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Performance of a High Velocity Pulse-jet Filter

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Performance of a High Velocity Pulse-jet Filter

by

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ABSTRACT

Pulse-jet filtration at velocities higher than conventional will permit use of filtration equipment that is smaller and less expensive to purchase. Against these advantages must be set higher than conventional operating costs. An economic analysis of pulse-jet filtration shows that if the device is operated continuously, the filtration velocity associated with least total annualized cost is about 3 cm/s (6 cfm/ft^2). As annual operating time decreases, operating costs decrease whereas fixed cost remain the about the same. The least cost filtration velocity increases to about 10 cm/s (20 cfm/ft^2) for a filter operated three hours per day. Although the analyses presented here depend upon the particular values for cost factors used in the economic model, the least cost trend of increased velocity with decreased operating time should stand regardless of the values used. The cost factors used in this study are listed; other values can be used if appropriate.

As filtration velocity increases, penetration increases as well. Experiments reported here have determined that essentially all penetration through a pulse-jet filter is due to seepage, and that almost no particles penetrate straight through without stopping. At the end of a cleaning pulse, the fabric bag returns to and hits the cage which supports it during normal filtration. This collision causes particles to be loosened from the fabric surface, and subsequent filtration air flushes them into the cleaned air stream. Particles which seep through in this way are responsible for the dust "puff" seen in the cleaned gas stream immediately after each pulse. As filtration velocity increases, seepage increases because the higher filtration velocity drives the bags back to their cages more forcefully. In addition, higher velocities cause more dust redeposition on the fabric bags and this leads to a thicker dust deposit and higher pressure drop. High pressure drop also drives the bags back onto their cages more forcefully.

One way to reduce penetration through a pulse-jet filter is to reduce the impact with which the bags hit their cages at the end of a cleaning pulse. To accomplish this, modified cleaning pulses were developed and tested. Results of this program are described here. The modified pulses produce a gradual reduction in pulse pressure at the end of the cleaning pulse permitting a pulsed bag to return to its cage more slowly and gently than with a normal, square wave cleaning pulse which ends abruptly. Pulses

modified in this way were especially effective at reducing penetration at high filtration velocities. For example, at a velocity of 15 cm/s (30 cfm/ft^2), penetration was reduced by 46%. Because modified pulses allow the bags to return to their cages more gently, and reduce the severity of bag to cage impact, bag life may be increased. Pressure drop was unaffected by pulse modification. Compressed air use increased 27% but other pulse patterns will be investigated that do not increase compressed air usage.

Increased relative humidity through a pulse-jet filter decreased penetration as has been found for woven fabric filter bags cleaned by shaking. However, increased humidity increased pressure drop across the pulse-jet filter, unlike the situation for the woven bag filters and unlike the situation for small scale bench tests using new, uncleaned felts. Increased humidity should increase interparticle bond strengths and thereby keep particles more tightly attached to the fabric substrate, reducing seepage. Increased bond strengths may make the dust deposit more difficult to clean from the fabric surface, thereby increasing dust deposit thickness and pressure drop.

This work was performed under grant R 801399 by the President and Fellows of Harvard College under sponsorship of the U.S. Environmental Protection Agency. This report covers the period from August 1, 1976 through December 31, 1977.

ACKNOWLEDGEMENT

Buffalo Forge Co., Buffalo, NY kindly donated the Venturis, bags, bag support cages, and pulse valves used in this project. Their contribution is gratefully acknowledged.

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FIGURES

TABLES

LIST OF SYMBOLS

A_p -- surface area of particles

c -- inlet mass dust concentration

D -- diameter of a bag, cm

F -- fraction of a cleaning cycle during which dusty air was swept from the filter housing by clean air, and vice versa

F_1 -- fraction of installed cost charged annually to depreciation

F_2 -- fraction of installed cost charged annually to maintenance and repair, except bag replacement

H -- hours per year the filter operates

k -- constant in Equation 4-3

K -- constant in Equation 4-3

K_1 -- constant in Equation 4-4

M_b -- mechanical efficiency of blower

M_c -- mechanical efficiency of air compressor

M_m -- mechanical efficiency of electrical motor

M_{off} -- fraction of total downstream sample mass which should be collected while no dust was fed to the filter

M'_{off} -- fraction of total downstream sample mass actually collected while no dust was fed to the filter

M_{on} -- fraction of total downstream sample mass which should be collected while dust was fed to the filter

M'_{on} -- fraction of total downstream sample mass actually collected while dust was fed to the filter

N -- number of bags installed

N_{se} -- outlet mass flux accountable to seepage penetration

N_{st} -- outlet mass flux accountable to straight through penetration

N_{total} -- total outlet mass flux

P -- pulse pressure measured at header, atmospheres

Q -- volume of air released by a cleaning pulse, m^3 (Section 4), volumetric gas flowrate through the filter (Section 5)

t -- time between cleaning pulses to a bag (Section 4), time necessary to replace dusty gas in filter housing with clean gas and vice versa (Section 5)

TAC -- total annualized cost, $/$m^3$/hr/year

V -- superficial filtration velocity, cm/s (Section 4), volume of ducts and filter housing (Section 5)

V_p -- volume of particles

W -- total areal density of dust cake on fabric, mg/cm^2

X -- height of a bag, cm

X_{se} -- fraction of dust penetrating the filter accountable to the seepage penetration mechanism

X_{st} -- fraction of dust penetrating the filter accountable to the straight through penetration mechanism

ΔW -- increase in areal density of dust cake between cleanings, mg/cm^2

ΔP -- pressure drop across filter bags, cm of water

ε -- dust cake porosity

μ -- gas viscosity

ρ_p -- particle density

$\$_1$ -- installed cost of filter per m^3/hr gas flow, $\$/m^3$/hr

$\$_2$ -- cost per kilowatt hour for electricity, \$/kwh

$\$_3$ -- installed cost of replacement fabric, $\$/m^2$

SECTION 1

INTRODUCTION

The work described in this report is a continuation of studies on high velocity pulse-jet filtration carried out at the Harvard Air Cleaning Laboratory over the past several years. The objective of the program has been to determine the factors which govern efficiency and pressure drop in a pulse-jet filter, then apply this knowledge to improving filter performance, particularly at high filtration velocities. As filtration velocity increases the size of a filter to process a fixed gas flowrate decreases; capital cost decreases as well.

The studies reported here are comprised of three sections. In the first section, an empirical model for pressure drop in a pulse-jet filter is presented, and the relationship between filtration velocity and total annualized cost of operating a pulse-jet filter is described. In the second section, the relationship between filtration velocity, seepage, and straight through penetration are discussed. In the third section, the effectiveness of modified cleaning pulses for seepage minimization is described. The effects of gas stream relative humidity on penetration and pressure drop are reported and discussed, and compared to humidity effects for woven fabric bags cleaned by shaking.

SECTION 2

CONCLUSIONS

A model has been developed which relates pressure drop in a pulse-jet filter to pulse pressure, the amount of dust fed to each bag between pulses, and filtration velocity. Pressure drop is much more sensitive to filtration velocity than is predicted by fundamental filtration theory, probably because high velocity aggravates filter cake redeposition.

An analysis of installed cost, bag replacement cost, compressed air use, and fan horsepower was used to determine the filtration velocity associated with lowest annualized cost. If a pulse-jet filter is operated continuously, the "conventional" filtration velocities of 3 cm/s (6 cfm/ft^2) are reasonable. However, if the filter is used occasionally, it is more economical to install a smaller unit and operate it at a higher filtration velocity. If the filter is operated 3 hours per day, a filtration velocity of about 10 cm/s (20 cfm/ft^2) is more appropriate.

Essentially all the dust that penetrates through a pulse-jet filter does so by seepage. The amount of dust that penetrates straight through without stopping is negligible by comparison. Seepage increases rapidly with increasing filtration velocity. It occurs when a pulsed bag returns to and hits its supporting cage. This accounts for the dust "puff" seen in the outlet gas stream immediately after cleaning a pulse-jet filter.

Modified cleaning pulses are effective at reducing seepage. For these pulses, pressure drops off gradually at the pulse end and allows the bag to return to its supporting cage gently. Pulse modification is especially effective at high filtration velocity, where seepage is greatest. At a filtration velocity of 15 cm/s, pulse modification was found to reduce penetration by 46%.

Increased relative humidity decreased penetration but increased pressure drop. The reason for both effects may be that humidity increases interparticle bond strengths. More tightly bound particles collected at higher relative humidities should be less likely to seep, and bring about the penetration reduction found. However, more tightly bound particles may also be more difficult to clean from the fabric, thereby allowing thicker dust deposit to build up, and cause the increased pressure drop found.

SECTION 3

RECOMMENDATIONS

Pulse-jet filters run occasionally should be designed for high velocity operation, as reductions in total annualized cost would result.

Modified cleaning pulses should be used to reduce seepage. Seepage is especially high, and modified pulses especially effective, at high filtration velocities.

Because additional pressure drop reductions would reduce operating costs, further research should be conducted to see how pressure drop in a pulse-jet filter could be reduced at high filtration velocities.

Increased dust cake redeposition is associated with both higher pressure drop in pulse-jet filters and higher penetration. Therefore, the key to successful high velocity operation may be development of means for the reduction of deposition. Additional research in this area is warranted.

SECTION 4

PRESSURE DROP AND LEAST COST FILTRATION VELOCITY

INTRODUCTION

Pulse-jet fabric filters have captured an increasing share of the industrial air filtration market and currently make up half the fabric filter sales in the United States.(1) Part of the reason for their popularity is that pulse-jet filters operate with an air to cloth ratio, or superficial filtration velocity, substantially higher than that used in a filter cleaned by other means. As a result, pulse-jet filters are more compact and may be less expensive to purchase, although the cost for compressed air used in pulse cleaning can be appreciable.

Early fabric filter studies were most concerned with pressure drop across shaker-cleaned units. Models derived to predict pressure drop across beds of particles(2-6) were adapted to describe filter behavior.(7,8) These models relate pressure loss to variables such as filtration velocity and the characteristics of the deposited dust cake. Although pressure drop in pulse-jet filters has been shown to relate to the duration of the cleaning pulse,(9) the most important operating variable affecting bag acceleration and cleaning effectiveness is pulse pressure. Fabric type, dust type, and fabric-dust interactions may also be important, but their influence has not been quantified.

