining the extent of aerosol penetration, P, as $\frac{n_o}{n_i}$, Eq. (3) can be written as

$$P = \exp\left[-\eta_T \, N_{eff} \, \frac{\pi D_c^2}{4} \, L\right] \tag{4}$$

The overall collection efficiency of the bed, E, is given by Eq. (5)

$$E = 1 - P = 1 - \exp\left[-\eta_T \, N_{eff} \, \frac{\pi D_c^2}{4} \, L\right] \; . \tag{5}$$

In order to utilize Eqs. (4) or (5) to predict the performance of a fluid bed, expressions for N_{eff} and η_T must be known. In any actual fluid bed operating on an industrial source of particulate pollutants, N_{eff} and η_T will be dependent upon the characteristics of the particulate pollutant and carrier gas stream. Furthermore, both parameters are likely to be functions of bed age (i.e., vary in time). The manner in which the parameters vary with bed age is unknown and will not be specifically included in our model. However, both η_T and N_{eff} can be varied so that changes in bed conditions with time can be qualitatively assessed.

N_{eff} is assumed to be a function of N_{TOT} which is in turn a function of the diameter of the bed material and bed porosity. Assuming spherical bed particles, the total number of collector bodies, N_{TOT} , is related to the ideal bed porosity, ε , by

$$N_{TOT} = \frac{\text{total volume of solids}}{\text{volume per collector body}}$$

$$= \frac{(1-\varepsilon)\ (\text{total volume of bed})}{\pi D_c^3/6} \tag{6}$$

$$= \frac{6\ (1-\varepsilon)\ V_{bed}}{\pi D_c^3} \quad .$$

As noted previously, $N_{eff} < N_{TOT}$ but the functional relationship between N_{eff} and N_{TOT} is not known. For the purpose of estimating bed performance, we assumed that Eq. (7) is applicable

$$N_{eff} = \frac{6\ \alpha\ (1-\varepsilon)\ V_{bed}}{\pi D_c^3} \quad , \tag{7}$$

where α is the bed availability factor ($\alpha < 1$). In an actual fluid bed, the total bed porosity is the sum of the porosity between individual aggregates, ε_b , and the porosity within individual aggregates, ε_i (i.e., $\varepsilon = \varepsilon_b + \varepsilon_i\ (1-\varepsilon_b)$). Also, the bed availability factor is really related to the microstructure of the bed and hence to ε_b and ε_i . An in-depth analysis of this interrelationship was judged to be outside the scope of this task and we assumed that α, ε, ε_b, and ε_i could be uncoupled as indicated in Eq. (7). Assuming $V_{bed} = 1\ ft^3$ and porosity = 0.7 (typical for fluid beds), Eq. (7) simplifies to

$$N_{eff} = \frac{6\ (1-0.7)\ \alpha}{\pi D_c^3} = \frac{1.8\ \alpha}{\pi D_c^3} \quad \frac{\text{particles}}{ft^3 \text{ of bed}} \quad . \tag{8}$$

Substitution of Eq. (8) into Eq. (5), results in the following expression for the collection efficiency of the bed

$$E = 1 - \exp\left[\frac{-0.45\ \alpha\ \eta_T\ L}{D_c}\right] \quad . \tag{9}$$

The overall single target efficiency, η_T , was calculated from Ref. 12 assuming that only electrostatic and inertial forces are important in an electrofluidized bed composed of collector bodies of 100 μm and 150 μm diameter particles. George and Poehlein[12/] have determined single target efficiencies for a two-body system expressing inertial and electrostatic forces in terms of dimensionless parameters. The dimensionless constants for inertial and coulombic force parameters given in Ref. 12 are

$$\psi = \frac{C\rho_p\ V_o\ D_p^2}{18\ \mu\ D_c} \tag{10}$$

and

$$ES^* = \frac{C\ Q_1\ Q_2}{3\pi^2\ \epsilon_o\ \mu\ V_o\ D_p\ (D_c+D_p)^2} \quad , \tag{11}$$

respectively. In the above equations

C = Cunningham correction factor (assumed to be 1),

ρ_p = density of particle,
= 2.8 $\frac{g}{cm^3}$ (assumed to be iron foundry particles),

V_o = gas velocity in cm/sec,
= fluidization velocity in the EFB,

D_p = diameter of particle,
= 1×10^{-4} cm, 0.8×10^{-4} cm and 0.5×10^{-4} cm,

μ = viscosity of gas,
= 1.8×10^{-4} poise,

D_c = collector diameter,
= 100×10^{-4} cm, 150×10^{-4} cm,

Q_1 = particle charge in coulomb, and

Q_2 = collector charge in coulomb.

