EPA-600/2-76-164
June 1976

Environmental Protection Technology Series

EVALUATION OF REXNORD GRAVEL BED FILTER

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

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

EPA REVIEW NOTICE

This report has been reviewed by the U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policy of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

EPA-600/2-76-164
June 1976

EVALUATION OF REXNORD GRAVEL BED FILTER

by

Joseph D. McCain

Southern Research Institute
2000 Ninth Avenue South
Birmingham, Alabama 35202

Contract No. 68-02-1480
ROAP No. 21ADL-004
Program Element No. 1AB012

EPA Project Officer: Dale L. Harmon

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

ABSTRACT

This report presents the results of fractional and overall mass efficiency tests of a Rexnord, Inc., gravel bed filter system. The tests were performed on a full scale system used for controlling particulate emissions from a Portland cement plant clinker cooler. Total flue gas particulate mass concentrations and emission rates were determined at the inlet and outlet of the gravel bed system by conventional (Method 5) techniques. Inlet and outlet emission rates as a function of size were determined on a mass basis using cascade impactors for sizes from about 0.5 μm to 5 μm, and on a number basis for sizes smaller than about 1 μm using optical and diffusional methods.

The text of this report includes brief descriptions of the Portland cement process, the Rexnord gravel bed filter system, the measurement methods, inlet and outlet particle size distribution data, and fractional efficiencies.

This report was submitted in partial fulfillment of contract number 68-02-1480 to Southern Research Institute under the sponsorship of the Environmental Protection Agency. The work reported here was completed January 31, 1976.

TABLE OF CONTENTS

Contents | Page

TABLE OF CONTENTS (Cont'd.)

FIGURES (Cont'd.) Page

TABLES

TABLE OF CONTENTS (Cont'd.)

SECTION I

CONCLUSIONS

This evaluation was one of a series of studies being conducted by the Industrial Environmental Research Laboratory of the Environmental Protection Agency to identify and test novel devices which are capable of high efficiency collection of fine particulates. The test methods used may not be consistent with compliance-type methods, but were state-of-the-art techniques for measuring mass and fractional efficiency using the standard mass train and inertial, electrical, optical and diffusional techniques.

The collection efficiency of the Rexnord gravel bed filter, determined by conventional (Method 5) techniques on a source producing particulate having a mass median diameter of about 200 μm ranged from 95% to 98% during three days of testing throughout which the collector was not operating in an optimum mode. Overall efficiencies determined from cascade impactor data during a second two-day test series were found to be 99.3% and 99.7%. The system pressure drops in the first test series ranged from 11.6 to 17.6 cm w.c. while during the second test series the system pressure drop ranged from 9.6 to 14 cm w.c. Measured fractional efficiencies were about 50% at 0.04 μm, zero or negative over the size interval from about 0.08 μm to 1.0 μm, approximately zero at 1 μm, 30% at 2 μm, and about 97.5% at 5 μm. The system energy usage during the tests was approximately 1780 joules /SCM (47.7 BTU/ 1000 SCF) at a pressure drop of 11.8 cm (4.7 inches) w.c.

Most of the devices tested to date under the novel device test program have been scrubbers. For this reason it has been convenient to compare their performance to a conventional venturi scrubber. The Rexnord gravel bed, while not a scrubber, has also been compared on the same basis as shown in Figure 9. It was determined that the power consumption of the Rexnord unit was somewhat higher but not substantially different from that of a well-designed venturi scrubber giving the same particulate collection efficiency.

SECTION II

INTRODUCTION

This report presents results of tests conducted by Southern Research to determine the capability of the Rexnord gravel bed filter to collect fine particulates. The goals of the tests were to determine the overall mass efficiency and the fractional efficiency of the filter when operating under normal conditions in controlling the effluent from a Portland cement plant clinker cooler.

Figure 1 is a schematic of the basic Portland cement kiln, clinker cooler, and gravel bed systems showing the inlet and outlet sampling locations. The tests were conducted on a gravel bed filter system controlling the emissions from clinker coolers on two 500-tons/day Portland cement kilns. Both kilns were operating at full capacity during the majority of the tests. In the process a slurry of water and powdered raw materials is introduced to a kiln in which they are calcined, forming clinker which drops onto a moving bed clinker cooler. A series of fans beneath the moving bed blow cool, ambient air through it to reduce the temperature of the product. The bulk of the air from the clinker cooler is used as combustion and secondary air for the kiln. Scavenge air from the system (that air not required by the kiln) is drawn off through the gravel bed filter. Because the air to the gravel bed is scavenge air, the airflow through the filter is subject to considerable variation in both temperature and volumetric flow rate. Inlet gas temperatures ranged from 70°C (170°F) to 230°C

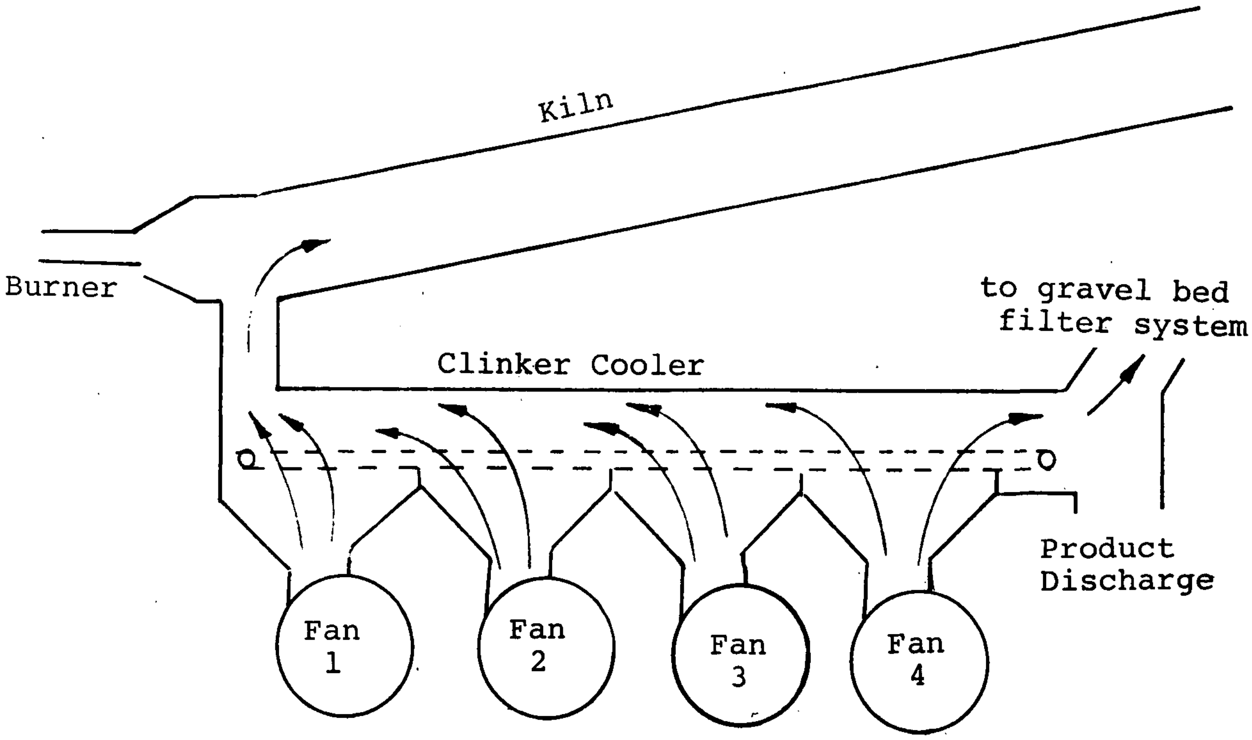


Figure 1a. Portland cement kiln and clinker cooler layout. Arrows indicate directions of air flow.

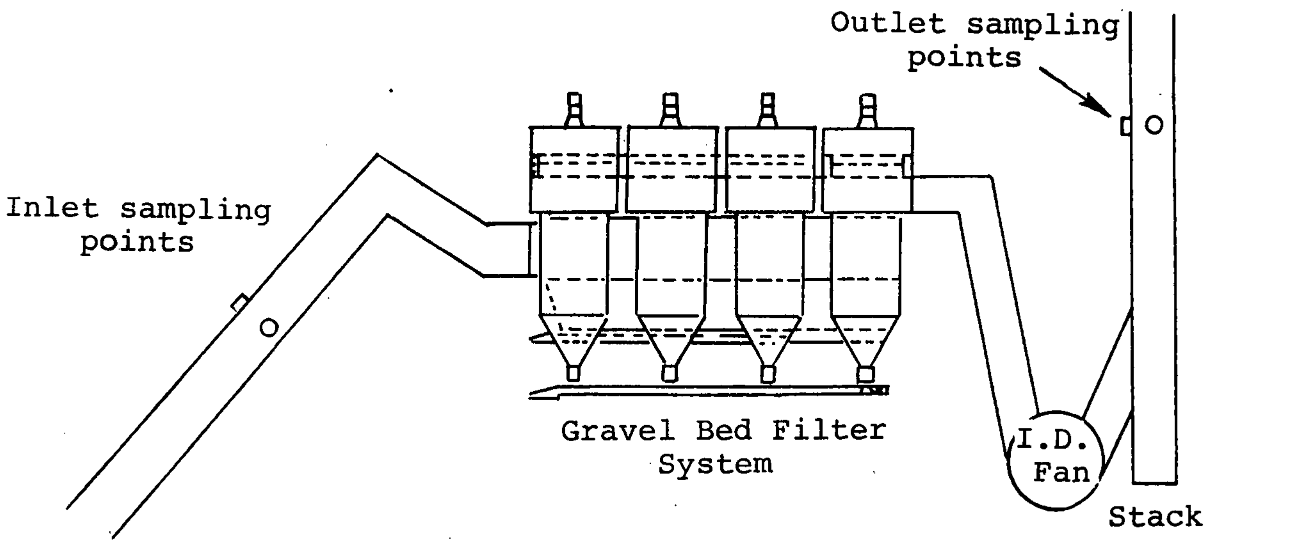


Figure 1b. Gravel bed filter system layout and sampling locations.

(450°F). Outlet temperatures ranged from 71°C (160°F) to 129°C (265°F). The temperature drop between the inlet and outlet results primarily from the addition of approximately 283 m^3/min (10,000 cfm) of ambient air which is used to periodically clean the gravel beds. During these tests, the gravel bed system pressure drop was approximately 12 cm water column (4.7 in). The system flow rate ranged from about 600 to 1000 DNM^3/min at the inlet. (The latter figures exclude the backflush air). Testing took place during the months of August and November 1975. The second series of tests were done as a result of a determination by the manufacturer that the system was not operating under optimal conditions during the August test. The results of the November tests did show substantial improvement in system performance as compared with the August data.

SECTION III

DISCUSSION

A total of five measurement techniques were used during the tests. These were: (1) diffusional techniques using condensation nuclei counters and diffusion batteries for determining concentration and size distribution on a number basis for particles having diameters less than approximately 0.2 μm, (2) optical techniques to determine concentrations and size distribution for particles having diameters between approximately 0.3 μm and 1.5 μm, (3) optical techniques for monitoring outlet concentration variations over the size range from 0.6 to 50 μm, (4) inertial techniques using cascade impactors for determining concentrations and size distributions on a mass basis for particles having diameters between approximately 0.5 μm, and 5 μm, and (5) standard mass train (Method 5) measurements for determining total inlet and outlet mass loadings.