In this section, the relationships between pressure drop and pulse pressure, amount of additional dust collected since last cleaning, and filtration velocity will be discussed for a filter collecting fly ash. The relationships among these variables and annualized cost will be examined and procedures for adjusting the variables to minimize cost will be described. Because this analysis describes results for a single fabric and dust, it will not apply to all collection situations. Accordingly, the trends identified may be more significant than the numerical values of pressure drop and filter cost reported.

EQUIPMENT

A three bag pulse-jet filter was designed, fabricated, and fitted with industrial* pulse-jet filter components throughout. A schematic drawing of the pilot scale unit and experimental

*Buffalo Forge Co., Buffalo, NY

arrangement of equipment is shown in Figure 4-1; characteristics of the bags used are given in Table 4-1. The test dust was electrostatically precipitated pulverized coal fly ash with count median diameter of 1.4 μm and standard geometric deviation of 2.9. A turntable dust feeder metered dust at a controlled rate to a pneumatic aspirator, which injected the test dust to the filter inlet air stream.(10,11) A Stairmand disc(12) in the gas inlet duct mixed the dust and inlet air thoroughly before it reached the filter housing. The relationship between pressure drop across the Stairmand disc and volumetric gas flowrate through the unit was determined and used to measure entering gas flow rate. Pressure drop across the filter bags and across the Stairmand disc were recorded on a strip chart.

TABLE 4-1. BAG CHARACTERISTICS

Diameter	11.4 cm
Height	244 cm
Weight	0.543 kg/m^2
Material	polyester needled felt
Fiber diameter	16 μm
Surface treatment	none
Supplier	Summit Filter Co., Summit, NJ
Permeability	15 cm/s at 1.3 cm water

RESULTS

The experimental program examined three important variables influencing pressure drop across the filter bags: (a) filtration velocity, which was increased in four steps from 5 to 12.5 cm/s; (b) pulse pressure, which was increased in five steps from 5 to 9 atmospheres; and (c) mass of dust collected since last cleaning, which was increased in six steps from 0.12 to 0.72 mg/cm^2. The mass of dust collected, or areal density of the dust deposited between pulses, ΔW, can be calculated from mass inlet dust concentration, c, filtration velocity, V, and the time between pulsations to each bag, t, as follows:

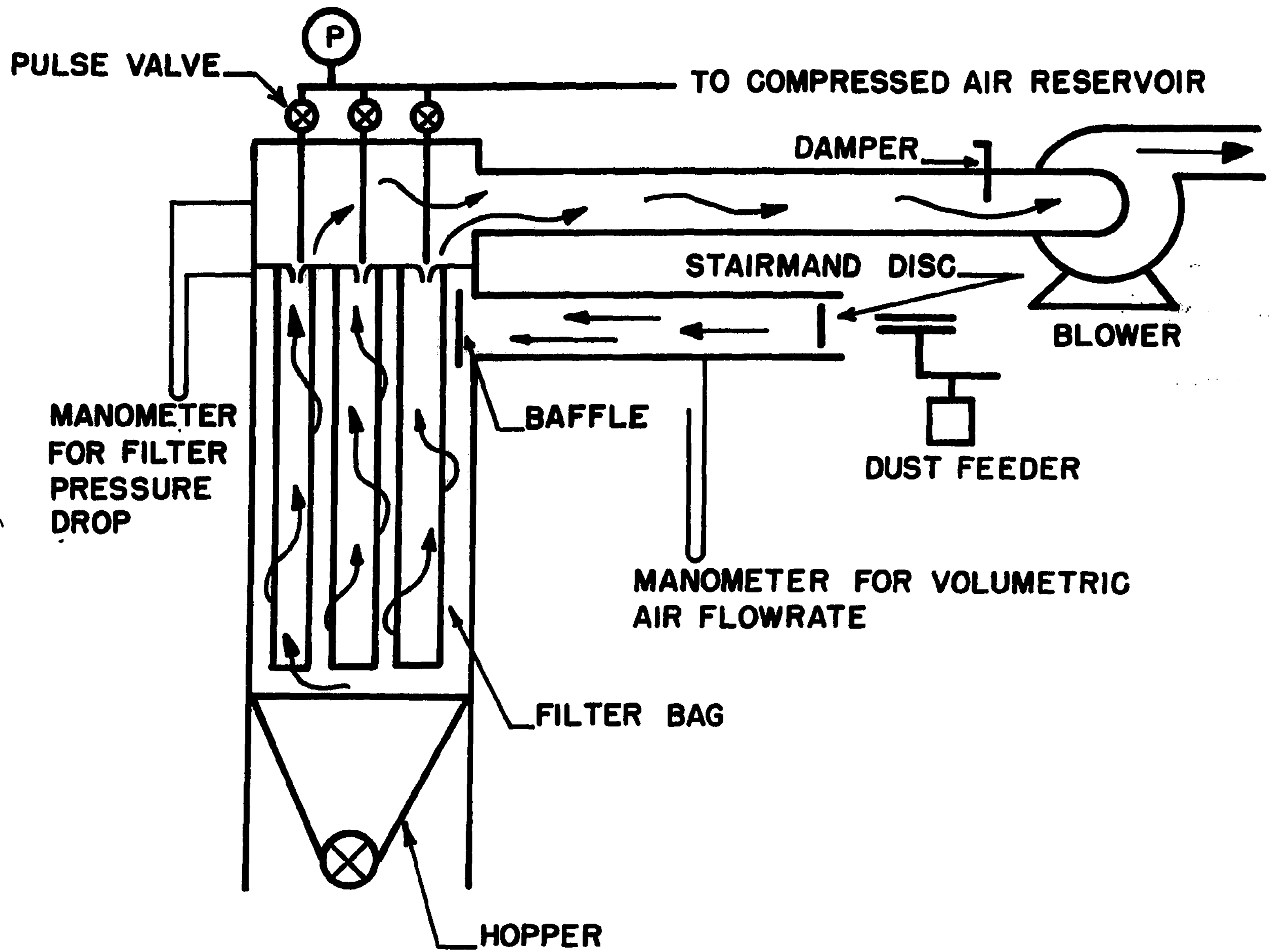

Figure 4-1. Schematic of fabric filter apparatus.

$$\Delta W = c\ V\ t \tag{4-1}$$

The experiments were run in random order. Each experiment was continued until pressure drop equilibrated with time.

Figure 4-2 is a log-log plot of pressure drop against filtration velocity; Figure 4-3 is a log-log plot of pressure drop against increase in areal density of the dust deposit; and Figure 4-4, a plot of pressure drop against pulse pressure. A power law regression equation relating pressure drop, ΔP, to increase in areal density, ΔW, pulse pressure, P, and filtration velocity, V, was generated and the constants evaluated by a least squares procedure. The resulting relationship is:

$$\Delta P = 2.72\ \Delta W^{0.45}\ P^{-1.38}\ V^{2.34} \tag{4-2}$$

Here, change in dust deposit areal density, ΔW, has the dimensions of mg/cm^2, pulse pressure, P, is in atmospheres, and filtration velocity, V, is in cm/s. The solid lines plotted in Figures 4-2 through 4-4 come from this regression equation.

A modified form of the Kozeny Carman equation (5,6) is often used to describe pressure drop across the filter cake on a woven bag cleaned by bag shaking or by reverse air (13,14).

$$\Delta P = K\ V + [k\ (\frac{A_p}{V_p})^2\ \frac{\mu(1-\varepsilon)}{\rho_p \varepsilon^3}]W\ V \tag{4-3}$$

Here, A_p and V_p are the surface area and volume of deposited particles, μ is gas viscosity, ρ_p is the density of individual particles, ε is porosity of the dust deposit, k and K are constants. All terms within the brackets in Equation 4-3 will be constant for a particular dust and temperature. The Kozeny-Carman equation should only be used for pressure drop increase within the zone of homogenous cake filtration, that is, after formation of the filter cake.

The total areal density of the dust deposit on the bags just before cleaning, W, will be the sum of the residual dust present on the fabric after the last cleaning and the increased areal density due to dust collected in the interim, ΔW. However, residual dust loading is not generally known and so the true total areal density cannot be calculated. It is customary when using Equation 4-3 to assume residual loading is negligible and that the total areal density is approximately equal to the increase in areal density caused by dust collection between cleaning pulses, that is, W equals ΔW. Because even the most rigorous change is not the dust deposit, the complete change assumption is poor.