---

* A more recent report,[13/] in response to reference 12, actually shows that the denominator of Eq. (11) should contain D_c^2 instead of $(D_c + D_p)^2$. However, $D_c >> D_p$, therefore the two expressions are almost identical. This fact is also acknowledged in reference 13.

The range of superficial gas velocities for stable bed fluidization (V_o in Eqs. (10) and (11)) is about 3 to 10 times the minimum velocity for fluidization. The minimum velocity for fluidization is given by [14]

$$V_{min} = \frac{g\ (\rho_\delta - \rho_f)\ D_c^2\ \epsilon_m^3}{150\ \mu\ (1-\epsilon_m)} \qquad (12)$$

where g = acceleration due to gravity,

ρ_δ = density of bed solids,

ρ_f = density of fluid (i.e., air in this case)

D_c = diameter of collector bodies in bed,

μ = viscosity of fluid, and

ϵ_m = minimum porosity.

The minimum velocity for fluidization is typically about 0.1 ft/sec depending upon the physical characteristics of the bed and the fluidizing medium. For purposes of illustrating the effect of fluidizing velocity on the inertial and electrostatic constants and hence on the single particle target efficiency, we used a range of velocities from 0.1 to 3.0 ft/sec.

Equations (10) and (11) were used to calculate ψ and ES for different particle and collector diameters under varying velocity conditions. Aerosol particles were assumed to be charged to saturation in a field of 2.5×10^5 v/m. Bed particles were assumed to be charged to saturation in a field of 5×10^5 v/m.[10] The single target efficiency was then obtained from the graph of Ref. 13 which shows the single particle target efficiency as a function of ψ and ES, the inertial and coulombic force parameters. The results of the calculations are shown in Tables 1 and 2.

PREDICTED PERFORMANCE OF FLUID BED

The collection efficiency for a bed length of 1 ft was calculated using Eq. (9) and the single particle target efficiencies given in Tables 1 and 2. The constant, α , was assumed to vary from 10^{-4} to 10^{-1} which is equivalent to assuming that N_{eff} varies from about 10^5 to 10^9 particles per cubic foot for collector bodies of 100 µm and 150 µm in diameter. The computed overall collection efficiencies are shown in Tables 3 and 4 and graphically presented in Figures 3 and 4, respectively.

Table 1. SINGLE TARGET EFFICIENCY AS A FUNCTION OF PARTICLE SIZE AND FLUIDIZATION VELOCITY[a]

Particle Diameter (cm)	Fluidization Velocity (cm/sec)	Particle Charge (coulombs)	ES	ψ	Single Target Efficiency
1×10^{-4}	3.04	4.97×10^{-17}	3.53	0.0026	14.0
1×10^{-4}	15.20	4.97×10^{-17}	0.70	0.0132	2.50
1×10^{-4}	30.48	4.97×10^{-17}	0.35	0.0263	0.90
1×10^{-4}	60.96	4.97×10^{-17}	0.18	0.0527	0.25
1×10^{-4}	91.44	4.97×10^{-17}	0.12	0.0790	0.16
0.8×10^{-4}	3.04	3.20×10^{-17}	2.86	0.0017	10.0
0.8×10^{-4}	15.20	3.20×10^{-17}	0.57	0.0084	2.0
0.8×10^{-4}	30.48	3.20×10^{-17}	0.28	0.0169	0.80
0.8×10^{-4}	60.96	3.20×10^{-17}	0.14	0.0337	0.25
0.8×10^{-4}	91.44	3.20×10^{-17}	0.095	0.0506	--
0.5×10^{-4}	3.04	1.25×10^{-17}	1.79	0.0007	--
0.5×10^{-4}	15.20	1.25×10^{-17}	0.36	0.0033	1.40
0.5×10^{-4}	30.48	1.25×10^{-17}	0.18	0.0066	0.64
0.5×10^{-4}	60.96	1.25×10^{-17}	0.09	0.0132	--
0.5×10^{-4}	91.44	1.25×10^{-17}	0.02	--	--

a/ Collector diameter = 100×10^{-4} cm; collector charge = 1.04×10^{-13} coulomb.