Description of the Gravel Bed Filter System

The gravel bed filter is constructed on a modular basis, with eight modules making up the system in this instance. Each module consists of a cyclonic inlet section followed by two gravel beds operating in parallel.

At any one time, during normal operations, seven (7) of the eight (8) modules are on line in the forward flow direction with one being cleaned and renewed by backflushing with heated ambient air. In the installation tested, the modules were cleaned in sequence with a backflush time of 6 to 20 minutes. During the first 45 seconds of the backflush period, a mechanical raking system is actuated to stir up the dirty gravel. The particulate laden air from the module being backflushed is exhausted into the inlet plenum of the remaining modules. This backflush and raking operation and the frequency with which it takes place has a very pronounced influence on the collection efficiency achieved by the system as will be discussed later in this report. The tests of this unit were done under long term steady-state conditions with backwash periods of 12 and 6 minutes. In addition, limited short term tests under transient conditions were made using 6 and 20 minute backwash intervals during a period when the system was normally being operated with a 12-minute backwash interval. A more complete description of the gravel bed system, together with illustrations, are given in Appendix A. Design values for the system tested are given in Table 1.

Method 5 Results and Overall Collection Efficiencies

Because of economic considerations and limited working space, Method 5 testing was done only during the first three days of the first (August) test series.

The data obtained by Method 5 technique is summarized in Tables 2 and 3. The overall collection efficiency for each of these tests is also given in Table 3, together with the gas flow per module (at flue conditions). It would appear from these data that the collection efficiency of the system is sensitive to the gas flow per module and improved markedly with decreasing gas flow

Table 1

Design Specifications Of The System As Tested

Inlet Volume Flow: 2266 ACM/min at 204°C
(80,000 ACFM at 400°F)

Backflush Volume Flow: 317 ACM/min at 66°C
(11,200 ACFM at 150°F)

Pressure Drop: 25.3 cm w.c. (10 inches w.c.)

Gravel Size: 4 mm (5/32 inch) x No. 6 mesh

Bed Depth: 11.4 cm (4½ inch)

Bed Area: 3.72 m^2/Bed (40 ft^2/Bed)

(For a total of 59.5 m^2 of bed area with 52 m^2 actively filtering in normal operation.)

Table 2

Mass Emission Tests - Method 5

Inlet

Run #	1	2	3	4	5
Date	8-25-75	8-26-75	8-26-75	8-27-75	8-27-75
Time	1350	1015	1435	1050	1515
%, Moisture	2.33	1.65	2.60	1.54	1.80
Velocity, m/s (f/s)	10.44(34.24)	9.70(31.48)	7.42(24.35)	8.50(27.89)	7.97(26.15)
ACM/min (ACFM)	1467.3(51812)	1364.5(48140)	1043.5(36847)	1195.2(42203)	1120.6(39570)
SDCM/min (SDCFM)	937.1(33089)	1088.4(38431)	761.6(26891)	875.3(30906)	739.9(26128)
Grams/ACM (Grains/ACF)	2.039(0.891)	1.144(0.500)	1.602(0.700)	2.130(0.931)	2.078(0.908)
Grams/SDCM (Grains/SDCF)	3.192(1.395)	1.435(0.627)	2.197(0.960)	2.911(1.272)	3.146(1.375
Kg/hr. (Lbs/hr.)	179.46(395.65)	93.68(206.54)	100.37(221.27)	152.84(336.96)	139.68(307.94)

Table 3

Mass Emission Tests - Method 5

Outlet

Run #	1	2	3	4	5
Date	8-25-75	8-26-75	8-26-75	8-27-75	8-27-75
Time	1400	1015	1445	1100	1515
Velocity, m/s(f/s)	8.82(28.94)	8.76(28.73)	6.79(22.29)	7.98(26.18)	7.26(23.81)
%, Moisture	2.29	1.83	1.86	1.64	1.38
ACM/min(ACFM)	1631.7(57619)	1619.9(57201)	1256.8(44379)	1476.2(52124)	1342.5(47405)
SDCM/min(SCDFM)	1239.3(43759)	1326.4(46837)	1017.5(35927)	1174.2(41461)	1049.7(37067)
Grams/ACM(Grains/ACF)	0.094(0.041)	0.030(0.013)	0.064(0.028)	0.043(0.019)	0.034(0.015)
Grams/SDCM(Grains/SDCF)	0.121(0.053)	0.037(0.016)	0.080(0.035)	0.055(0.024)	0.043(0.019)
Kg/hr.(Lbs/hr.)	9.02(19.88)	2.91(6.42)	4.89(10.78)	3.87(8.53)	2.74(6.04)
No. of Active Modules	7	7	4	7	7
Average Flow per Active Module in ACM/min(ACFM)*	233.1(8230)	231.4(8170)	314.2(11095)	210.8(7445)	191.7(6770)
Efficiency	95.00	96.9	95.1	97.5	98.0

*Includes backflush air.

over the range of values that were obtained during this series of tests. The differences in the inlet and outlet gas flows in Tables 2 and 3 are due to the addition of the backflush air. During these tests, the backwash duration was 12 minutes.

On a service-inspection trip by Rexnord personnel subsequent to this test series, it was found that the rakes were being activated a fraction of a second to a few seconds before the backwash valves were actuated, which would tend to reduce the average collection efficiency of the device. In addition, accumulated experience with the gravel bed system in this application indicated that the beds were not being adequately cleaned with the 84 minute forward-flow/12 minutes backwash cycle, which results in a buildup of dust within the beds. This increases the energy requirements and decreases the collection efficiency of the system. Resetting the rake timers and changing the backwash intervals to provide a 42-minute forward flow/6 minute backwash cycle resulted in a substantial improvement in performance as reported by plant personnel. Consequently, a second series of tests were run during the month of November, 1975. Method 5 measurements were not made during the retests. The outlet impactor data during the second test series, indicated a reduction in the outlet particulate loading by approximately a factor of 3.5 as compared to the impactor outlet data obtained during the first test series, while inlet data from cascade impactors indicated no discernable differences in loading and size distribution between the two test series. Thus, in steady state operation under a more nearly optimum operating cycle, the overall efficiency in this application is estimated to be approximately 99.5%.

Cascade Impactor Results

Inertial sizing was accomplished using Brink and Andersen Cascade impactors for inlet measurements and Andersen Impactors only for outlet measurements. Sampling was done at near isokinetic rates. Errors due to deviations from isokinetic sampling should be of little consequence for particles having aerodynamic diameters smaller than 5 μm. Inlet sampling times of three hours produced catches of substantially less than one milligram on all stages collecting particles smaller than 3 μm with the Brink impactors. These catches were considered too low to give reliable loadings so only the Andersen inlet data was used for fractional efficiency calculations.

Cyclone precollectors were required on the inlet impactors because of the very high concentrations of +10 μm particles (approximately 98% by weight of the influent particulate was in particles larger than 10 μm). The cyclones which were available for use with the Andersen impactors in this application had particle collection characteristics such that no information on the inlet size distribution could be obtained for sizes larger than about 5 μm. Because this program was concerned primarily with fine particles, this limitation was of little consequence.

The impactor data are summarized in Figures 2 and 3. Figure 2 shows averaged inlet and outlet mass size distributions on a cumulative percentage versus aerodynamic diameter basis. Figure 3 shows the same size distributions on a cumulative mass concentration basis. The high concentrations of large particles in the gas streams coupled with the non-ideal particle separation and collection characteristics of the impactors tend to make the impactor filter catches difficult to interpret. In sampling particulate having the properties and size distribution of the type encountered here the impactor back-up filter catches can be dominated by oversize particles, a small fraction of which are not retained by the stages which should collect them. As a result, no fractional efficiencies were based on the impactor back-up filters and the size distribtuions obtained with the impactors as shown in Figures 2 and 3 are given both with and without the back-up filter catches.

The fractional efficiencies as calculated from the impactor data are given in Table 4 together with the gravel bed operating

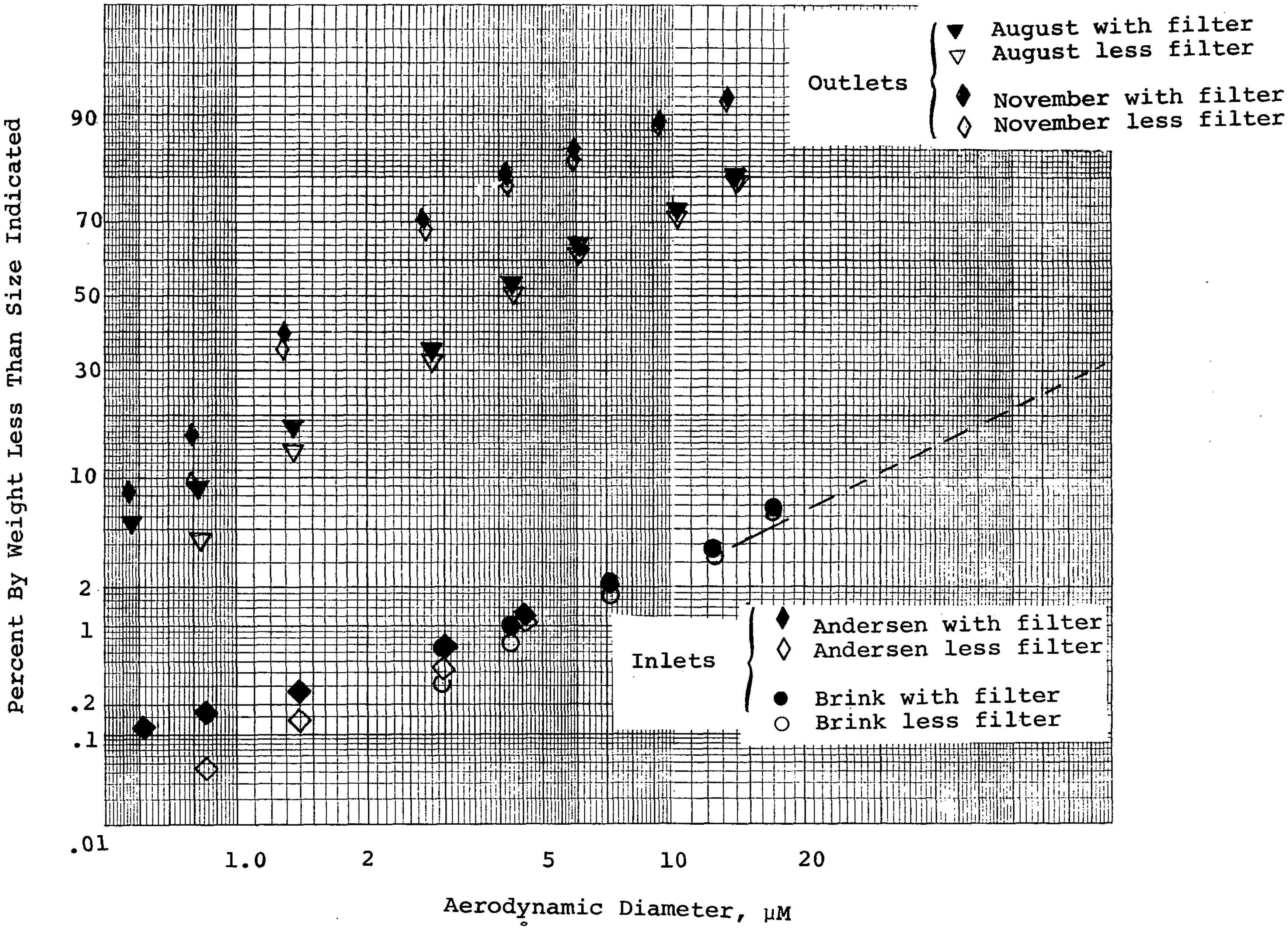


Figure 2. Inlet and outlet size distributions on a cumulative percentage by weight basis.