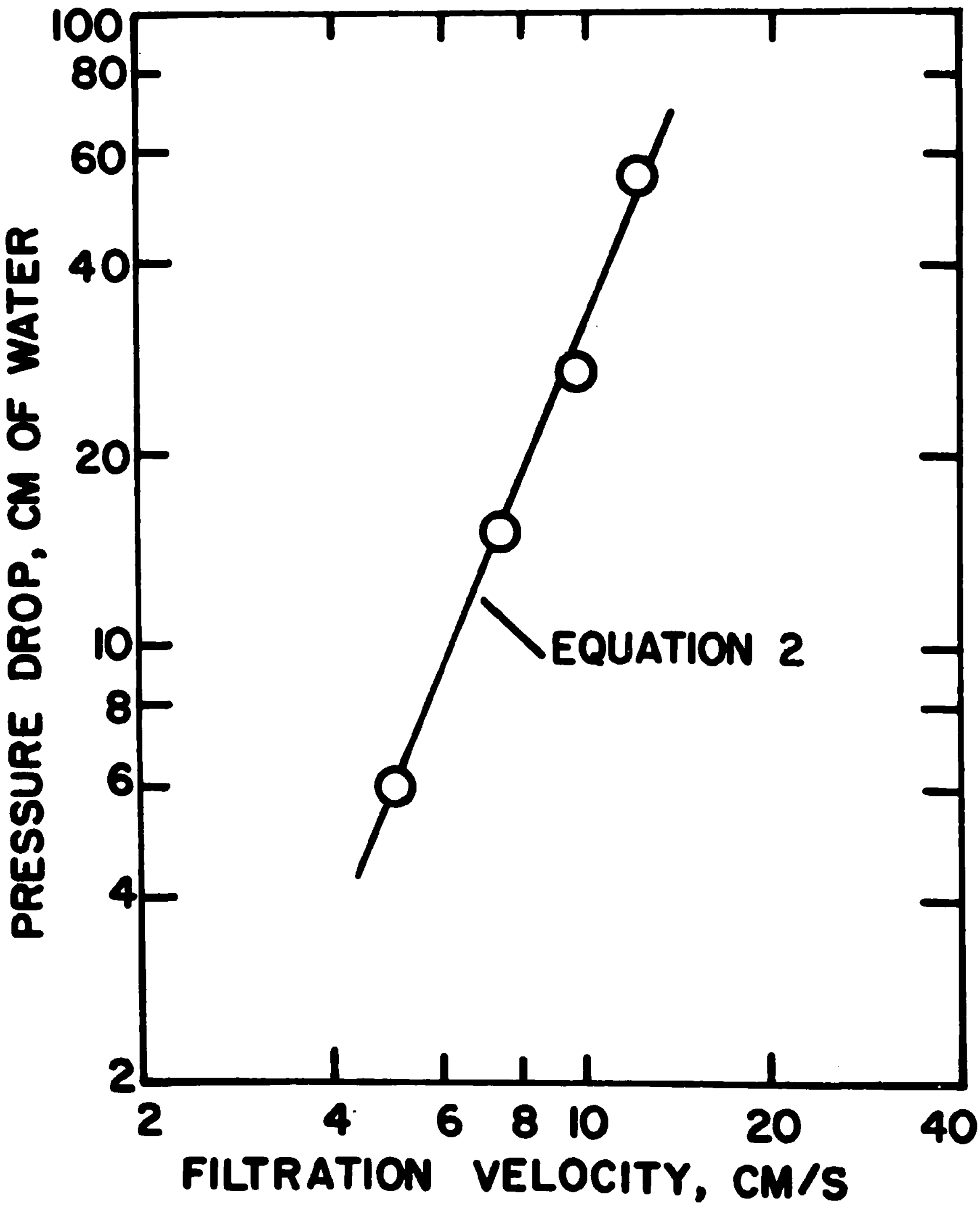

Figure 4-2. Pressure drop vs. filtration velocity.

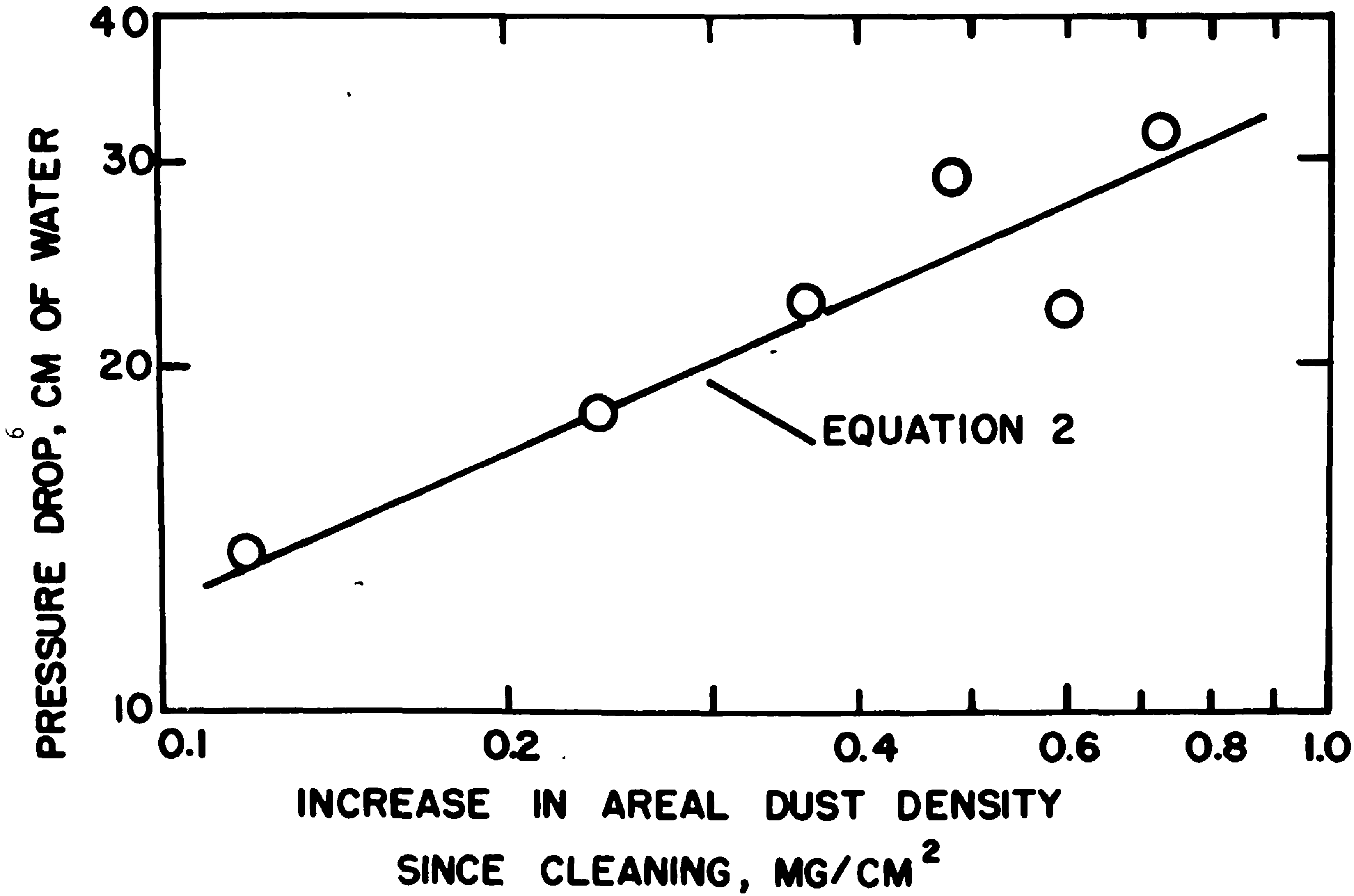

Figure 4-3. Pressure drop vs. increase in areal dust density since cleaning.

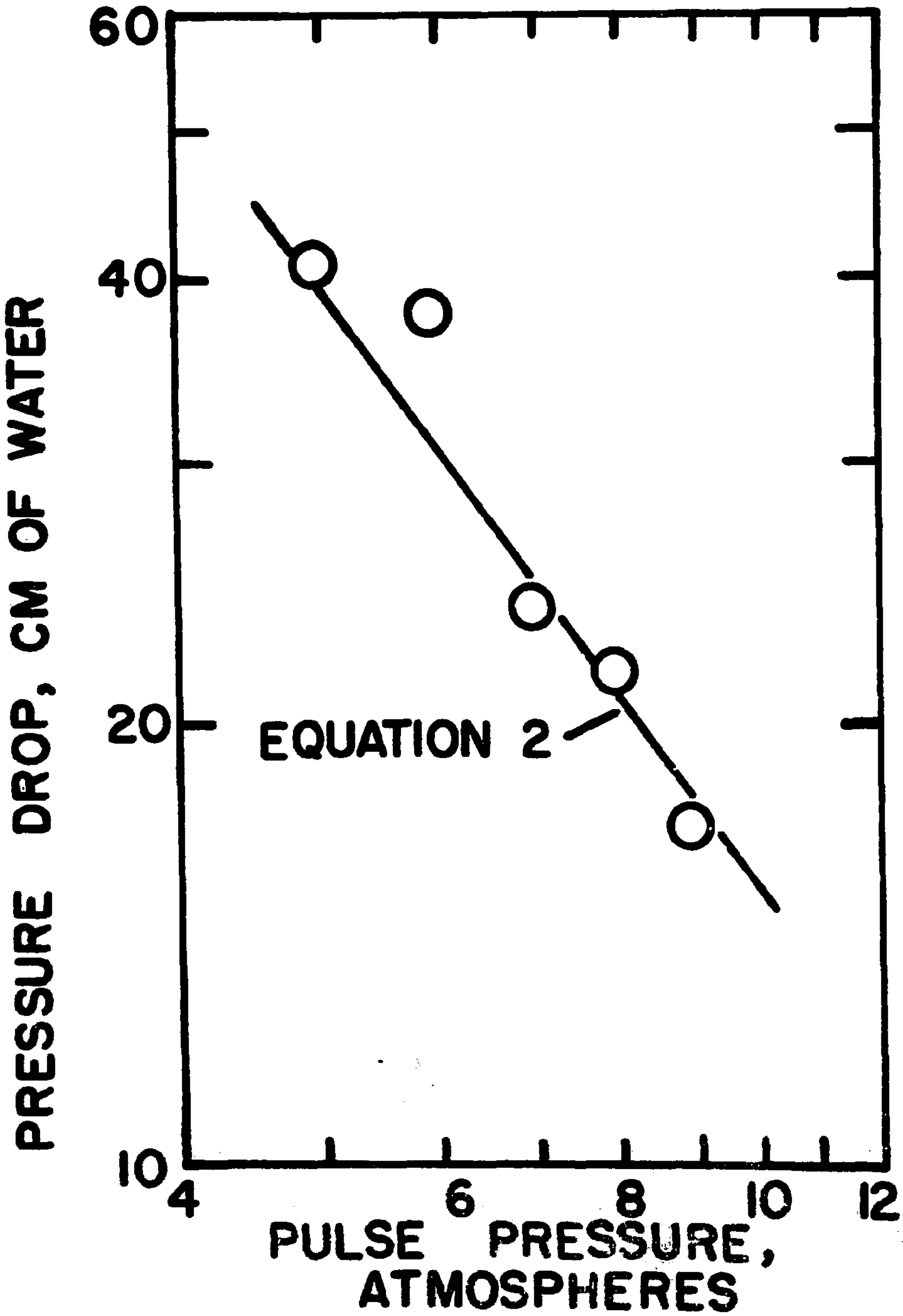

Figure 4-4. Pressure drop vs. pulse pressure.