Table 2. SINGLE TARGET EFFICIENCY AS A FUNCTION OF PARTICLE SIZE AND FLUIDIZATION VELOCITY[a]

Particle Diameter (cm)	Fluidization Velocity (cm/sec)	Particle Charge (coulombs)	ES	ψ	Single Target Efficiency
1×10^{-4}	3.04	4.97×10^{-17}	3.57	0.0018	14
1×10^{-4}	15.20	4.97×10^{-17}	0.71	0.0090	2.5
1×10^{-4}	30.48	4.97×10^{-17}	0.36	0.0180	1.2
1×10^{-4}	60.96	4.97×10^{-17}	0.18	0.0370	0.40
1×10^{-4}	91.44	4.97×10^{-17}	0.12	0.0550	0.13
0.8×10^{-4}	3.04	3.20×10^{-17}	2.88	0.0011	11.0
0.8×10^{-4}	15.20	3.20×10^{-17}	0.58	0.0056	2.0
0.8×10^{-4}	30.48	3.20×10^{-17}	0.29	0.0110	1.0
0.8×10^{-4}	60.96	3.20×10^{-17}	0.14	0.0230	0.34
0.8×10^{-4}	91.44	3.20×10^{-17}	0.10	0.0340	0.14
0.5×10^{-4}	3.04	1.25×10^{-17}	1.81	0.0004	--
0.5×10^{-4}	15.20	1.25×10^{-17}	0.36	0.0020	1.30
0.5×10^{-4}	30.48	1.25×10^{-17}	0.18	0.0043	0.70
0.5×10^{-4}	60.96	1.25×10^{-17}	0.09	0.0085	0.28
0.5×10^{-4}	91.44	1.25×10^{-17}	0.06	0.0130	--

a/ Collector diameter = 150×10^{-4} cm; collector charge = 2.35×10^{-13} coulomb.

Table 3. OVERALL COLLECTION EFFICIENCY AS A FUNCTION OF PARTICLE DIAMETER AND FLUIDIZATION VELOCITY[a]

Particle diameter (cm)	Fluidization velocity (cm/sec)	Single target efficiency (%)	Overall collection efficiency (%)			
			$\alpha = 10^{-4}$	$\alpha = 10^{-3}$	$\alpha = 10^{-2}$	$\alpha = 10^{-1}$
1×10^{-4}	3.04	14.0	1.9	17.45	85.31	100.0
1×10^{-4}	15.20	2.50	0.34	3.37	29.0	96.75
1×10^{-4}	30.48	0.90	0.12	1.23	11.6	70.86
1×10^{-4}	60.96	0.25	0.03	0.31	3.1	27.03
1×10^{-4}	91.44	0.16	0.02	0.22	2.17	19.68
0.8×10^{-4}	3.04	10.0	1.36	12.8	74.59	100.0
0.8×10^{-4}	15.20	2.0	0.27	2.7	23.97	93.55
0.8×10^{-4}	30.48	0.80	0.11	1.09	10.38	66.58
0.8×10^{-4}	60.96	0.25	0.03	0.31	3.1	27.0
0.8×10^{-4}	91.44	--	--	--	--	--
0.5×10^{-4}	3.04	--	--	--	--	--
0.5×10^{-4}	15.20	1.4	0.19	1.9	17.45	85.31
0.5×10^{-4}	30.48	0.64	0.09	0.87	8.39	58.39
0.5×10^{-4}	60.96	--	--	--	--	--
0.5×10^{-4}	91.44	--	--	--	--	--

a/ Collector diameter = 100 µm.