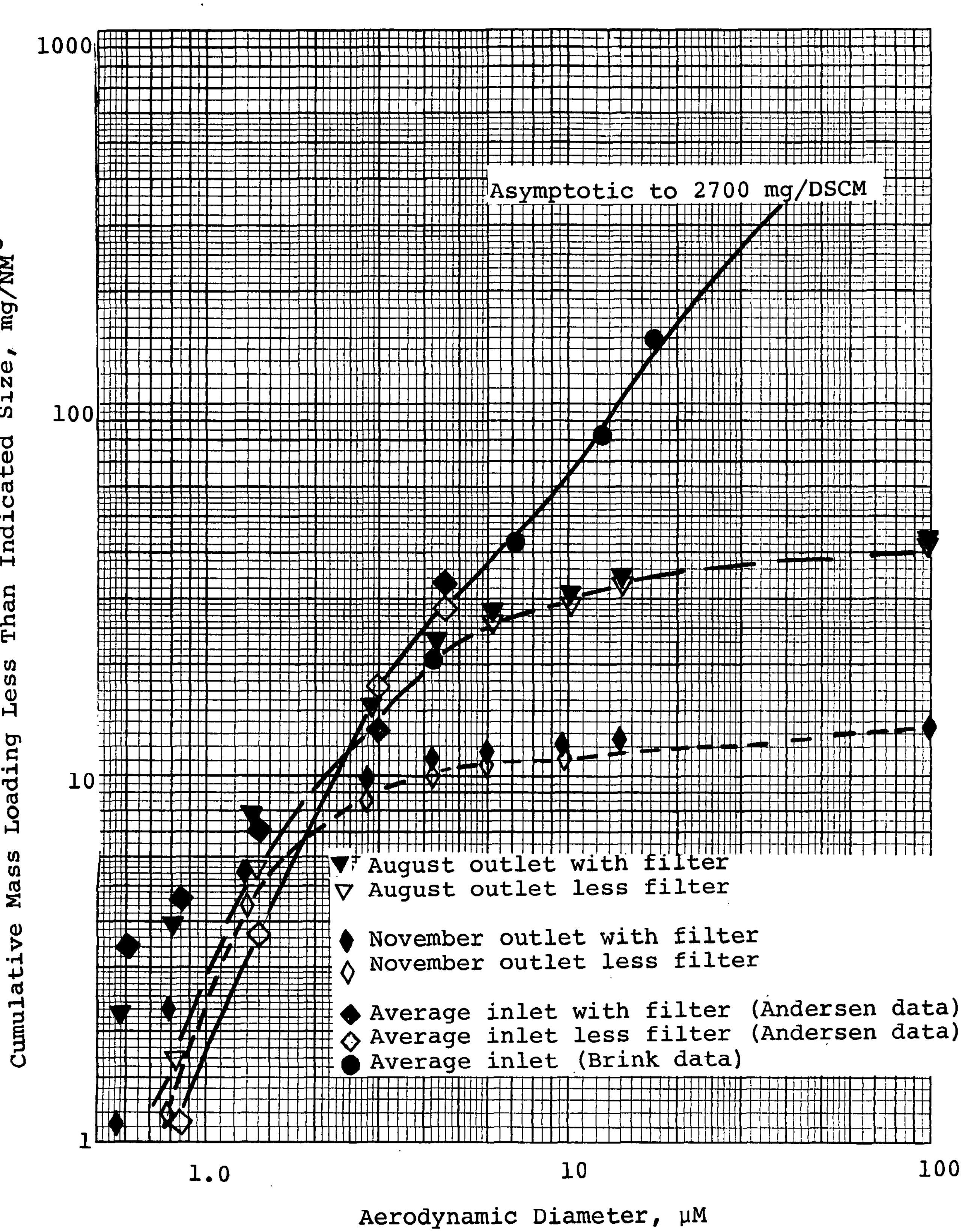


Figure 3. Inlet and outlet size distributions on a mass basis.

Table 4

Gravel Bed Filter Fractional Efficiencies As Measured With Andersen Impactors

Date	Inlet Gas Flow DSCM/min.	Inlet Temp. °C	Typical Bed Pres. Drop cm/H_2O	System Pres. Drop cm/H_2O	Backflush Period	Collection Efficiencies At Indicated Aerodynamic Diameters: .72	1.09	2.04	3.70	5.45	8.26
8/27	739	149	11.0	12.39	12 min.	-37	-68	32	60	91	97.7
8/28	917	181	13.6	17.3	12 min.	-146	-56	2	34	>71	
8/28	606	227	10.2	12.8	12 min.	4	-32	-42	19	>40	
8/29	1039	193	13.26	17.58	12 min.	13	-43	11	37	>67	
8/29	682	149	9.75	11.58	12 min.	-229	-56	25	67	>57	
11/4	732	166	6.4	9.6	6 min.	-104	-29	66	93	98.1	
11/5	856	152	9.1	14.0	6 min.	-31	0	78	94.1	96.3	

pressure loss and are shown in Figures 4 and 5. Also shown in Figures 4 and 5 are fractional efficiency curves derived from overall averages of the respective data obtained during the two test series. Because the outlet loadings appear to be decoupled from the inlet insofar as short term behavior is concerned, these overall averages may better illustrate the system performance than do the individual tests. The negative efficiencies shown for some particle sizes are discussed in a later section of the report. Data from all impactor runs including blank runs which were made to determine the possible level of any interferences on the impactor data are given in Appendix B.

The sizes reported here for the inertial data are given in two forms, "aerodynamic" and "physical", or Stokes' diameters. The "physical" diameters are based on a particle density of 2.7 g/cm^3, which was determined with a helium pycnometer from a bulk sample of the particulate. If the true particle densities are lower than this value, the sizes as given should be increased by a factor equal to the square root of ratio of the assumed density of true density. Aerodynamic diameters are diameters based on a particle density of 1 g/cm^3.

Ultrafine Particulate Data

Data on the concentration and size distribution of ultrafine particulates were determined during the first test series using diffusional sizing techniques with General Electric Condensation nuclei counters for determining the various ultrafine particulate concentrations. Attempts were made to use a Thermosystems Model 3030 Electrical Aerosol Analyzer; however, rapid random fluctuations in particulate concentrations and size distribution in this size range rendered the data from this method almost totally uninterpretable. In addition, a Gardner small particle detector (a manually operated CNC) was used throughout the tests as a crude monitor of the exit concentration and size distribution (using a variable supersaturation method) of ultrafine particles. Some inlet data were also obtained with the variable supersaturation method during the November tests. This instrument was used without

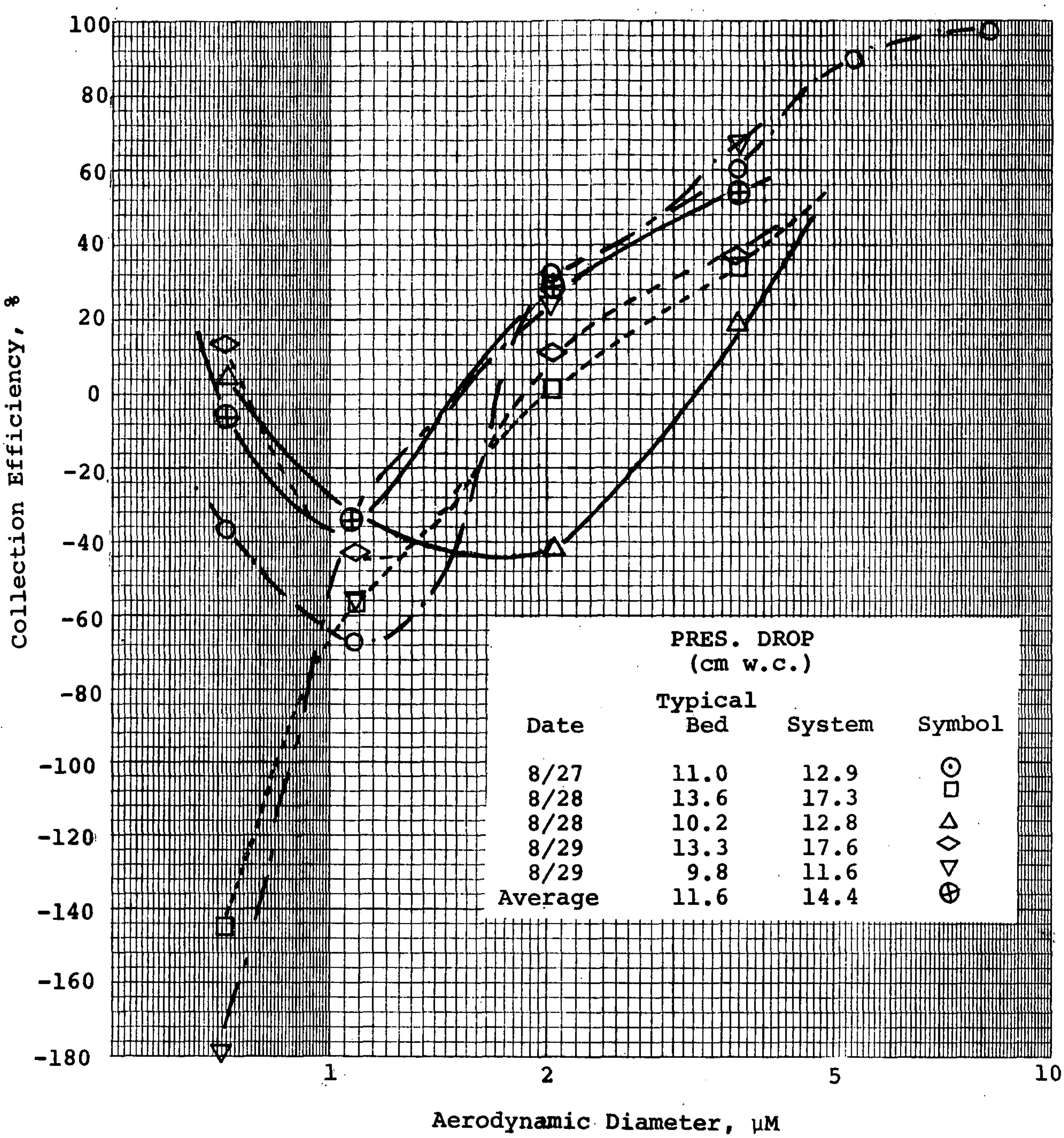


Figure 4. Fractional efficiencies as determined using Cascade impactors. August data.