A comparison can now be made between pressure drop in a pulse-jet cleaned filter and a shaken bag or reverse air cleaned filter. The relationship for pressure drop in the pulse-jet filter, Equation 4-2, shows that the effect of velocity on pressure drop is substantial, proportional to velocity to the 2.34 power. In contrast, the modified Kozeny-Carman relationship for shaken or reverse air cleaned bags, Equation 4-3, indicates that pressure drop is proportional to velocity to the first power although this equation may underestimate the effect of filtration velocity.(15,16) It has been shown in a pulse-jet filter that considerable dust redeposits upon the bags following each cleaning pulse rather than falls to the dust hopper.(17) Because redeposition increases with velocity, the total areal density of the dust deposit increased with velocity as well. Increased filter cake redeposition may cause the strong dependence of pressure drop on filtration velocity in the pulse-jet filter.

The equation for pressure drop in the pulse-jet filter shows a strong inverse dependence of pressure drop on pulse pressure, whereas the Kozeny-Carman equation, which implicitly assumes complete cake removal with each filtration cycle, shows no dependence of pressure drop on cleaning parameters. Increasing pulse pressure may remove the dust collected on the filter bags more effectively, push it further from the pulsed bag at the time of cleaning, and theneby help prevent redeposition of the filter cake upon the pulsed bag immediately after cleaning. Both the present study and a prior study(18) have confirmed the dependence of pressure drop on pulse pressure. In the prior study, pressure drop was found to be proportional to pulse pressure to the -2.1 power, whereas for the present study, the exponent was -1.4.

FILTER OPERATING COSTS

The empirical relationship for pressure drop in a pulse-jet filter, Equation 4-2, can be used with purchasing and operating cost information to calculate filtration velocity and other operating conditions that will result in minimum annualized cost. Values of the constants associated with the costs discussed in the following paragraphs are given in Table 4-2.

Installed Cost

The installed cost of industrial eqiupment such as fabric filters can, in general, be related to the processing rate of the equipment raised to the 0.6 power.(19) When tranposed to filtration velocity and expressed in terms of cost per cubic meter per hour of gas throughput, this relationship becomes:

$$\$/m^3/hr = \frac{K_1}{V^{0.6}} \qquad (4\text{-}4)$$

TABLE 4-2. VALUES FOR VARIABLES IN COST EQUATIONS

Installed cost(20)	$\$_1$	\$2.00/m^3/hr capacity
Electrical cost	$\$_2$	\$0.03/kwh
Fabricated bag installed cost	$\$_3$	\$20/m^2
Amortization factor	F_1	0.10
Maintenance factor	F_2	0.05
Annual operating time	H	750, 1500, 3000, 6000 hrs.
Inlet dust concentration	C	2.0 g/m^3
Bag diameter	D	11.4 cm
Bag height	X	244 cm
Mechanical efficiency of blower	M_b	0.60
Mechanical efficiency of compressor	M_c	0.90
Mechanical efficiency of motor	M_m	0.70

The constant K_1 in Equation 4-4 was evaluated using an average installed cost for a pulse-jet filter sized to process 100,000 m^3/hr of gas at a nominal filtration velocity of 5 cm/s. The installed cost per m^3/hr of capacity, $\$_1$, was found from suppliers to be \$2.00, including accessories.(20)

The annualized charge for installed filter and accessories can be estimated by adjusting the total installed cost with appropriate factors which include a component for depreciation of the filter, F_1, and a component for routine maintenance and repairs to the filter, F_2. Combining this information with Equation 4-4 yields a relationship for the annualized cost for capital equipment and routine maintenance associated with the operation of the pulse-jet filter.

$$\$/m^3/hr/yr = \$_1 \frac{(5)^{0.6}}{V} (F_1 + F_2) \qquad (4\text{-}5)$$

Component F_2 excludes the cost for bag replacement which is considered separately below.

Blower Cost

The annual cost associated with operation of the blower which moves air through the filter will be proportional to the pressure drop across the filter, ΔP, the number of hours per year the filter operates, H, and the cost per kilowatt hour for electricity to run the blower motor, $\$_2$, and will be inversely proportional to the mechanical efficiency of the blower itself and the blower motor, M_b and M_m. If pressure drop is expressed as in Equation 4-2, the annualized cost associated with blower operation becomes:

$$\$/m^3/hr/yr = \frac{7.40 \times 10^{-5}\ H\ \$_2 \Delta W^{0.45}\ P^{-1.38}\ V^{2.34}}{M_b\ M_m} \qquad (4\text{-}6)$$

Compressed Air Cost

The cost of operating the compressor used to supply air to the pulse jets will be proportional to the compressed air pressure, P, the number of hours per year the filter is operated, H, the time interval between pulses, t, the number of bags installed, N, the volume of compressed air discharged per pulse, Q, and the cost per kwh for electricity to run the compressor, $\$_2$, and will be inversely proportional to the mechanical efficiencies of the air compressor and the compressor motor, M_c and M_m.

The volume of compressed air discharged per cleaning pulse per bag was measured over a range of pulse pressures from 5 to 7 atmospheres using an electrical on-time of 75 milliseconds per pulse. Each of these valves was pulsed fifteen times and the air collected in a spirometer. Air volume per pulse was found to depend upon pressure as follows:

$$m^3 = 0.00142\ P(atm)^{0.92} \qquad (4\text{-}7)$$

The time between cleaning pulses, t, is related to dust deposit areal density, as given in Equation 1, whereas the number of bags, N, is inversely proportional to the surface area per bag and to filtration velocity.

The annual cost for supplying compressed air to the pulse-jet unit can now be expressed as:

$$\$/m^3/hr/yr = \frac{2.11 \times 10^{-6}\ P^{1.92}\ c\ H\ \$_2}{\Delta W\ D\ X\ M_c\ M_m} \qquad (4\text{-}8)$$

Here, D is the diameter of the filter bag, and X is its height.

Fabric Cost

Filter bag replacement is an important component of maintenance costs and will be considered apart from routine maintenance expressed as factor F_2 of Equation 4-5. Although much practical experience with replacement has been gained on an installation-specific basis, little work has been done to generalize these results and correlate them with process variables.

Hobson(21) presented operating data on fabric filters used to collect fly ash, and showed that bag life may decrease as filtration velocity increases. The few data available included shaker, reverse air, and one pulse-jet filter. Quantitative conclusions regarding the factors influencing bag life were difficult to draw, although wide variations in bag life were found. The installations with shortest bag life had fiberglass bags cleaned by reverse air; the longest lived bags were Teflon felt and were pulse-jet cleaned.

The life of shaker filter bags is often described in terms of the number of shakes the bags experiences before failure. The pulse-jet filter analogue would be the number or pulses before failure. If under "normal" operating conditions a pulse-jet bag is replaced after one year of continuous operation at "standard" intervals between pulses of one minute per bag, the actual annualized replacement cost can be estimated by determining the number of pulses per year the bag experiences, dividing by the pulses experienced if the bag were operated continuously, and multiplying by the bag replacement cost for one year's continuous operation.

$$\$/m^3/hr/yr = \frac{1.90 \times 10^{-7} \; H \; \$_3 \; c}{\Delta W} \qquad (4\text{-}9)$$

Here, $\$_3$ is the installed cost of replacing a square meter of fabric. This analysis assumes that filtration velocity has no influence on bag life although this may be incorrect.

Total Annualized Cost

The total annualized cost of operating a fabric filter per m^3/hr of gas processed can now be determined by adding the annualized costs associated with capital cost, with operating blower, operating the air compressor, and with replacing the bags, as given in Equations 4-5, 4-6, 4-8 and 4-9.

$$\$/m^3/hr/yr = \$_1 \frac{(5)}{V}^{0.6} (F_1 + F_2) + \frac{7.40 \times 10^{-5} \; H \; \$_2 \Delta W^{0.45} \; P^{-1.38} \; V^{2.34}}{M_b \; M_m} + \frac{2.11 \times 10^{-6} \; \$_2' \; P^{1.92} \; c \; H}{\Delta W \; D \; X \; M_c \; M_m} + \frac{1.90 \times 10^{-7} \; \$_3 \; c \; H}{\Delta W} \qquad (4\text{-}10)$$

The optimum filtration velocity for pulse-jet filter operation can be determined by differentiating Equation 4-10 with respect to velocity, V, setting the derivative equal to zero, and solving the resultant equation for filtration velocity. The result is Equation 4-11.

$$V = 22.3 \frac{(\$_1 \; (F_1 + F_2) \; M_b \; M_m)}{\$_2 \; H}^{0.33} \Delta W^{-0.15} \; P^{0.46} \qquad (4\text{-}11)$$

Equation 4-11 shows that no unique optimum filtration velocity exists; rather, the best filtration velocity will depend upon the cost parameters used, the annual operating time, and the conditions under which the filter is operated.

Figure 4-5 is a plot of optimum filtration velocity against areal dust density at cleaning, with annual operating time as parameter, as determined from Equation 4-11. The other parameters used for constructing this figure are given in Table 4-2. Figure 4-6 is a plot of pressure drop found from Equation 4-2 against areal dust density at cleaning for the operating conditions shown in Figure 4-5. Annual operating time is again the parameter.