Table 4. OVERALL COLLECTION EFFICIENCY AS A FUNCTION OF PARTICLE DIAMETER AND FLUIDIZATION VELOCITY[a/]

Particle diameter (cm)	Fluidization velocity (cm/sec)	Single target efficiency (%)	Overall collection efficiency (%)			
			$\alpha = 10^{-4}$	$\alpha = 10^{-3}$	$\alpha = 10^{-2}$	$\alpha = 10^{-1}$
1×10^{-4}	3.04	14.0	1.27	11.96	72.03	100
1×10^{-4}	15.20	2.50	0.23	2.25	20.35	89.72
1×10^{-4}	30.48	1.20	0.11	1.10	10.34	66.45
1×10^{-4}	60.96	0.40	0.04	0.36	3.57	30.51
1×10^{-4}	91.44	0.13	0.01	0.12	1.18	11.16
0.8×10^{-4}	3.04	11.0	0.99	9.53	63.25	100
0.8×10^{-4}	15.20	2.0	0.18	1.80	16.64	83.8
0.8×10^{-4}	30.48	1.0	0.09	0.91	8.70	59.75
0.8×10^{-4}	60.96	0.34	0.03	0.31	3.05	26.61
0.8×10^{-4}	91.44	0.14	0.01	0.13	1.27	11.96
0.5×10^{-4}	3.04	--	--	--	--	--
0.5×10^{-4}	15.20	1.30	0.12	1.18	11.16	69.36
0.5×10^{-4}	30.48	0.70	0.06	0.63	6.17	47.11
0.5×10^{-4}	60.96	0.28	0.03	0.25	2.52	22.49
0.5×10^{-4}	91.44	--	--	--	--	--

a/ Collector diameter = 150 µm.