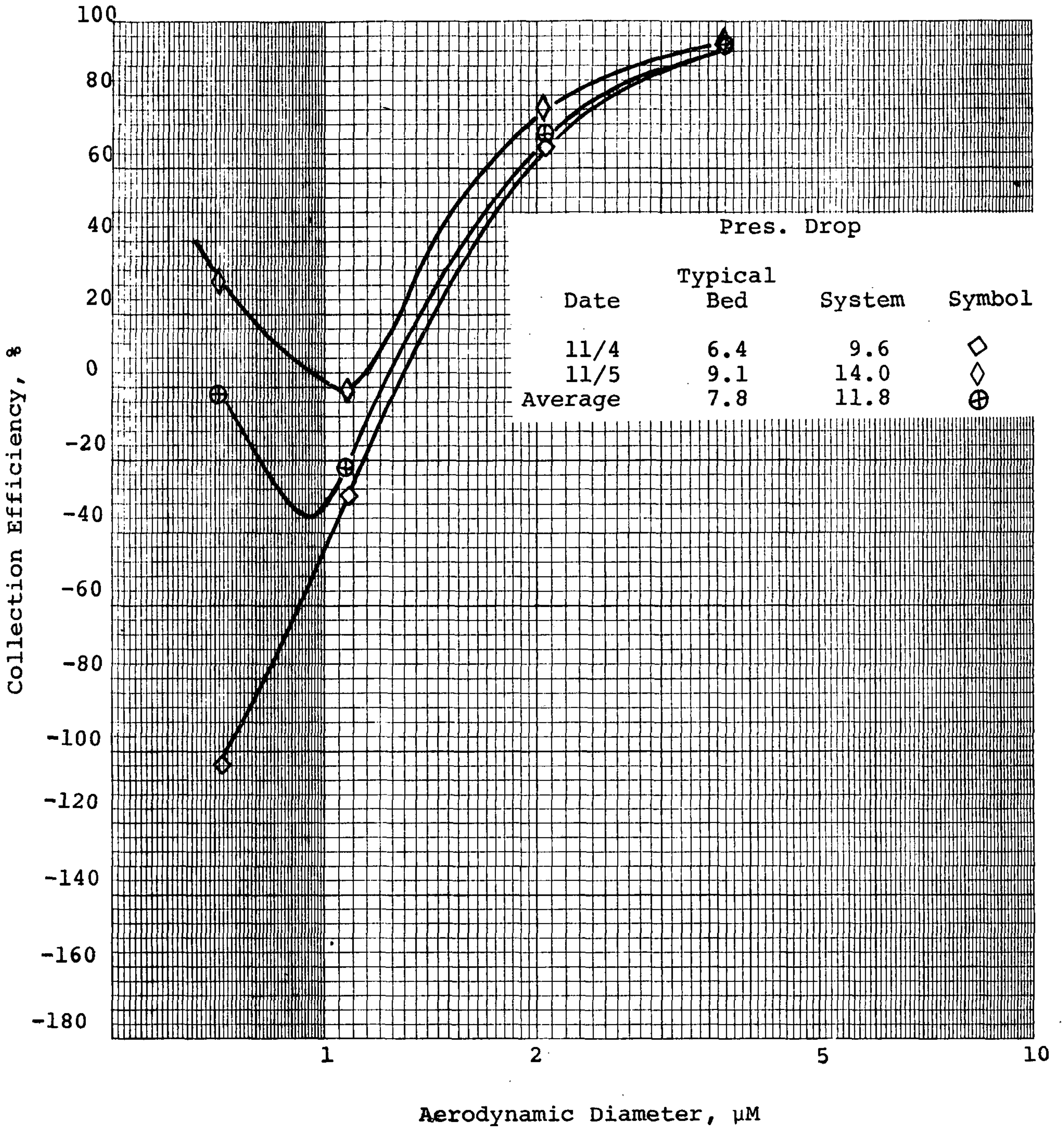


Figure 5. Fractional collection efficiencies as determined using Cascade impactors. November data.

dilution and much of the time the particulate concentration exceeded its range, however, it showed qualitative agreement with the data obtained using the more elaborate system in those instances during which they were at a common location. During the second (November) tests series, only the Gardner small particle detector was used to obtain data on ultrafine particulates.

The useful concentration ranges of the electrical aerosol analyzer and the condensation nuclei counter are such that extensive dilution of the gas streams being sampled was required in order to obtain reliable data. Dilution factors of about 50:1 were used for both inlet and outlet measurements. In order to insure that condensation effects were minimal, and that the particles were dry as measured, the diluent air was dried and filtered, and diffusional driers were utilized in the lines carrying the diluted samples to the various instruments.

Because only one set of electrical and diffusional sizing equipment was available, it was not possible to obtain simultaneous inlet and outlet data with these methods. The system was first installed at the inlet sampling location, and all the inlet data were obtained. For the purposes of calculating the efficiency of the filter, the assumption was made that the process was sufficiently repetitive that the inlet data, as obtained above, were a valid representation of that which would have been obtained during the time the outlet measurements were made.

The ultrafine particulate data were confused by the nature of the particulate source which produced large, sporadic concentration changes. Because the clinker cooler is not a combustion process, it is likely that the ultrafine particles were introduced to the flue gas for the most part via the ambient air supplied to the clinker cooler fans. The concentration and size distribution of this component of the ultrafines would be expected to be highly variable. An additional complicating factor was the ultrafine particulate brought into the system by the backwash air, which was also subject to large fluctuations in concentration. Accuracy in the measurements was limited by the rapid and frequent concentration variations and the efficiencies derived from these data are uncertain. However, the trends in the fractional efficiencies derived from the data are probably real and the fractions of the influent materials that penetrate the scrubber are believed to be generally correct to within a factor of two. The data obtained during the August test series are summarized in Table 5. The fractional efficiencies derived from the data are shown in Figure 6. Also shown on Figure 6 are fractional efficiencies obtained from simultaneous measurements with the small particle optical counter and cascade impactors. The limited comparison data obtained during the November tests are given in Table 6. The efficiency for the +0.2 μm diameter particles in the November data appears to be substantially higher than was the case in August. It is unlikely that the collection efficiency in the .02 to .2 range was increased to a value as high as 80 to 90%, however values of about 50% cannot be excluded.

Optical Particle Counter Results

Two optical particle counters (Royco Model 225) were used during these tests. The first was used in conjunction with the ultrafine measurement system to obtain data on fractional efficiencies over the size range from 0.35 μm to 2.0 μm. The second was used only at the outlet of the gravel bed for obtaining real time information on relative changes in concentration of particles over the size range from 0.6 to 50 μm.

The optical data are presented on the basis of equivalent polystyrene latex sizes and the indicated sizes can differ from the true sizes by factors as large as two to three. Data obtained using this method were primarily intended as a means of real time monitoring of process changes, but also serve as rough checks on the data obtained with the cascade impactors.

Table 5

Ultrafine Particulate Data—August Test

	Cumulative Concentration Larger Than Indicated Size					
	Diffusional Method			Variable Supersaturation Method		
	Inlet	Inlet	Outlet	Outlet	Outlet	Outlet
Date:	8/26	8/27	8/28	8/26	8/27	8/28
Dia., μm						
.01	3.5×10^6	2.3×10^6	4.2×10^6	1.3×10^6	2.5×10^6	$>2.8 \times 10^6$
.02	2.0×10^6	1.8×10^6	1.7×10^6	7.9×10^5	2×10^6	$>2.8 \times 10^6$
.063	5.5×10^5	4×10^5	9.6×10^5			
.10	2.9×10^5	2×10^5	4.4×10^5			
.20	7×10^4	3×10^4	1.4×10^5	6.9×10^4	2.1×10^5	2.2×10^5

Table 6

Ultrafine Particulate Data—November Test

	Cumulative Concentration Larger Than Indicated Size*			
	Inlet		Outlet	
Date:	11/4	11/5	11/4	11/5
Dia., μm				
.01	$>2.8 \times 10^6$	$>2.8 \times 10^6$	$>2.8 \times 10^6$	$>2.8 \times 10^6$
.02	$>2.8 \times 10^6$	$>2.8 \times 10^6$	$>2.8 \times 10^6$	$>2.8 \times 10^6$
.20	2.1×10^5	3.0×10^5	1.8×10^5	3.5×10^5

*All by variable supersaturation method.

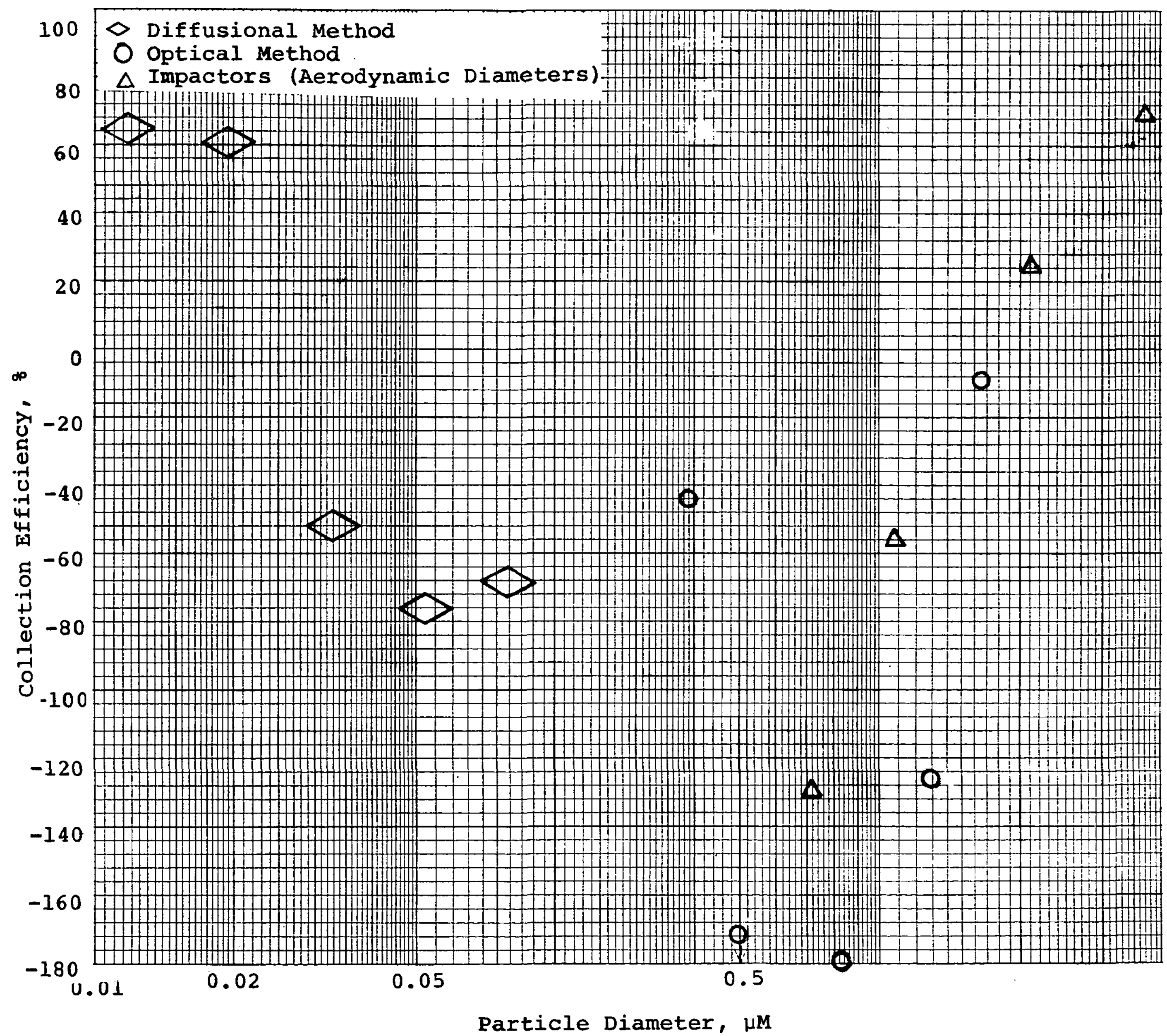


Figure 6. Fractional efficiencies as determined using diffusional, optical and inertial (Cascade impactor) methods. August data.