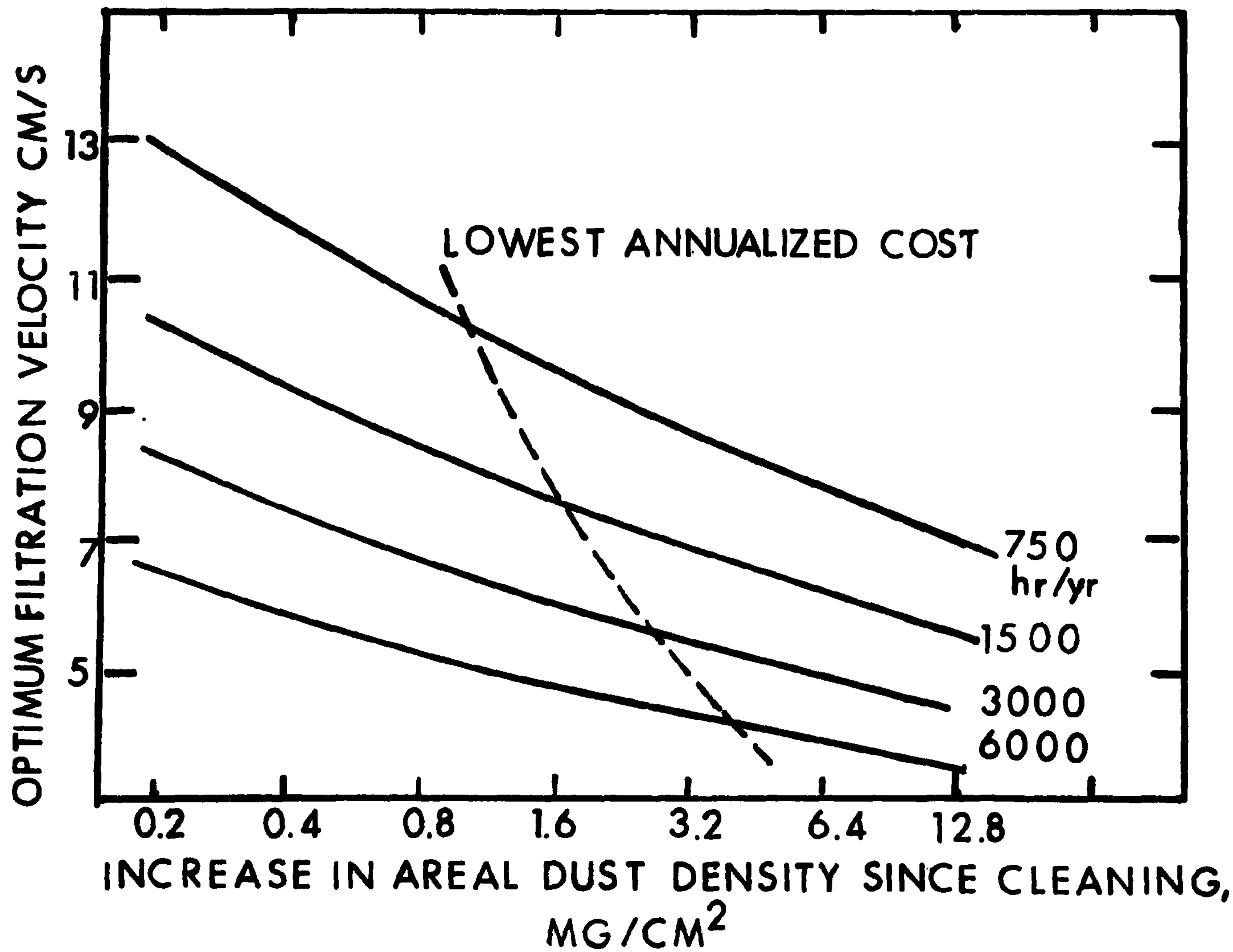

Figure 4-5. Optimum filtration velocity vs. increase in areal dust density since cleaning, annual operating time as parameter.

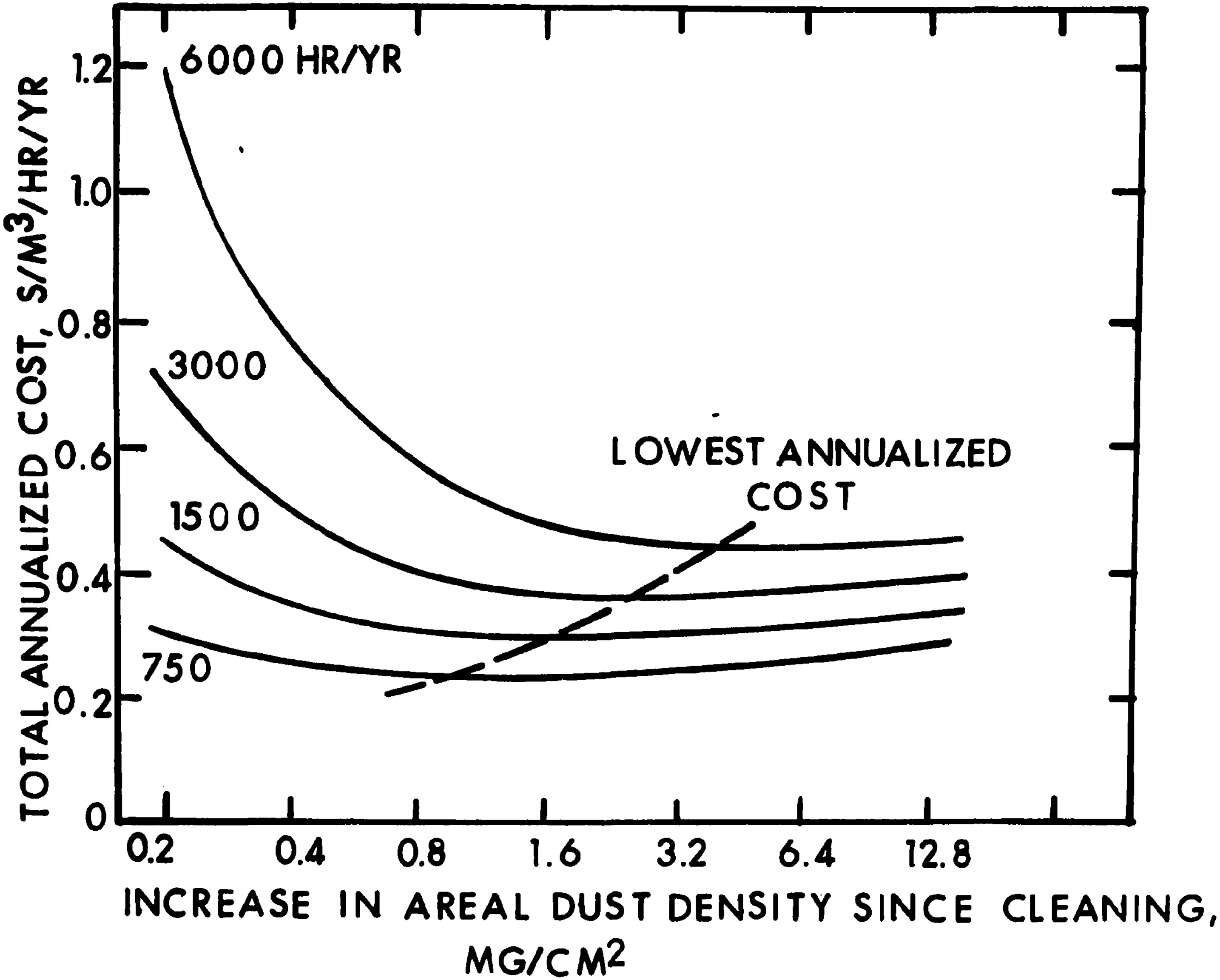

Figure 4-6. Optimum pressure drop vs. increase in areal dust density since cleaning, annual operating time as parameter.

Equation 4-10 for total annualized cost was used to predict the cost of operating a pulse-jet filter with various areal dust densities at cleaning. Pulse pressure for these calculations was fixed at 7 atmospheres. Figure 4-7 is a plot of the results for several values of annual operating time. Similar figures could be drawn for other values of the variables such as pulse pressure or electricity cost, by substituting the appropriate values for these variables in Equation 4-10.

Figure 4-7 shows that rather broad minima occur in the plots of annualized cost against areal density at cleaning. At low values of areal density the filter pulse-cleans often. Then the cost for compressed air to the filter is excessive and the fabric replacement cost is high. At high values of areal density at cleaning, compressed air use is low and fabric life is extended. However, the cost for overcoming the pressure drop through the thick dust cake is high. Also, at high values of areal dust density, the filter must be made large in order not to have excessive velocity and pressure drop through the thick filter cake. As a result, the capital cost for the unit is high.

The points at which minima occur in the total annualized cost curves from Figure 4-7 are also plotted in Figures 4-5 and 4-6 to show the filtration velocities and pressure drops associated with these least cost operating points. Figure 4-5 shows that as annual operating time decreases, the optimum filtration velocity increases. If the unit is to be used only a few hours per year, it is most economical to install a small unit, operate it at high filtration velocity, and pay the higher operating costs associated with rapid compressed air usage, rapid fabric wear, and high pressure drop across the bags. If the unit is to be operated continuously, it is more economical to build a larger unit, operate it at a lower filtration velocity, and save by reducing compressed air usage, fabric usage, and pressure drop. Because penetration increases with filtration velocity (24), a potential limit to higher velocity operation may be legal emission limits.

Although the pressure drop characteristics (and, thereby, the filtration velocity and the size) of the pulse-jet unit will vary with the characteristics of the dust to be collected, a typical filtration velocity for a fine dust such as the fly ash used in these experiments might be 5 cm/s; a typical design pressure drop might be 15 cm of water.(21-23) Pulse rate and thereby areal dust density at cleaning would then be adjusted at the plant site until pressure drop stabilized at the design pressure drop value.

If the filter were to be operated continuously, this analysis shows that the filtration velocity and pressure drop associated with minimum annualized cost are close to the values conventionally used. Often, however, the filter is not used continuously. Batch processes, processes which are used intermittently, and processes which produce dusts which need control only through part of the production cycle are situations in which