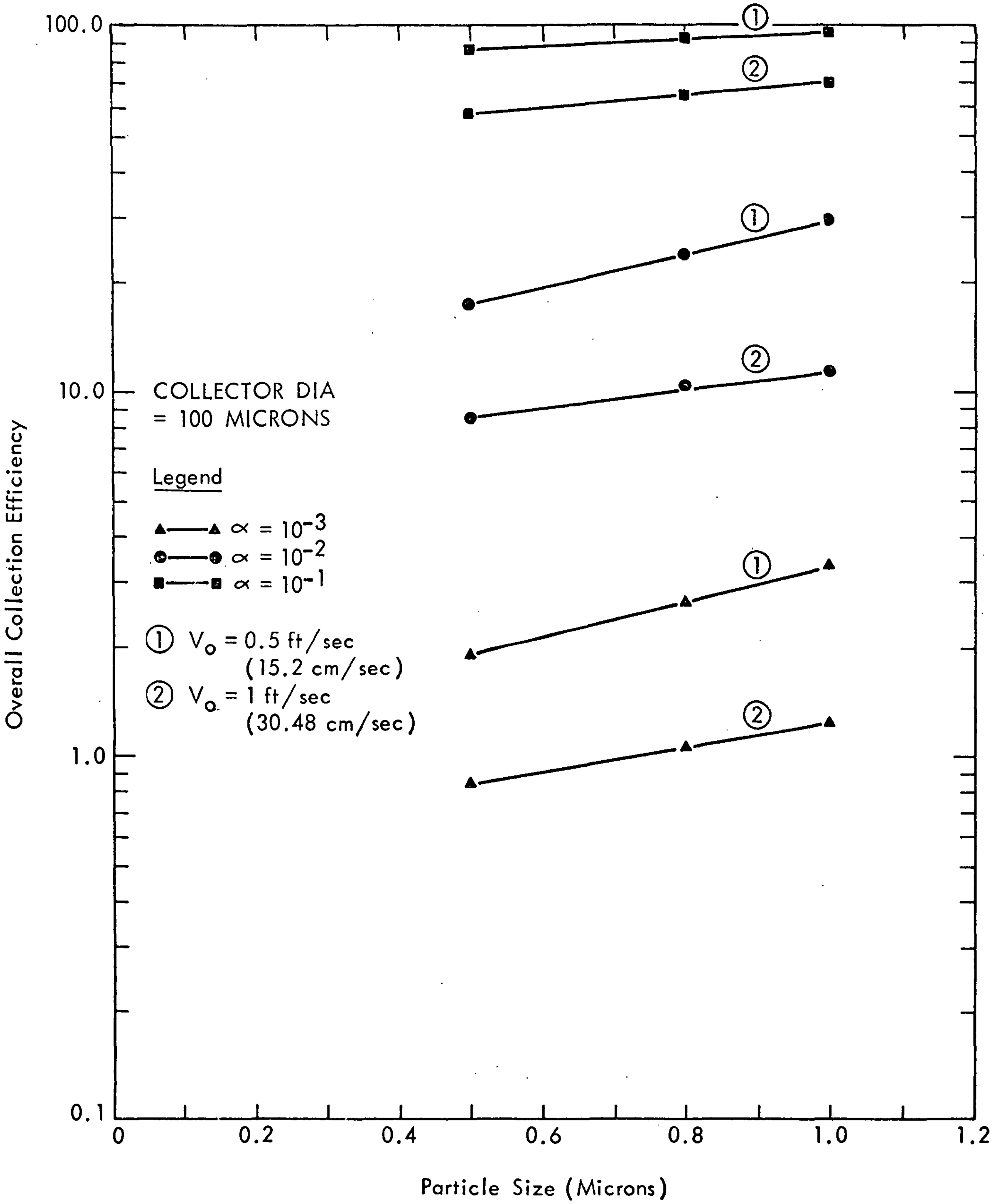

Figure 3. Overall collection efficiency as a function of particle size and fluidization velocity (D_c = 100 μm).