Inlet and outlet data with the small particle unit (0.35 to 2 μm) were obtained at the same times as were the ultrafine data. These data are thus not simultaneous sets and are subject to some of the same uncertainties as were the diffusional data. The inlet concentrations of particles in this size range was much more stable than the ultrafine concentrations, although still subject to large concentration swings, and were probably dominated by entrained particulate from the clinker cooler. Concentrations in this size range were believed to be relatively unaffected by the ambient airborne particulate. The results of the measurements are given in Table 7. Fractional efficiencies determined from the optical data were shown in Figure 6, from which it can be seen that the negative fine particle collection efficiencies which were found from the impactor data were verified by the particle counter data.

The outlet data from both the small particle (0.3 to 2 μm) and large particle (0.6 to 50 μm) systems showed pronounced effects from the backflush cycle on emission rates. Typical examples of the time variations in the outlet particulate concentrations are shown in Figure 7, which represents an approximate 30-minute data segment obtained with the continuous monitoring large particle system during the August tests. A large "puff" followed by a slow decline in concentration occurs each time a clean module is put back on line (once every 12 minutes in this case). During the August test series, this 12-minute interval was varied for two special one-hour duration tests (one with 6-minute intervals, the other at 20 minute intervals) in order to allow some estimate to be made of the sensitivity of the gravel bed system to changes in operating conditions. The results of these tests are given in Table 8.

It appears from the data shown in Table 8 that the effects on emissions resulting from changing the insertion intervals were small and only slightly size dependent, at least during these brief tests. Because of the brevity of these special condition

Table 7

Summary of Small Particle Optical Data

	Concentration In Size Range (number/cc)			
	Inlet		Outlet	
Date: Averaging Time Dia. Range, μm*	8/26 (2.5 hrs)	8/27 (6 hrs)	8/28 (0.75 hrs)	8/29 (5 hrs)
.35-.43	$5.0x10^2$	$7.46x10^2$	$14.3x10^2$	$9.0x10^2$
.43-.58	$3.4x10^2$	$4.7x10^2$	$14.0x10^2$	$13.0x10^2$
.58-1.2	$2.4x10^2$	$3.1x10^2$	$9.6x10^2$	$7.9x10^2$
1.2-1.4	$1.4x10^2$	$1.8x10^2$	$5.2x10^2$	$3.6x10^2$
1.4-2.0	$3.1x10^2$	$4.1x10^2$	$6.0x10^2$	$3.9x10^2$

*Polystyrene equivalent diameter

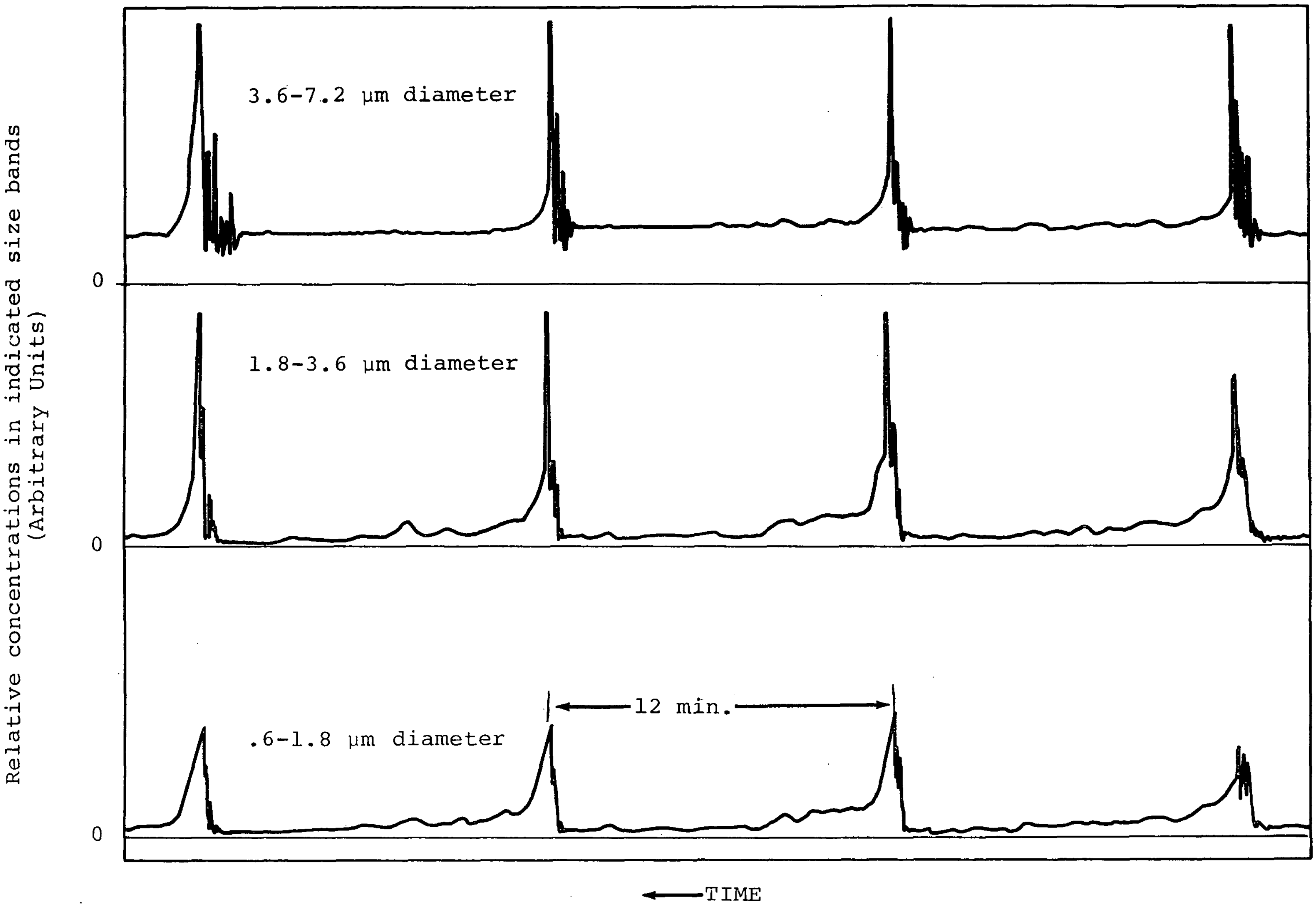


Figure 7. Temporal variations of particulate concentrations in three size bands at the outlet of the gravel bed filter system. Concentration units are arbitrary and not to the same scale for the three size bands.

Table 8

Effect of Backflush Interval On Particulate Emission Rate

Clean Module Insertion Interval (Minutes)	Relative Particulate Emission Rate In Size Bands Indicated (Arbitrary Units, 1 Hr. Avg.)		
	.6-1.8 μm dia.	1.8-3.6 μm dia.	3.6-7.2 μm dia.
6	36	42.5	37
12	31	39.2	40
20	25	38.5	52

tests, the system did not have time to come to a steady state condition, thus the results obtained during the one-hour test periods do not well represent what might be obtained if sufficient time had been available for testing under steady-state conditions. However, these results do provide some indications of the system sensitivity to changes in operating conditions.

The November tests, which were made with the gravel bed system operating in a steady state conditions with a 6-minute backflush time, showed a substantial improvement in performance as evidenced by the impactor data, in contrast to the rather small performance change observed during the one hour of operation with a 6-minute backflush cycle during the August tests.

The combined particle counter and cascade impactor data suggest that a large portion of the outlet fine particle emissions result from the breaking up of agglomerated fine particles during the raking operations in the cleaning of the off-line beds. The nature of the clinker cooler process is such that a substantial portion of the particulates lofted from the clinker bed by the cooling air could be agglomerates. A limited number of tests were run in November in order to explore the hypothesis that the negative efficiencies resulted from the breakup of agglomerates. These tests were made using only the realtime large particle system for monitoring the particulate concentrations in the gravel bed effluent gas stream. During these tests, clean beds were put on line without simultaneously backflushing another bed and dirty beds were backflushed with and without raking with no clean bed being put on line.

The effects of these operations are illustrated in Figure 8 which shows strip chart recordings of the particle counter output during these tests. Events marked as "N" are the puffs normally observed when a new bed is placed in the backflush mode at which time a clean bed is simultaneously placed on line. Events marked "C" are the result of placing a clean bed on line without initiating