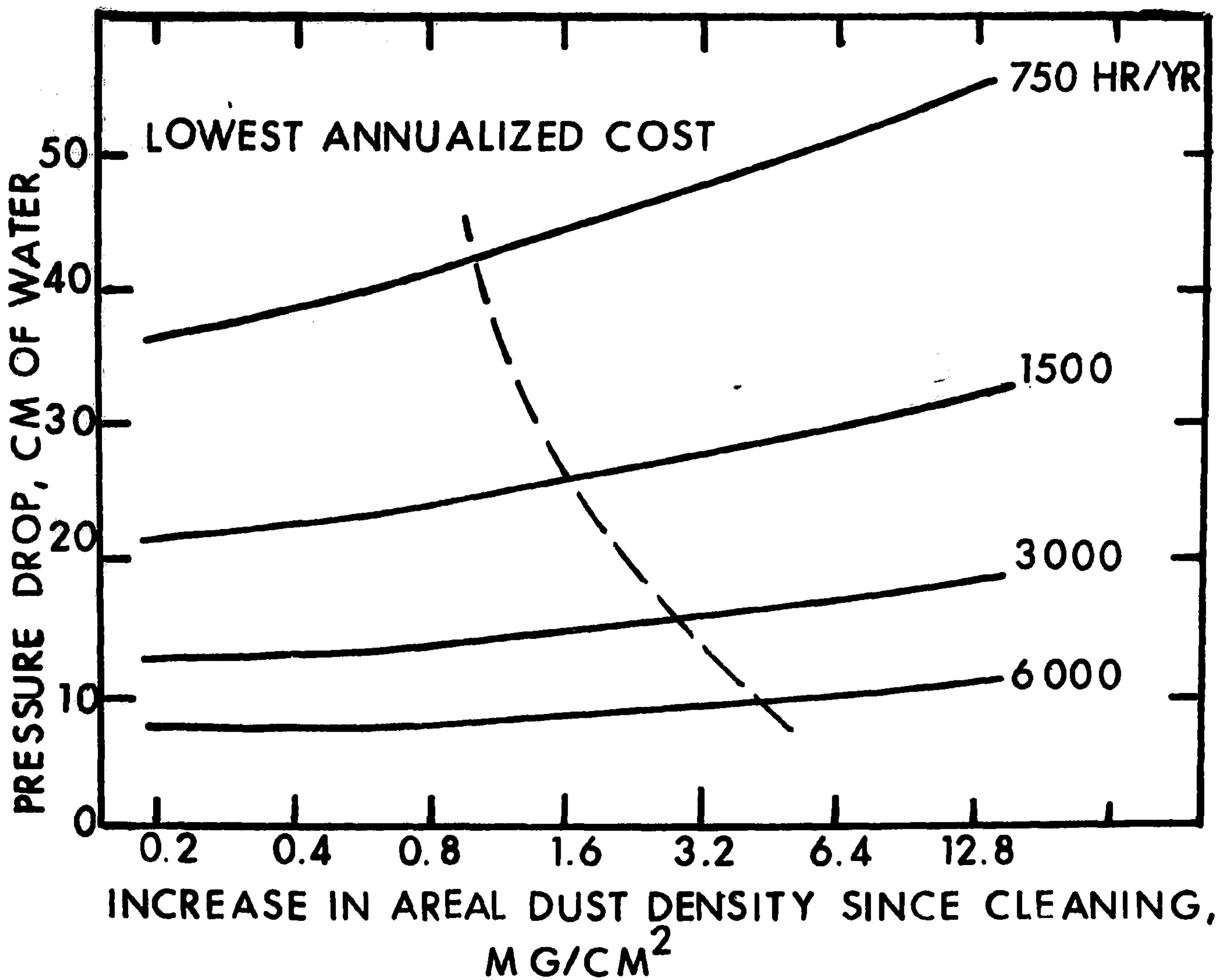

Figure 4-7. Annualized cost vs. areal dust density since cleaning, annual operating time as parameter.

the filter need not be operated all the time. Under these circumstances, savings in total annualized cost can be realized if the pulse-jet filter is designed and operated such that the filtration velocity is higher than usual. The velocity at which minimum annualized cost occurs increases rapidly as the number of hours per year decreases for which the filter is operated.

The design of an actual industrial pulse-jet filter installation will depend upon more factors than are considered here. For example, it has been shown that filtration efficiency decreases as filtration velocity increases in a pulse-jet filter.(24) This is also true for filters cleaned by shaking or reverse air.(25,26) Whether this decrease in efficiency will be significant for a filter designed to operate at a high velocity can only be evaluated on a case by case basis, although the inherent collection efficiency characteristics of a fabric filter are normally so good that some degradation in efficiency would be acceptable without exceeding emission standards.

SUMMARY

The relationship between filter pressure drop, pulse pressure, increase in areal dust density between cleanings, and filtation velocity for a pulse-jet cleaned fabric filter have been determined through an experimental program. Because only one fabric and one dust were considered, generalizations regarding the trends in pressure drop with these variables may be more appropriate than conclusions based on the magnitude of the specific measurements made. An equation is presented to describe the dependence of pressure drop on the variables considered.

The pressure drop results were used with economic factors to determine filter operating conditions that should result in lowest annualized cost of operation. As the number of hours per year decreases during which the filter is to be operated, the least cost filtration velocity increases to values several times those associated with "conventional" filter operation.

REFERENCES

1. R.E. Frey, "Types of Fabric Installations," J. Air Poll. Control Assoc., 24:1148 (1974).

2. T.H. Chilton and A.P. Colburn, "Pressure Drop in Packed Tubes," Ind. & Eng. Chem., 23:913 (1931).

3. G.M. Fair and L.P. Hatch, "Fundamental Factors Governing the Streamline Flow of Water Through Sand," J. Am. Water Works Assoc., 25:1551 (1933).

4. L.P. Hatch, "Flow Through Granular Media," J. Applied Mech., 62:A-109 (1940).

5. J. Kozeny, "Uber Kapillare Leitung des Wassers in Boden," Berichte Weiner Akademie, 136a:271 (1927).

6. P.C. Carman, Flow of Gases Through Porous Media, Academic Press, London (1956).

7. C.E. Williams, T. Hatch and L. Creenburg, "Determination of Cloth Area for Industrial Filters," Heating, Piping & Air Cond., 12:259 (1940).

8. D. Stephan, G. Walsh, and R. Herrick, "Concepts in Fabric Air Filtration," Am. Ind. Hyg. Assoc. J., 21:1 (1960).

9. R. Dennis and J. Wilder, Fabric Filter Cleaning Studies, EPA Report EPA-650/2-75-009, Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C. 20460 (1975).

10. M.W. First, L. Silverman, R. Dennis, G.A. Johnson, A.T. Rossano, Jr., R. Moschella, C.E. Billings, E. Berly, S. Friedlander and P. Drinker, Air Cleaning Studies Progress Report for Feb. 1, 1950 - Jan. 31, 1951, Atomic Energy Commission Report NYO-1581, Washington, D.C. (1952).

11. L. Silverman and C.E. Billings, "Methods of Generating Solid Aerosols," J. Air Poll. Control Assoc., 6:76 (1956).

12. C.J.Stairmand, "Sampling Gas-Borne Particles," Engineering, August 22, 1941, p. 141.

13. R.L. Lucas, "Gas-Solids Separations," in Chemical Engineers' Handbook, 5th ed., R.H. Perry and C.H. Chilton, Eds., McGraw Hill, New York (1973).

14. C. E. Billings and J. Wilder, Handbook of Fabric Filter Technology, Vol. 1, PB-200 648, National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22151 (1970).

15. R.H. Borgwardt, R.E. Harrington, and P.W. Spaite, "Filtration Characteristics of Fly Ash," J. Air Poll. Control Assoc., 18:387 (1968).

16. P.W. Spaite and G. Walsh, "Effects of Fabric Structure on Filter Performance," Am. Ind. Hyg. Assoc. J., 24:357 (1963).

17. D. Leith, M.W. First, and H. Feldman, "Performance of a Pulse-Jet Filter at High Filtration Velocity II. Filter Cake Redeposition," J. of Air Poll. Control Assoc., 27:636 (1977).

18. L. Silverman and R. Dennis, "Fabric Filter Cleaning by Intermittent Reverse Air Pulse," ASHRAE J., 4:43 (1962).

19. M.S. Peters and K.D. Timmerhaus, Plant Design and Economics for Chemical Engineers, 2nd ed., McGraw Hill, New York (1968).

20. Private Communication, Industrial Gas Cleaning Institute.

21. M. Hobson, "Review of Baghouse Systems for Boiler Plants," in Proceedings, The User and Fabric Filtration Equipment II, Specialty Conference, Air Pollution Control Association, 4400 Fifth Avenue, Pittsburgh, PA, p. 74 (1975).

22. R.R. Hall and R.W. Cass, "Mobile Fabric Filter System: Design and Preliminary Results," J. Air Poll. Control Assoc., 24:1177 (1974).

23. R. Dennis, "Collection Efficiency as a Function of Particle Size, Shape, and Density: Theory and Experience," J. Air Poll. Control Assoc., 24:1156 (1974).

24. D. Leith, S.N. Rudnick and M.W. First, High Velocity High Efficiency Aerosol Filtration, EPA Report EPA-600/2-76-020, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711 (1976).

25. J.D. McKenna, J.C. Mycock and W.O. Lipscomb, "Performance and Cost Comparisons Between Fabric Filters and Alternate Particulate Control Techniques," J. Air Poll. Control Assoc., 24: 1144 (1974).

26. P.W. Spaite and G. Walsh, "Effect of Fabric Structure on Filter Performance," Am. Ind. Hyg. Assoc. J., 24: 357 (1963).

SECTION 5

PENETRATION BY FAULT PROCESSES

INTRODUCTION

Past ideas of how fabric filters collect and retain particles are being challenged by recent data. In this section, the idea will be examined that most emissions from a fabric filter result from fault processes--dust seepage through the fabric, or bypass of part of the dusty gas stream through pinholes in the dust cake and fabric. The penetration characteristics of woven filter bags and felt bags cleaned by pulse-jet action are similar and both will be discussed. Experimental results are presented for a pulse-jet filter only. Previous studies of penetration mechanisms considered only emissions between cleaning pulses (1,2) whereas work in this section considers all emissions arising over many pulse-cleaning and filtering cycles.

Collection Characterists of Fabric Filters

Several important operating characteristics for fabric filters have been described.

Penetration vs. Velocity--

Penetration increases rapidly with increasing filtration velocity. This occurs for woven filters (3-7) and for felt filters cleaned by reverse-jet (7) or pulse-jet (1,2). Doubling face velocity has been found to increase penetration from one (7) to over four times (5).

Penetration vs. Particle Diameter--

No distinct trends emerge for efficiency as a function of particle diameter. Although differences in analytical technique for submicrometer and larger particles often make comparisons difficult, penetration may remain fairly constant (6) or even increase (1,2) for particles larger than a micrometer in diameter. This occurs for both woven and felt filters.

Penetration vs. Dust Deposit Density--

Penetration is at a maximum immediately after cleaning, but decreases rapidly and often levels off to remain constant thereafter. This behavior seems always to occur for pulse-jet cleaned felts (1,2,8), and frequently occurs for woven fabrics as well

(8,9). At times, penetration through a woven fabric decreases continuously with additional dust deposit (8,9), in so far as the particle measurement technique used can determine.