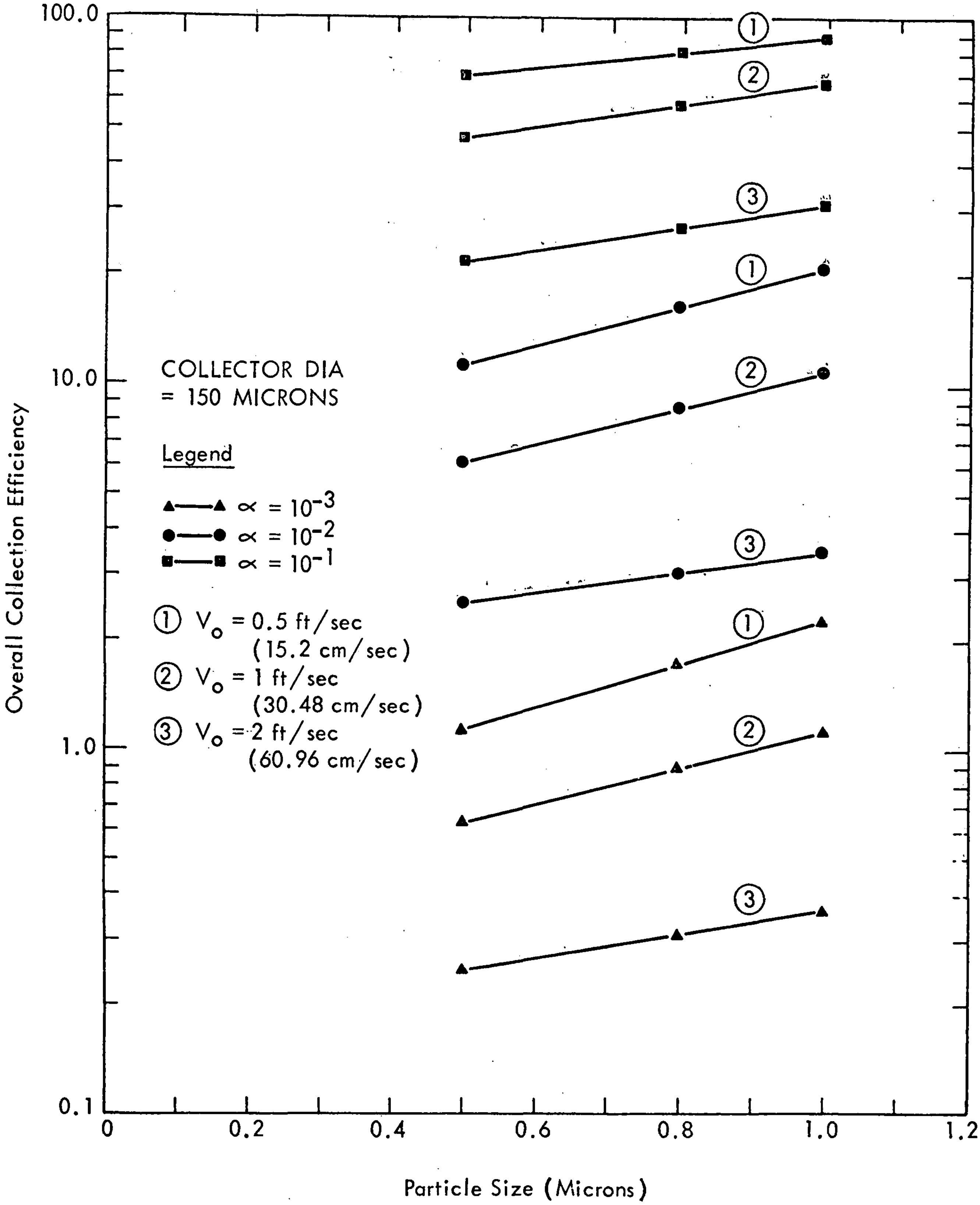

Figure 4. Overall collection efficiency as a function of particle size and fluidization velocity (D_c = 150 μm).

Inspection of Tables 3 and 4 or Figures 3 and 4 indicates that: (1) predicted collection efficiencies decrease with decreasing aerosol particle size for a given superficial velocity and bed availability factor (α); (2) predicted collection efficiencies decrease with increasing superficial velocity at a given bed availability factor; (3) collection efficiencies decrease with decreasing bed availability at a given superficial velocity; and (4) collection efficiency decreases with increasing size of the fluid bed particles. The predicted behavior of the fluid bed is in general agreement with the experimental results of work on fluidized beds discussed in the background section of this report.

A major weakness of the simple model proposed is that it makes no allowance for changes in bed parameters with time. Bed age is expected to exert some influence on performance in an actual industrial gas cleaning application. However, the agreement between the predicted and experimental performance suggests that the very simple model can be used to assess qualitatively the changes in bed performance with changes in major bed parameters. The probable influence of time dependent factors (i.e., bed age) on fluid bed performance is discussed in more detail in the next section.

EFFECT OF CHANGES IN BED PARAMETERS ON PERFORMANCE

As mentioned in the preceding section, changes in bed parameters are anticipated with time in any actual industrial application of electrofluidized beds. Among the changes anticipated are:

1. Changes in bed particle size

2. Changes in surface characteristics of bed particles

3. Changes in bed availability

These changes are expected to influence both the collector-particulate interaction mechanisms and the dynamics of the fluid bed itself. Some of the possible effects that may occur are discussed next.

Collector-Particulate Interaction Mechanisms

Electrostatic phenomena are a function of particle properties as well as particle charge. The influence of an increase in collector body size can be qualitatively assessed, in terms of our simple model, by writing the electrostatic constant in the alternate form suggested by George and Poehlein[12/]

$$ES = \left[\frac{C \; \epsilon_o \; \delta^2 \; \epsilon_{ps_1} \; \epsilon_{ps_2}}{3 \; \mu} \right] \frac{D_p \; D_c^2}{V_o \; (D_p + D_c)^2} \quad . \tag{13}$$

If $D_c \gg D_p$ as is our case

$$ES = \left[\frac{C \; \epsilon_o \; \delta^2 \; \epsilon_{ps_1} \; \epsilon_{ps_2}}{3 \; \mu} \right] \frac{D_p}{V_o} \tag{14}$$

where ϵ_{ps_1} = surface gradient of charge on particulates,

ϵ_{ps_2} = surface gradient of charge on collector bodies,

δ = dielectric constant.

Equation (14) indicates that the parameter, ES , is a direct function of the charge surface gradient of the collector. An increase or decrease in ϵ_{ps_2} , which is a function of collector size and the charge-to-mass ratio of particles, will be reflected in a corresponding increase or decrease in ES , and depending upon the superficial velocity, a change in the single target collection efficiency and overall bed collection efficiency.

Changes in bed particle size and shape can also alter the particle charging characteristics of the bed. The net effect may be detrimental or favorable depending upon the change in the charge per bed particle.