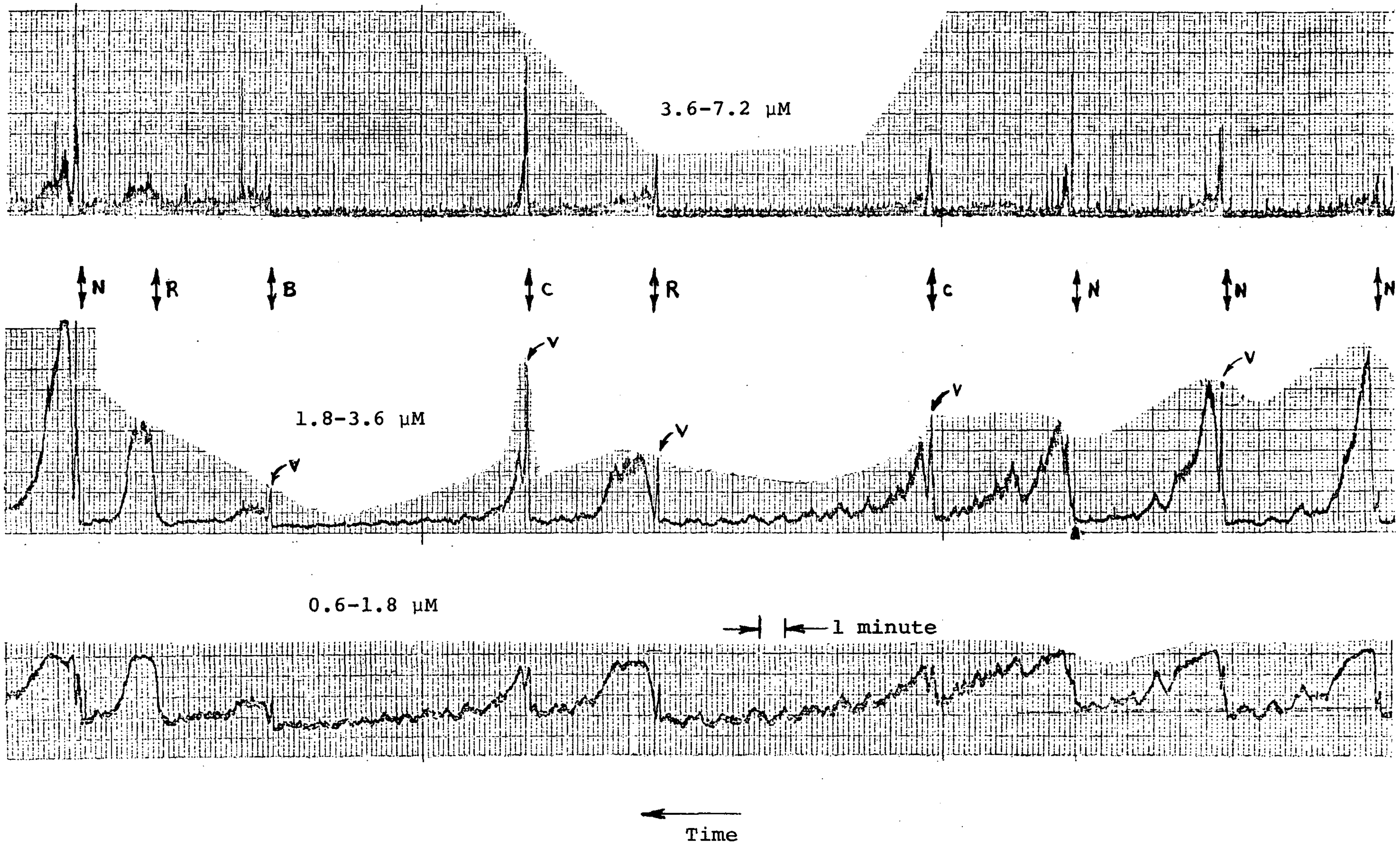


Figure 8. Relative emission rates in three particle size intervals during explorations of the effects of backwash operations on emissions. For explanation of symbols see text.

a backflush cycle on another module. Events marked "R" are the result of raking a dirty bed which is being backflushed without simultaneously placing a clean bed on line. The event marked "B" resulted from backflushing a bed without raking it and without simultaneously placing a clean bed on line.

It appears that when a clean bed is placed on line, some residual particulate which has been loosened by the backwash operation is carried out directly to the stack causing a short duration, low amplitude puff. The valving operations also appear to produce a very short duration, concentration spike designed "V" in Figure 8. The initial burst of backflush air to a bed that is entering the cleaning cycle appears to create a puff of lesser amplitude. The raking process during the backwash process produces moderate to large amplitude concentration increases which last slightly longer than the time period during which the rakes are activated. The puffs labeled "B" and "R" result from particulate that was entrained in the backwash air and passed in the normal, forward flow direction through the on line, active, modules. It was therefore concluded that the backwash and raking cycle does in fact result in a large amount of deagglomeration of the particulate which has been collected by a bed, and that in some aerodynamic size range, the emissions resulting from the portion of this reentrained material which is not recollected by the active beds exceeds the rate at which particulate in those size ranges is carried into the system from the clinker cooler. Estimates of the percentages of total emissions in several size intervals resulting from the puffs were made from the data obtained with realtime monitors. These estimates are presented in Table 9 for the August and November tests.

Estimates of the fundamental collection efficiencies of the gravel beds were made by subtraction of relative contributions due to the puffs from the cascade impactor outlet data and recalculating fractional efficiencies based on the revised data. The results of these calculations are given in Table 10, together with

Table 9

Percentage of Emissions In Puffs

		Monitor #1		Monitor #2		
Date:	Size Interval:	.35-.6	.6-1.2	.6-1.8	1.8-3.6	3.6-7.2
August	(12 min Backwash)	29	51	55	70	62
November	(6 min Backwash)	N.A.	N.A.	(29)	67	(41)

N.A.: Not Available - Monitor #1 not used during November tests.
Values in parentheses are uncertain.

Table 10

Fractional Efficiencies From August and November Data With and Without Contribution From Cleaning Cycle

Collection Efficiencies At Indicated Aerodynamic Diameters

Date	.72 μm		1.09		2.04		3.7	
	with	w/o	with	w/o	with	w/o	with	w/o
8/27	-37	42	-68	13	32.1	69	60	72
8/28	-146	-3	-56	19	2.2	56	33.8	54
8/28	4.4	71	-32	31	-42	36	19	43
8/29	13	63	-43	26	11	60	37.2	56
8/29	-229	-38	-56	19	24.5	66	67	77
11/4	-104	(-53)	-29	(33)	66.2	90	93	97
11/5	-116	(-62)	15.5	(55)	73.8	92	94.8	98

Value in parentheses uncertain.

the efficiencies calculated from the original data. These estimates indicate that the collection efficiency of the gravel bed under the conditions of these tests was low for particles smaller than about 2 μm even without the effect of the puffs.

The performance obtained with the Rexnord gravel bed filter during these tests can be compared with the expected performance figures for scrubbers using the "cut diameter" method described by Calvert (1974) J APCA, 24: 929. This method is based on the idea that the most significant single parameter to define both the difficulty of separating particles from gas and the performance of a scurbber is the particle diameter for which the collection efficiency is 0.5 (50%). Figure 9 is adapted from one presented by Calvert (op cit). It shows control device aerodynamic cut diameter graphed against power per unit flow rate (hp/1000 acfm). Also shown is the equivalent air pressure drop if all power went into moving the volume of air through a flow resistance. The lines shown are theoretical and not experimental. Lines 1a and 1b are for sieve plate-type scrubbers with froth density, F=0.4, and hole diameters, d_h=0.5 and 0.3 cm, respectively. Line 3 is for impingement plates and line 4 is for a packed column from 1 to 3 M high and packing of nominal 2.5 cm diameter. Line 2a for venturi scrubbers (f=0.25) represents the performance of venturi scrubbers in collecting hydrophobic particles while line 2b (f=0.5) represents the same class of scrubbers in collecting hydrophyllic particles. From the gravel bed operating conditions and the measured performance data as previously given, the gravel bed produced the aerodynamic cut diameters shown in Figure 9 when operating at respective power levels. The estimated cut diameters with the effects of the puffs removed are also shown in Figure 9.

The difference between the August test results and the November results is attributed primarily to the more frequent backwashing resulting in less pluggage of the beds. This results in lower operating pressure drops for the same gas flows. At the same time,

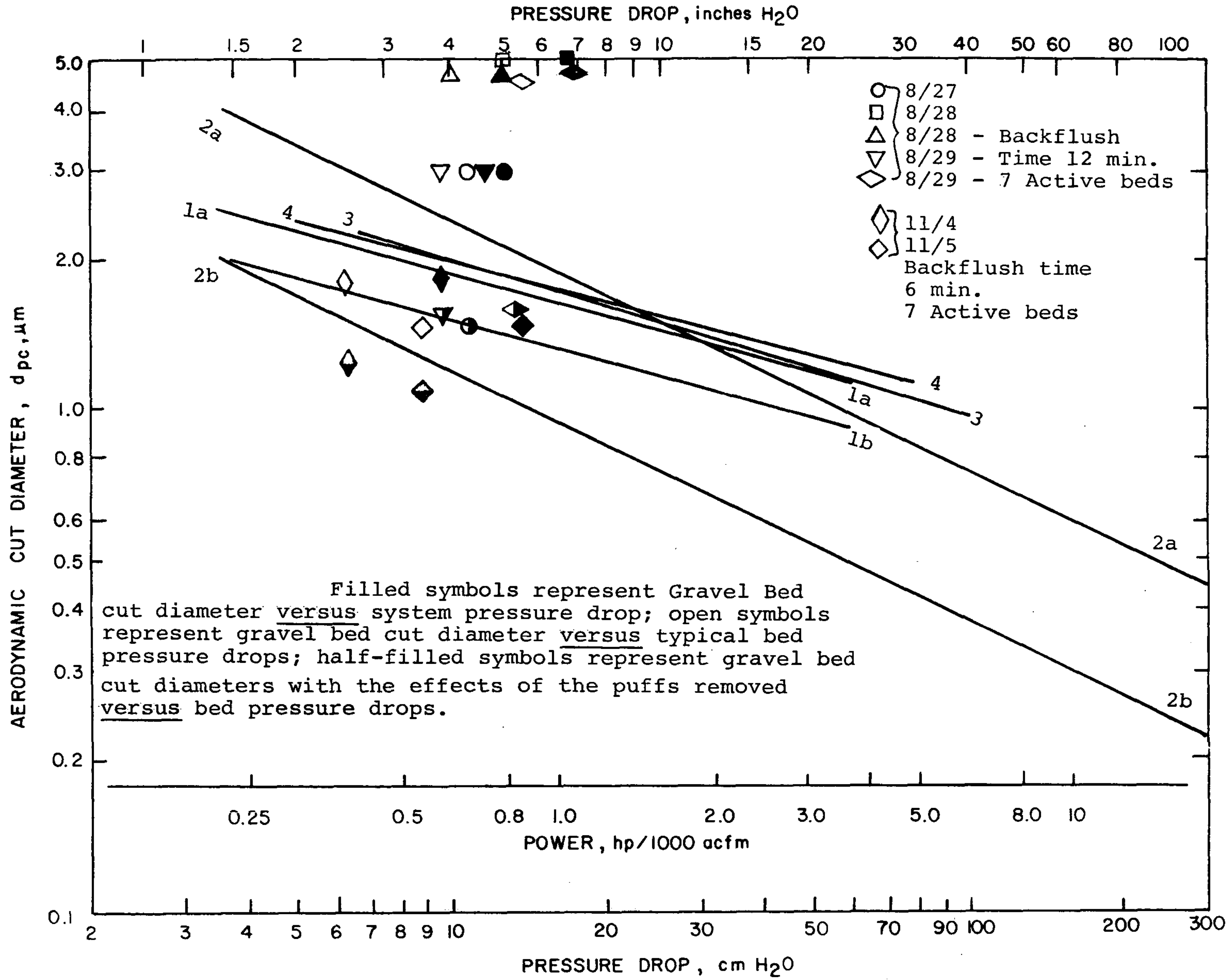


Figure 9. Representative cut diameters as a function of pressure drop for several scrubber types, after Calvert (1974), J. APCA 24:929.

as a result of the better cleaning of the beds, the residual dust concentration in the beds is reduced which in turn reduces the loading surge to the active beds when a bed is backwashed. The lower bed loadings also reduce the available dust which can be carried directly out to the stack when a bed is put back on line. It is also possible that with the beds in the highly plugged condition that existed during the August tests they may have become partially fluidized during the backwash cycle. This would enhance the deagglomeration process and perhaps result in the production of particulate from coarser particles by mechanical actions.