Pinholes in Dust Deposit--

Pinholes have been seen and photographed on the surfaces of dust laden fabrics, both woven (10,11) and felt (12-14). In one instance (11), the number density of pinholes observed on a woven fabric was 250/m^2. A calculation taking into account pinhole diameter and number density showed that over 8 per cent of the gas flowed through them rather than through the dust cake. For woven fabrics, there may be a velocity threshold below which no pinholes occur (15).

Penetration Mechanisms--

Dust particles can pass through a filter by a "straight through" mechanism or by "seepage". The essential characteristic of straight through penetration is that the particles pass through without being stopped. The path a particle follows in passing straight through may be the tortuous route through the filter cake and supporting fabric. This is frequently assumed to be the only way in which particles penetrate the filter. However, a model developed by Cooper and Hampl (16) shows that penetration by this means becomes unimportant soon after cleaning.

Another way dust penetrates straight through a filter is by "pinhole bypass", that is, by passing through small holes present in the filter cake and fabric (11). Pinholes may be formed during cleaning or during the filtration process (12,13). Probable sites for pinholes are the pores between yarns in a woven fabric (17), and the places where a synthetic felt was needle-punched in manufacture (14). Straight through penetration due to pinhole bypass may be especially important after a filter cake has been formed, when straight through penetration through the dust cake is improbable (2,16).

In contrast, dust initially arrested by the filter may pass through it later by the mechanism of "seepage". The essential characteristic of seepage penetration is that arrested particles move from their deposition sites and pass through the filter at some later time. Previously arrested dust seeps through the fabric as particles that become loosened by cleaning are flushed out when the filtration cycle resumes after cleaning. Another type of seepage is that caused by pinhole generation (1,2). Although pinholes through the fabric may be opened during cleaning, some may also form during filtration (13) as agglomerates of collected dust above a hole in the fabric break from the deposit and slip through. Seepage, as discussed here, includes both the "seepage" and pinhole generation" mechanisms described in a previous paper (2). Seepage may be aggravated by high pressure drop (17), by high filtration velocity (5), or by mechanical vibration of the supporting structure.

The fault processes, pinhole bypass and seepage, help to explain fabric filter performance characteristics. The additional penetration found when operating at high face velocity may result from increased seepage due to high pressure drop across the dust deposit. Also, increased pinhole incidence at high velocity leads to increased pinhole bypass and less flow through the efficient dust cake. Normal penetration theory predicts (16) that penetration of particles larger than a few tenths micrometer should decrease the increasing filtration velocity, contradicting the trend observed experimentally.

Dennis et al. (11) state that the presence of particles several micrometers in size downstream of a woven fabric strongly suggests penetration by pinhole bypass. Constant penetration for particles smaller than several micrometers would be expected if pinhole bypass accounts for most penetration, because holes have no size fractionating capability. However, some particles larger than this might be removed by inertia from the gas passing through a pinhole as the streamlines bend to pass through it. This explains the anthill-shaped deposit surrounding a pinhole (11).

Increased penetration for particles larger than several micrometers in size may occur due to seepage. Large particles should seep through more readily because they will be more likely to shake loose during cleaning as the ratio of mass to contact area is greater for larger particles than for small particles. Because of their greater mass, larger particles will be more affected by inertial forces as the fabric vibrates during operation.

Constant penetration as the dust cake thickens may occur because of the inability of an established pinhole to seal (11). High gas velocity through the pinhole may preclude effective hole blocking except by very large particles. However, for those situations in which few pinholes form, and where seepage is unimportant, penetration should continue to decrease with increasing dust deposit density.

Finally, the insensitivity of fabric filter emission rate to variations in inlet dust loading (7,8) can be explained by seepage. Because seepage is the penetration of previously arrested dust, the rate at which new dust arrives at the filter surface may not significantly affect seepage rate.

EXPERIMENTAL PROCEDURES

An experimental procedure was devised using a pulse-jet filter to test the relative importance of straight through penetration, either through the dust deposit or by pinhole bypass, and delayed dust emissions by seepage. The three-bag pulse-jet filter described in the previous section was used for these tests. Fly ash, collected by electrostatic precipitation from a coal burning power plant, had the size distribution shown in Figure 5-1 and was used as the test dust. Information on the fabric, bags, and cleaning procedures is given in Table 5-1. Before taking data, the bags were brought to pressure drop equilibrium.

TABLE 5-1. FILTER OPERATING CHARACTERISTICS

Dust		
	Material	Fly ash
	Density	2.2 g/cm^3
	Inlet flux	0.040 $g/cm^2/s$
Bags		
	Type	Polyester needled felt
	Weight	540 g/m^2
	Size	11.4 cm dia., 244 cm long
	Number	3
	Treatment	None
	Permeability	15 cm/s at 1.3 cm water
	Supplier	Summit Filter Corp., Summit, NJ
Cleaning		
	Pressure	6.8 atm
	Valve on time	75 ms electrical on time
	Interval	1 pulse/minute/bag
Equilibrium Pressure Drop		
	5 cm/s:	9.2 cm of water
	7.5 cm/s:	16.5 cm
	10 cm/s:	29 cm
	12.5 cm/s:	46 cm
Duration		
	Each experiment lasted 60 minutes.	

The filter was operated and dust samples taken to allow distinguishing straight through penetration from penetration by seepage. This may be done because dust can penetrate straight through the filter only while dust is fed to it; that is, only when there is dust in the inlet gas stream. In contrast, dust can seep through the filter whenever dust is present in or on the fabric, regardless of the dust concentration in the upstream gas.

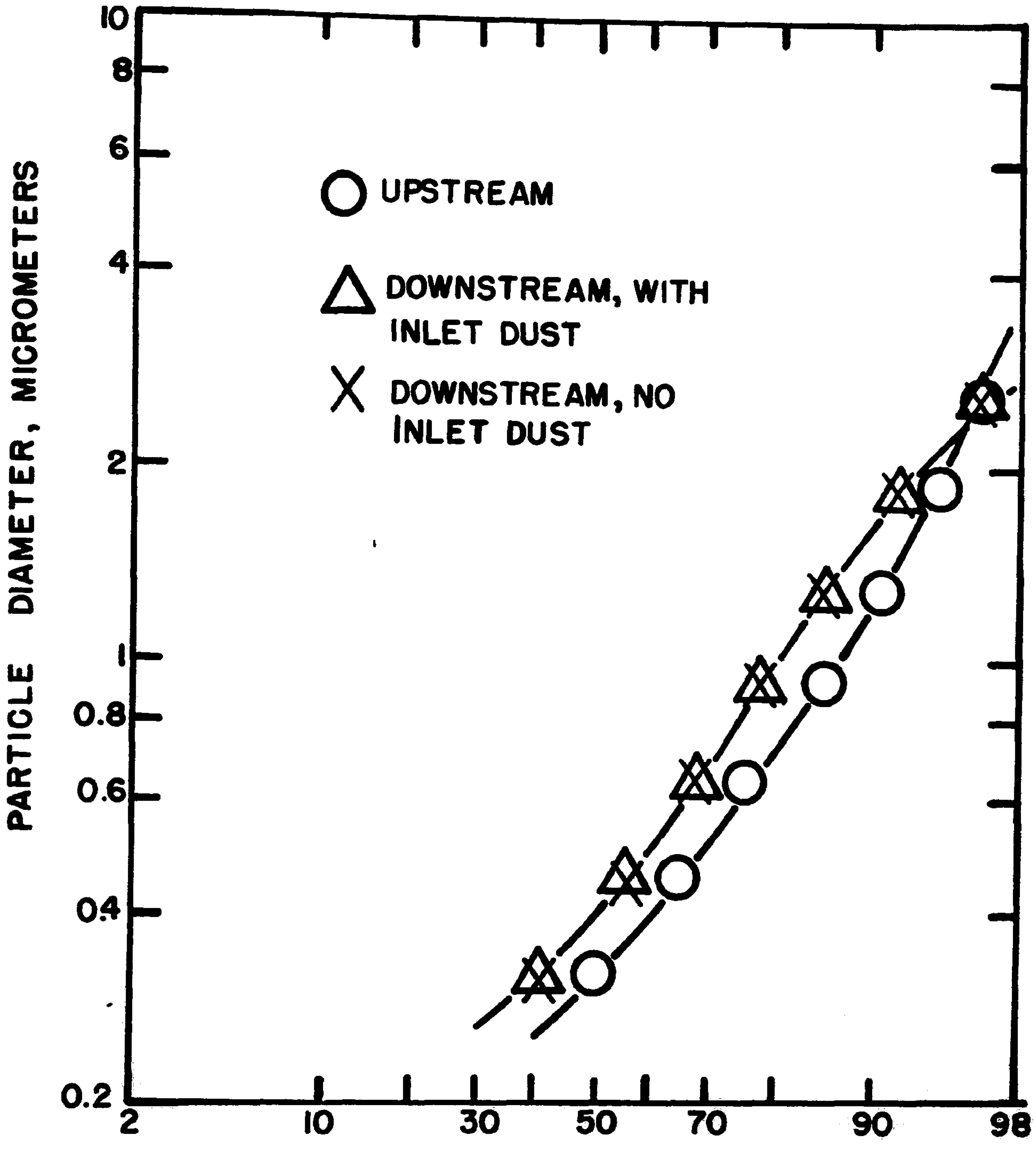

Figure 5-1. Cumulative size distributions by count, upstream, downstream with inlet dust feed on, downstream with inlet dust feed off.

In these experiments, dust was fed alternately on for twenty seconds, then off for twenty seconds, then on, then off, etc. Cleaning pulses were evenly distributed between times when the inlet dust feed was on and off. The average concentration of dust in the inlet air stream to the fabric filter was determined by sampling the inlet air stream continuously. Downstream, two sampling filters were used. One, the "on" sampling filter, was connected only while dust was fed, whereas the other, or "off" sampling filter, was connected only while no dust was fed.

If dust penetrates a fabric filter exclusively by the straight through mechanism and no seepage occurs, then dust will pass through the filter and be present downstream only when dust is fed to the inlet air. Accordingly, dust will collect only upon the "on" sampling filter. No dust will collect on the "off" sampling filter. In contrast, if dust penetrates the filter exclusively by seepage and no straight through penetration occurs, then dust will penetrate the filter continuously, the dust concentration downstream of the fabric filter will be constant and not depend upon short term fluctuations of the inlet dust concentrations, and equal amounts of dust will be present on both the "on" and "off" sampling filters.