An increase in the collector body size or a change in collector body shape can also influence particle to particulate cohesion or adhesion. Here we refer to the interaction between collector body and aerosol particle following the electrically induced collision of the two.

Dynamics of Fluid Bed

Because of the complexity of the flow and the inherent mechanical instablity of gas-solids fluidized systems, operational problems may occur if the characteristics of the bed particles change during the course of particulate collection.

It may very well be that the gas-solids mixing patterns determine the effect of electrostatic forces, and hence the performance of an EFB.

The dynamics of fluid beds are influenced by the design and internal configuration of the bed, the design of the gas-inlet system, the size and size distribution of bed particles, and the shape and density of the bed particles. Bed design and internal configuration can change gas-solids mixing patterns and slugging (i.e., formation of large gas bubbles) can occur in improperly designed beds. Proper placement of electrodes may be quite important in this regard. The gas distribution system will influence fluidization characteristics--especially channeling tendencies. Channeling will decrease the bed availability factor, α , and as shown in Figures 3 and 4, overall collection efficiency is a strong function of bed availability.

The characteristics of the solid phase are related to various abnormalities of fluid beds. Bed particle size and size distribution, bed particle shape and bed particle density all influence channeling. Quantitative correlations of bed particle properties with channelization tendencies are not available. However, irregular particles exhibit a greater tendency to channeling than do smooth spherical particles. Increasing the size of bed particles generally results in a decrease in channeling tendencies.

Even under normal or good conditions for fluidization, much of the gas travels through the bed in bubbles. This phenomenon is called aggregation. The causes of aggregative fluidization are not well defined. However, particle size of the bed material is a factor with a trend toward less aggregation with increasing particle size.

Size segregation will also occur in gas-fluidized systems if the solids are not of uniform size or density. The finer or less dense bed material will tend to move toward the upper part of the bed.

The preceding brief discussion of bed dynamics suggests several problems which might occur in an EFB during aging or between cleaning or regeneration cycles. First, the size of the bed particles will increase and the shape will change as a result of particulate collection. The net influence of these two changes on collection efficiency is difficult to predict because increasing bed particle size generally improves bed dynamics while a change in shape to a more irregular particle can result in increased channeling. Also, as shown in Figures 3 and 4, an increase in bed particle size would be expected to result in a decrease in overall collection efficiency.

The suggestion that the most attractive application of the EFB is where the large particles comprising the bed are made up of the same material as that being collected is open to question.[8] The start-up of such a device might involve seeding the bed with foreign particles. The particulate will then have to be captured on these particles starting the agglomeration process. At some point in the operation, presumably under steady state conditions, the bed particles will have to be removed to retain the required population density of the collector bodies. In light of the preceding comments on bed dynamics, attainment of a stable fluidized self-agglomerating system may be very difficult. It is also questionable whether stable agglomerates of 100 to 200 μm can actually be produced in a fluid bed system.

CONCLUSIONS

Our analysis of the EFB concept indicates that theoretically at low superficial velocities and high values of electrostatic forces fluidized beds augmented by electrostatic forces will be more effective for the removal of particulates than are conventional fluid beds. It is not clear that the expected performance can actually be achieved because of the inherent problems involved in operating fluid beds. Previous experience would indicate that single pass fluidized beds are not likely to attain collection efficiencies much in excess of 90%. Attainment of high efficiencies by staging may be possible.

The performance of an EFB will be dependent upon both the electrostatic phenomena occurring in the bed and the bed dynamics. Electrostatic phenomena have been considered in detail, in the literature, but the importance of bed dynamics needs further investigation. Experience gained from the use of fluid beds in the chemical industry indicates that bed dynamics may actually be the more important factor influencing collection efficiency.

REFERENCES

1. Meissner, H. P., and H. S. Mickley, "Removal of Mists and Dusts from Air by Beds of Fluidized Solids," Industrial and Engineering Chemistry, 41, 1238 (1949).

2. Scott, D. S., and D. A. Guthrie, "Removal of a Mist in a Fluidized Bed," Can. J. Chem. Engr., 37, 200 (1959).

3. Black, C. H., and R. W. Boubel, "Effectiveness of a Fluidized Bed in Removing Submicron Particulate from an Air Stream," I/EC Process Design and Development, 8, 573 (1969).