APPENDIX A

CASCADE IMPACTOR DATA BY RUN

Table A-1

Inlet Mass Loading By Size Interval From Andersen Impactor Data

Mass Loading In Indicated Size Interval, mg/DNM^3

Date	Start	Duration (Minutes)	Dia., µm	ρ=1.0	>4.70	3.1-4.7	1.4-3.1	.87-1.4	.63-.87	<.63*	
8/27	1320	20			3459	28.6	20.7	4.84	2.42	13.5	
8/27	1620	20			341[1]	20.9	13.8	3.59	1.00	4.99	
8/27	1730	20			313[1]	14.5	11.4	2.43	1.42	2.23	
8/27	1800	20			581[1]	25.8	14.8	3.5	1.39	2.52	
8/28	0950	45			2737	9.2	5.20	1.11	0.48	4.65	
8/28	1105	120			4252	11.1	7.82	2.66	0.52	3.84	
8/28	1440	120			2098	9.3	6.44	3.26	2.64	13.5	
8/29	1015	120			2711	12.2	7.44	2.31	2.04	6.89	
8/29	1400	120			2131	14.4	9.34	2.42	0.42	1.43	
					2896	16.22	10.77	2.90	1.37	5.94	Average 8/27-8/29
					3569	20.69	13.85	3.55	1.90	9.70	90% Upper Confidence Limit
					2223	11.74	7.69	2.25	0.84	3.09	90% Lower Confidence Limit
11/4	1100	65			2474	18.8	9.5	2.4	0.12	1.54	
11/4	1130	60			661[2]	19.3	12.2	0.51	1.03	4.60	
11/4	1430	135			1941	14.9	10.7	3.7	0.53	1.47	
11/4	1435	120			1791	12.4	8.53	2.53	0.67	1.52	
11/5	0935	120			2384	9.11	14.5	1.12	0.23	1.37	
11/5	0930	120			2453	14.6	7.51	1.32	0.03	0.69	
11/5	1415	120			4607	17.5	7.97	3.31	4.37	11.2	
11/5	1415	120			4232	19.7	10.6	4.02	3.42	14.4	
					2840	15.79	10.19	2.36	1.30	4.60	Average 11/4-11/5
					3650	18.31	11.72	3.23	2.41	1.05	90% Upper Confidence Limit
					2031	13.27	8.61	1.50	0.19	8.14	90% Lower Confidence Limit
			Dia., µm	ρ=2.7	>2.8	1.8-2.8	0.83-1.8	.48-0.83	.34-0.48	<0.34	

*Filter catches - May be dominated by oversize particles.

[1]Nozzles turned downstream to avoid overloading upper stages.

[2]Nozzle pointed wrong direction.

Table A-2

Outlet Mass Loadings By Size Interval For August Test Series

Mass Loading* In Indicated Size Interval, mg/DNM[3]

Date	Start Time	Duration	Dilution Correction Factor	Pres. Drop	Dia. ρ=1.0	>14.3	10.1-14.3	6.2-10.1	4.4-6.2	2.9-4.4	1.35-2.9	.82-1.35	.58-.82	<.58*
8/25	1440	120	1.32	16.5		2.89	2.77	2.57	2.90	4.83	4.41	2.13	0.96	1.49
8/25	1440	120	1.32	16.5		2.79	2.74	0.45	0.90	1.76	3.07	1.56	0.15	1.32
8/26	1119	84	1.22	17.0		2.39	1.57	2.19	3.55	5.97	4.21	3.36	0.94	0.21
8/26	1124	84	1.22	17.0		3.81	2.24	3.06	4.47	6.45	5.46	2.33	0.71	0.33
8/26[1]	1515	120	1.34	15.8		9.09	2.34	2.86	4.75	7.64	6.09	2.38	0.97	10.2
8/26[1]	1515	120	1.34	15.8		8.87	2.54	3.42	3.90	6.21	6.14	3.11	1.52	1.10
8/27	1100	120	1.34	15.8		12.0	3.31	3.14	4.37	7.80	7.16	3.48	1.54	0.93
8/27	1150	120	1.34	15.8		7.98	5.30	3.93	5.21	6.31	7.50	4.14	1.41	1.43
8/27	1515	120	1.42	12.9		7.40	2.83	2.89	4.02	5.56	7.43	4.36	1.77	1.54
8/27	1515	120	1.42	12.9		11.4	2.26	2.48	3.12	7.11	6.99	4.01	1.47	0.90
8/28	1045	120	1.31	17.3		7.16	2.22	2.20	3.17	6.23	5.17	2.71	1.15	1.61
8/28	1045	120	1.31	17.3		7.74	1.97	2.25	4.35	4.40	5.35	2.58	0.88	1.79
8/28	1415	120	1.47	12.8		7.72	2.14	2.60	3.25	5.26	5.57	3.00	1.92	5.73
8/28	1415	120	1.47	12.8		5.69	2.96	2.26	3.68	4.88	6.67	2.70	1.53	4.67
8/29	1000	120	1.27	17.6		10.2	2.13	3.11	4.14	5.77	5.13	2.53	1.70	3.98
8/29	1000	120	1.27	17.6		5.79	1.60	1.76	3.05	6.27	5.21	2.57	1.23	3.82
8/29	1400	120	1.41	11.6		2.69	1.51	1.17	1.15	1.55	3.93	2.30	1.28	1.27
8/29	1400	120	1.41	11.6		6.92	1.68	2.56	3.35	5.19	6.10	3.07	0.93	1.03
						8.85	3.31	3.24	4.58	7.15	7.55	3.77	1.66	2.74**
						10.71	3.87	3.73	5.23	8.13	8.43	4.34	1.95	3.76***
						6.99	2.74	2.76	3.93	6.17	6.67	3.19	1.37	1.73****
					Dia. ρ=2.7	>8.6	6.1-8.6	3.7-6.1	2.6-3.7	1.7-2.6	.78-1.7	.46-.78	.32-.46	<.32

*Because of the dilution that results from the addition of the backwash air, the results from the outlet impactors must be adjusted to compensate for the difference in inlet and outlet gas flows before comparisons among the various operating conditions can be made and before fractional collection efficiencies can be calculated. The correction factor by which the measured outlet concentrations must be multiplied in order to effect this adjustment are given for each impactor run in the table.

**Average after correcting for dilution.

***Upper 90% Confidence Limit.

****Lower 90% Confidence Limit.

Table A-3

Outlet Mass Loadings By Size Interval For November Test Series

Mass Loading* In Indicated Size Interval, mg/DNM^3

Date	Start	Duration	Dilution Correction Factor	System Pres. Drop	Dia., µm ρ=1.0	>13.9	9.8-13.9	6.0-9.8	4.2-6.0	2.8-4.2	1.3-2.8	.79-1.3	.57-.79	<.57*
11/3	1545	120	1.35	NA		0.66	0.43	0.40	0.43	8.01[2]	9.45[2]	2.56	0.96	1.15
11/3	1545	120	1.35	NA		18.4[1]	0.71	0.64	0.61	1.08	3.80	2.21	0.66	0.63
11/4	1130	240	1.39	9.6		0.23	0.13	0.19	0.18	0.64	2.63	2.58	1.02	0.57
11/4	1130	240	1.39	9.6		0.00	0.14	0.16	0.34	0.92	3.36	2.22	0.68	0.38
11/5	0945	240	1.32	14.0		0.99	0.49	0.51	0.61	1.16	3.78	2.51	0.86	0.97
11/5	0945	240	1.32	14.0		1.35	0.45	0.38	0.56	0.20	0.65	1.16	1.03	1.12
						.86	.53	0.51	.61	1.08	3.60	2.99	1.18	1.18**
						1.55	.77	0.71	.80	1.59	5.19	3.61	1.36	1.51***
						.17	.28	0.31	.43	.58	2.00	2.37	0.99	.85****
					Dia., µm ρ=2.7	>8.4	5.9-8.4	3.6-5.9	2.6-3.6	1.7-2.6	.76-1.7	.44-.76	.31-.44	<.31

* (Same as for Table A-2).

**Average after correcting for dilution.

***Upper 89% Confidence Level.

****Lower 90% Confidence Level.

[1]Nozzle scrapped port on entry

[2]Omitted from average

Table A-4

Inlet Mass Loading By Size Interval From Brink Impactor Data

Mass Loading In Indicated Size Interval, mg/DNM^3

Date	Time	Duration	Dia., ρ=1	>17.8	12.6-17.8	7.2-12.6	4.3-7.2	3.0-4.3	1.6-3.0	1.14-1.6	0.67-1.14	<.67
8/26	1010	20		2020	36.6	28.1	22.1	13.6	14.5	7.66	20.4	5.96
8/26	1700	40		2160	38.9	15.2	17.2	6.1	3.0	3.5	8.6	12.6
8/27	1045	180		963	17.7	7.7	8.2	7.0	2.6	1.2	1.0	2.83
8/27	1605	180		824	65.9	22.4	29.3	9.4	2.6	1.8	2.2	4.00
8/28	0945	180		1720	50.8	17.8	11.4	4.3	1.9	1.1	0.8	2.8
8/28	1310	180		597	48.2	12.3	14.7	3.3	1.9	1.6	1.6	6.4
8/29	1000	180		3640	49.5	84.3	22.5	6.9	2.5	2.0	2.0	6.9
8/29	1400	180		1150	116	19.2	15.4	6.1	2.6	.6	.6	11.8
				1634	53.0	25.9	17.6	7.09	4.06	2.43	4.65	6.66*
				2301	72.5	42.3	22.2	9.24	6.92	3.97	9.28	9.19**
				967	33.4	9.4	13.0	4.93	1.20	0.90	0.02	4.13***
			Dia., ρ=2.7	>10.8	7.6-10.8	4.3-7.6	2.6-4.3	1.8-2.6	.92-1.8	.65-92	.36-.65	<.36

*Average
**Upper 90% Confidence Limit
***Lower 90% Confidence Limit

Table A-5

Andersen Impactor Blank Weight Gains

	Weight Gain of Substrate, mg.							
Date	8/25	8/26	8/26	8/27	8/28	8/29	11/4	11/5
Weight Gain/ Stage								
1	-.02	.20	.32	.16	.04	.08	.33	.01
2	-.40	.18	.34	.25	.03	.10	.02	-.27
3	.04	.22	.21	.18	.01	.09	.07	.00
4	-.15	.25	.24	.32	.07	.01	-.11	-.06
5	.27	.20	.28	.21	.09	.03	.17	-.01
6	-.18	.19	.18	.18	.00	.08	.03	-.23
7	-.41	.23	.19	.12	.00	.11	.10	-.09
8	-.58	.17	.15	.21	.10	.06	.26	-.07
F	-.08	.14	.45	.13	.20	.25	.40	.29
Average	-.25	.21	.24	.20	.04	.07	.11	-.09
Std. Dev.	.21	.03	.07	.06	.04	.03	.14	.11

APPENDIX B

PLANT PRODUCTION DATA

Date	8/25	8/26	8/27	2/28	8/29	11/4	11/5
Production Tons/Day	742	533*	961	1031	1064	1063	995