4. Black, C. H., "Effectiveness of a Fluidized Bed in Filtration of Airborne Particulates of Submicron Size," Ph.D. Thesis No. 67-5646, University Microfilms, Ann Arbor, Michigan (1967).

5. Yankel, A. J., R. G. Patterson, and M. L. Jackson, "Fine Particle Collection with a Fixed-Fluidized Bed," under review by Industrial and Engineering Chemistry, Process Design and Development, 1973. Presented at the Annual Meeting, Air Pollution Control Association, Pacific Northwest International Section, Eugene, Oregon, 15 November 1972.

6. Jackson, M., "Fluidized Beds for Submicron Particle Collection," presented at the 75th National Meeting, AIChE, Detroit, Michigan, 3-6 June 1973.

7. Juvinall, R. A., et al., "Sand-Bed Filtration of Aerosols: A Review of Published Information on Their Use in Industrial and Atomic Energy Facilities," Argonne National Laboratory Report ANL-7683, June 1970.

8. Zahedi, K., and J. R. Melcher, "Electrofluidized Beds in the Filtration of Submicron Particulate," Paper No. 75-57.8, Presented at the APCA Meeting, June 1975.

9. Melcher, J. R., and K. S. Sachar, "Electrical Induction of Particulate Agglomeration," Final Report, EPA Contract No. 68-002-0018, Task No. 7, 10 August 1971.

10. Melcher, J. R., K. S. Sachar, J. F. Hoberg, and E. B. Devitt, "Research on Systems of Charged Droplets and Electric Fields for the Removal of Sub-Micron Particulates from Industrial Gases," Progress Report, Phase 1, EPA Contract No. 68-002-0018, 1 April 1973.

11. Melcher, J. R., and K. S. Sachar, "Charged Droplet Technology for Removal of Particulates from Industrial Gases," Final Report, EPA Contract No. 68-002-0018, Task No. 8, 1 August 1971.

12. George, H. F., and G. W. Poehlein, Environ. Sci. and Tech., 8 (1), 46 (1974).

13. Nielsen, K. A., and J. C. Hill, Environ. Sci. and Tech., 8 (8), 767 (1974).

14. McCabe, W. L., and J. C. Smith, Unit Operations of Chemical Engineering, Second Edition, McGraw-Hill, New York (1967).

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-76-040	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Evaluation of Electrofluidized Bed		5. REPORT DATE February 1976 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) K. P. Ananth and L. J. Shannon		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Midwest Research Institute 425 Volker Boulevard Kansas City, Missouri 64110		10. PROGRAM ELEMENT NO. 1AB012; ROAP 21ADL-029 11. CONTRACT/GRANT NO. 68-02-1324, Task 13
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Task Final; 6/74-1/75 14. SPONSORING AGENCY CODE EPA-ORD

15. SUPPLEMENTARY NOTES

EPA project officer for this report is D. C. Drehmel, 919/549-8411, Ext 2925.

16. ABSTRACT

The report gives results of an evaluation of the concept of using electrofluidized beds for fine particle collection. A simple model was developed to describe the interaction between an aerosol stream and the bed material. Overall collection efficiency of the device was theoretically predicted from single target efficiency values based on electrostatic and inertial forces. Maximum predicted overall collection efficiencies range from 96% for a 1 micron aerosol particle to 85% for a 0.5 micron aerosol particle, with collector bodies of size 100 micron, an availability factor of 0.1, and fluidization velocities of 0.5 ft/sec. An increase in fluidization velocity or a decrease in collector number density (i.e., larger collector bodies) diminishes the overall collection efficiency for the conditions used in this investigation. The performance of the electrofluidized bed depends upon the interaction of the electrostatic forces and bed dynamics. The inherent instability of solids flow patterns in gas-fluidized beds may limit the collection efficiency that can be achieved.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Fluidizing Electrostatics Aerosols	Air Pollution Control Particulate Fine Particles Electrofluidized Beds Collection Efficiency	13B 07A, 13H 20C 07D

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 29
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)