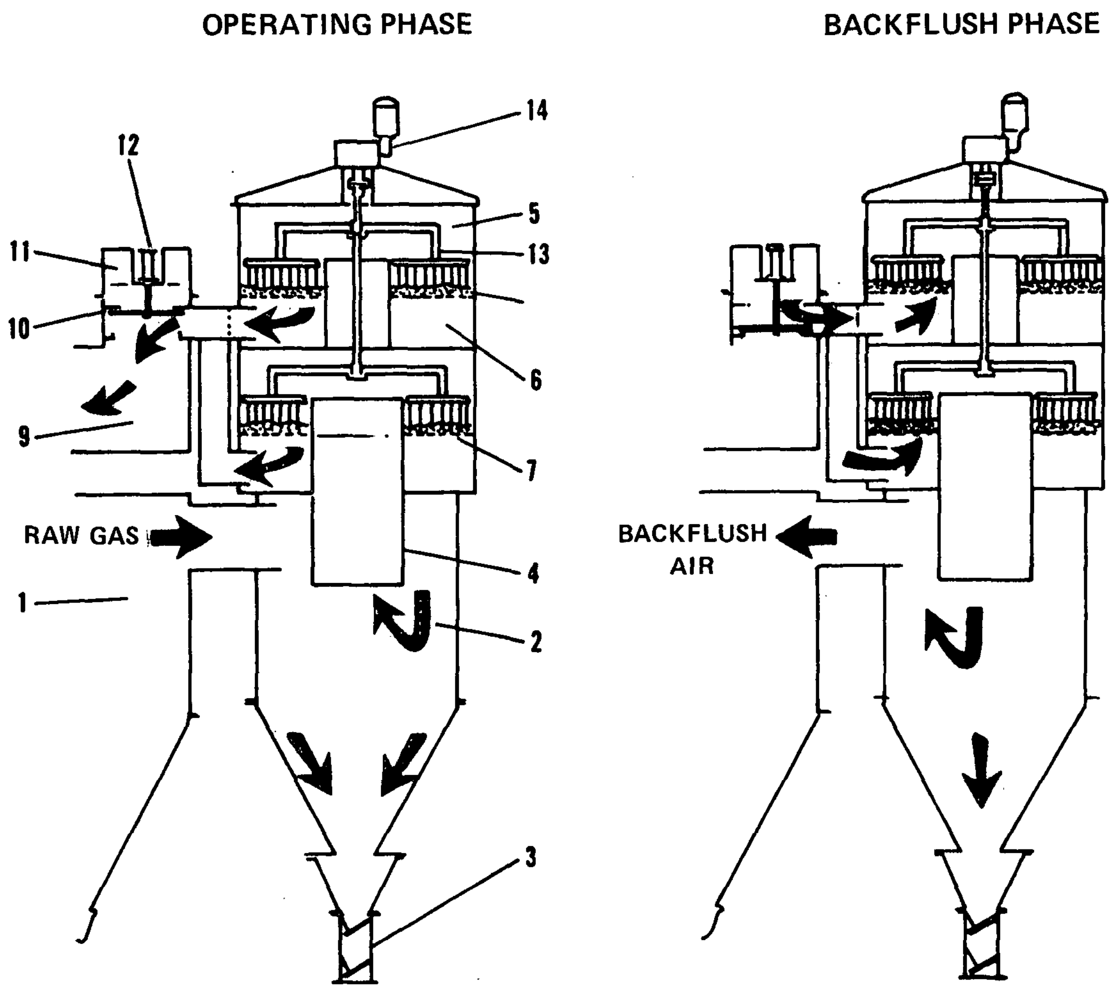
*Single kiln

Appendix C

Method of Operation of Gravel Bed Filters and Design Specifications of the System Tested

The gravel bed filter system is a system comprised of particulate filter beds used in conjunction with mechanical or other particulate separators in different configurations and combinations for the purpose of collecting dry particulates from dust-laden gas streams. The gravel bed filter system process consists basically of pre-separating large coarse particles from the dust-laden gas stream by means of mechanical collectors, although other means can be employed. The mechanical collector is usually the least expensive method for achieving this precleaning operation. The mechanical collectors can be in series with the filter beds, an integral part of each module, or they can be separate pieces of equipment connected in different arrangements by ductwork.

The multichamber cyclone-gravel bed filter combination consists of several units of equal size, connected by common raw gas and clean gas ducts. The operation of the system is illustrated in Figure C1. The raw gas is led into the filter via a parallel-connected raw gas plenum (1). An immediate separation of very coarse materials, by settling, takes place in this plenum chamber. From there, the gas enters the cyclone type preliminary separator (2), where the entrained medium and coarse dust is separated and removed via the discharge airlock (3) at the outlet. The precleaned raw gas now rises from the cyclone through the vortex tube (4) and enters the filter chambers (5). It passes from the top of the horizontal filter beds to the bottom, so that the remaining fine dust is deposited on the quartz grains and in the interstices of this bed (6). The cleaned gas now flows through the clean gas collection chamber (8), and passes via the 3-way



1. INLET CHAMBER
2. PRIMARY COLLECTOR (CYCLONE)
3. DOUBLE TIPPING GATE (DUST DISCHARGE)
4. VORTEX TUBE
5. FILTER CHAMBER
6. GRAVEL BED
7. SCREEN SUPPORT FOR BED
8. CLEAN GAS COLLECTION CHAMBER
9. EXHAUST PORT
10. BACKWASH CONTROL VALVE
11. BACKWASH AIR INLET
12. VALVE CYLINDER
13. STIRRING RAKE
14. STIRRING RAKE MOTOR/REDUCERS

Figure C1. Operation of gravel bed filter.

valve (10) into the clean gas duct (9). Cleaning of a filter unit can be initiated by means of a preset sequencer or by a pressure differential across the filter bed. During the cleaning cycle, the unit is isolated from the gas stream by the 3-way valve. Then, backwash air is admitted to the filter chamber in a reverse flow direction. It is either forced in by using a backwash air blower, or sucked in by negative pressure (11). The backwash air loosens the filter bed. During the cleaning process the rake-shaped double arm stirring device (13) is rotated by the geared motor (14). Thus the dust is thoroughly removed from the gravel and entrained by the backwash air, and the fluidized filter gravel is again settled after the cleaning operation. The large agglomerated dust particles are carried by the backwash air via the vortex tube (4) into the preseparator (2), where the velocity is reduced and the gas stream deflected so that a large percentage of the dust is settled out. The backwash air, containing the remaining dust, mixes with the dust-laden air in the raw gas duct and is then subjected to cleaning in the remaining units of the filter. The filter, as has been described, consists of the filter top section, containing the filter bed, and the upstream cyclone located underneath. The flow rate of the filter bed is, of course, important to the dimensioning of the cyclone, which generally has a smaller diameter than the filter section proper. Attainment of optimum flow rate for both filter bed and cyclone would result in a very large filter bed relative to the cyclone.

To efficiently use the space required for the overall unit, it is desirable to increase the bed area without increasing the bed diameter to a value much greater than that of the cyclone. As can be seen from Figure C2, this objective was obtained by placing two parallel-connected filter beds one on top of the other.

The cyclone-gravel bed filter combination is automatically controlled via a program transmitter. Following the signals of this continuously operating program transmitter, the clean gas port for a chamber to be cleaned is shut and the backwash air port opened. The drive of the raking device is started after a time lag. The adjustment of the duration of the cleaning process and of the intervals presents no difficulty. When the cleaning process is over, the raking device is stopped first. Then, after another time lag, the clean gas port is opened; and, at the same time, the backwash air flow is stopped so that filtering can be resumed in this chamber.

The design of the double bed filter element and its stirring (leveling) device and drive is also simple.

The rake-shaped double arm of the raking device is firmly connected to the vertically arranged geared motor via a rigid coupling. This coupling is provided with an asbestos washer serving as a thermal insulation. The bearing of the geared motor is reinforced so that the forces, which result when the rake is rotating, can be absorbed without any further intermediate bearing. The filter bed is spread on a woven supporting screen made of spring or stainless steel. Thanks to the special method applied for dust removal, this supporting screen is not subject to significant wear.

As has already been mentioned, the gases enter the cyclone at relatively low velocities, so that generally no significant wear occurs in the cylindrical section. The outlet cone of the preseparator is protected against wear by means of a ceramic lining. A weighted double-acting valve assembly (tipping valves) is arranged beneath the outlet cones, where it serves as a dust discharge device and as an air seal. In many cases, this valve assembly is mechanically actuated. All moving parts required for the cleaning process will be in operation during that period only. Normally, the duration of the cleaning phase is about three to five minutes.

Once the large dense particulates have been removed in the first pass of the raw gas through the precleaning stages of the system, the gas containing the residual fines passes through the packed solids filter beds. In this passage, the impingement of the small particulates on the discrete filter media causes an agglomeration to take place in which the fine particles are joined with other fine particles to form larger agglomerates. Periodically that particular filter is taken out of the system and back-washed by reversing a gas flow upwardly through the bed while it is being mechanically stirred by a rake. The bed is both mechanically and pneumatically disturbed and this results in a semifluidized state in which the agglomerates (which are lighter than the filter media and have a greater surface area/weight ratio) are blown backwards from the bed and are then collected in the common precleaning cyclones or recollected in the remaining gravel bed.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/2-76-164		

4. TITLE AND SUBTITLE	5. REPORT DATE / 6. PERFORMING ORGANIZATION CODE
Evaluation of Rexnord Gravel Bed Filter	5. June 1976 6.
7. AUTHOR(S)	**8. PERFORMING ORGANIZATION REPORT NO.**
Joseph D. McCain	SORI-EAS-76-299
9. PERFORMING ORGANIZATION NAME AND ADDRESS	**10. PROGRAM ELEMENT NO. / 11. CONTRACT/GRANT NO.**
Southern Research Institute 2000 Ninth Avenue South Birmingham, Alabama 35202	10. 1AB012; ROAP 21ADL-004 11. 68-02-1480
12. SPONSORING AGENCY NAME AND ADDRESS	**13. TYPE OF REPORT AND PERIOD COVERED / 14. SPONSORING AGENCY CODE**
EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711	13. Final; Through 1/31/76 14. EPA-ORD

15. SUPPLEMENTARY NOTES EPA-650/2-74-129a was earlier report in this series. IERL-RTP project officer for this report is D. L. Harmon, Mail Drop 61, 919/549-8411, Ext 2925.

16. ABSTRACT The report gives results of fractional and overall mass efficiency tests of a full-scale Rexnord gravel bed filter system used to control particulate emissions from a Portland cement plant clinker cooler. Total flue gas particulate mass concentrations and emission rates were determined at the inlet and outlet of the gravel bed system by conventional (Method 5) techniques. Inlet and outlet emission rates as a function of size were determined on a mass basis using cascade impactors for sizes from about 0.5 to 5 micrometers, and on a number basis for sizes smaller than about 1 micrometer using optical and diffusional methods. The report briefly describes the Portland cement process, the Rexnord gravel bed filter system, the measurement methods, inlet and outlet particle size distribution data, and fractional efficiencies.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Flue Gases	Air Pollution Control	13B
Filters	Measurement	Stationary Sources	14B
Dust Control	Tests	Rexnord Filter	
Portland Cement	Evaluation	Gravel Bed Filter	11B,13C
Industrial Processes		Particulate	13H
Clinker		Mass Efficiency	21B

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Unlimited	Unclassified	50
	20. SECURITY CLASS *(This page)*	**22. PRICE**
	Unclassified	