The fraction of dust which penetrates the fabric filter by the straight through mechanism, X_{st}, and the fraction which penetrates by seepage, X_{se}, can be determined from the amount of dust which collects upon each of the two downstream sampling filters. The fraction of total sample mass collected downstream by the "on" sampling filter, M_{on}, and the mass fraction collected by the "off" sampling filter, M_{off}, can be used to solve Equations 5-1 and 5-2 for unknowns X_{st} and X_{se}.

$$M_{on} = 1\ X_{st} + 1/2\ X_{se} \tag{5-1}$$

$$M_{off} = 0\ X_{st} + 1/2\ X_{se} \tag{5-2}$$

After discontinuation of the inlet dust feed, some time passed before the aerosol in the inlet duct and filter housing was completely flushed and replaced with dust free gas. Similarly, after resuming the inlet dust feed, some time passed before the gas in the inlet duct and filter housing was fully dust laden. Because the downstream dust sampling switched from the "on" to the "off" filter at the same time the inlet dust feed was turned off, and vice versa, it was necessary to correct the amounts of dust collected on the downstream sampling filters for these gas displacement effects. This was done using the method described in the appendix to this section. Generally, the corrections were small.

EXPERIMENTAL RESULTS

Experiments were run at filtration velocities of 5, 7.5, 10, and 12.5 cm/s. At each velocity, the fractions of total downstream dust collected by the downstream "on" and "off" filters, M_{on} and M_{off}, were determined and the fraction of total penetration accountable to the straight through and seepage mechanisms determined by solving Equations 5-1 and 5-2 for X_{st} and X_{se}. Results are given in Table 5-2.

TABLE 5-2. FILTER PENETRATION CHARACTERISTICS

Filtration Velocity, cm/s	Fraction of Mass Penetrating*		Outlet Mass Flux g/cm²/s		
	X_{st}	X_{se}	N_{st}	N_{se}	N_{total}
5	0.33	0.67	0.5×10^{-7}	1.0×10^{-7}	1.5×10^{-7}
7.5	-0.14	1.14	-0.8×10^{-7}	7.0×10^{-7}	6.2×10^{-7}
10	0.16	0.84	2.0×10^{-7}	11×10^{-7}	13×10^{-7}
12.5	-0.07	1.07	-2.0×10^{-7}	27×10^{-7}	25×10^{-7}

*Data corrected as described in Appendix.

This experimental procedure was also used to determine particle size distributions upstream and downstream of the fabric filter at the same four filtration velocities. Dust samples were collected isokinetically on membrane filters and were analyzed using the optical microscope. Downstream size distributions were determined during time periods when inlet dust was fed as well as for time periods during which no inlet dust was fed, and are plotted in Figure 5-1. All size distribution data taken both upstream and downstream of the filter showed no significant variations with filtration velocity. The downstream size distribution when inlet dust was fed was indentical to that when no inlet dust was fed, as can be seen in Figure 5-1. Both downstream dusts were slightly coarser than upstream dust.

CONCLUSIONS

When dust penetration is defined as the ratio of dust concentration in the outlet gas stream to concentration in the inlet stream, it becomes infinite and meaningless if dust penetrates the filter when no dust is fed to the filter. A better parameter to characterize filter emissions is mass emission rate per unit area of fabric, outlet mass flux, N. Flux is the product of concentration and filtration velocity. The outlet mass flux at a given filtration velocity accountable to each of the dust penetration mechanisms can be determined by multiplying the total outlet mass flux by the fraction of penetration assignable to the straight through mechanism, X_{st}, or to the seepage mechanism, X_{se}. These data appear in Table 5-2 are are plotted in Figure 5-2, outlet mass flux vs. filtration velocity with penetration mechanism as parameter. Also shown on the vertical axis are values of penetration, for those times when inlet dust was fed.

Because some of the values of X_{st} were calculated to be negative, the associated outlet mass fluxes are also negative. The negative values scatter with positive values about the zero outlet mass flux line. The conclusion reached after considering both the positive and the negative data for X_{st} is that the straight through mechanism contributed relatively little to total outlet mass flux when compared to the contribution of the seepage mechanism. The fact that some of the outlet mass flux data for the straight through mechanism are negative does not compromise this conclusion.

Figure 5-2, the plot of outlet mass flux against filtration velocity, shows several trends. First, the total outlet flux is very low at a conventional filtration velocity of 5 cm/s. However, the outlet mass flux increases rapidly as filtration velocity increases, and at 12.5 cm/s, a 2.5 times increase in filtration velocity, the outlet mass flux increased 16 times. The ability of the fabric filter to collect and retain particles degrades markedly with increasing filtration velocity. Figure 5-2 shows that the outlet mass flux by the straight through mechanism does not increase with increasing velocity. All degradation in filter performance is due to an increase in outlet flux by seepage. Figure 5-1 shows that the downstream size distributions are somewhat coarser than that upstream. This is consistent with the finding that most dust penetrates by seepage, which may pass larger particles more easily.

These results help explain the discrepancy between conventional filtration theory which predicts that penetration should decrease for particles larger than a micrometer as filtration velocity increases, and data given for actual filter performance which show that penetration increases with increasing velocity. Figure 5-2 indicates that particles are collected efficiently as filtration velocity increases; the outlet flux due to the straight through mechanism remains low. Theory is correct when it predicts that particles will be collected efficiently at high filtration velocity. The increased dust penetration from the filter is due entirely to the filter's inability to retain collected particles. Penetration by seepage accounts for all the increase found.

Although rapid outward bag acceleration caused by rapid

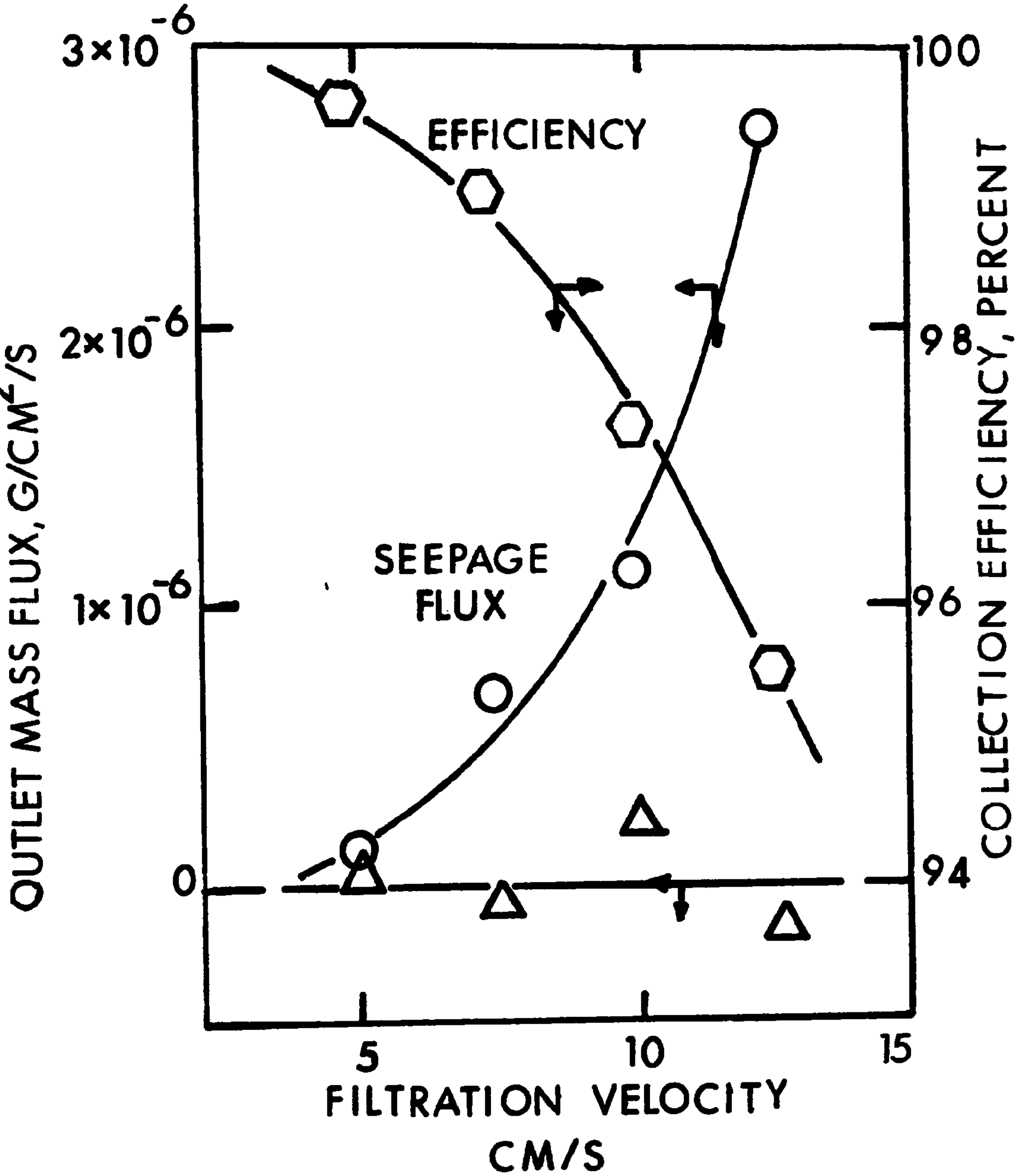

Figure 5-2. Outlet mass flux vs. filtration velocity for seepage and straight through penetration.

opening of the pulse valves may be essential for effective cleaning (9), rapid return and impact of the fabric on its supporting cage may drive dust through the fabric into the cleaned air stream. A dust puff could be seen through the transparent front of the experimental filter coming from each bag just after it was pulse-cleaned, whereas at all other times the outlet gas was clear. Seepage of this sort may account for a major portion of the total dust seeping through the filter. Seepage caused by bag snap-back should be aggravated by high filtration velocity, as more of the filter cake redeposits on the pulsed bag rather than falls to the dust hopper (18). The higher pressure drop caused by higher velocity gas passing through a thicker dust deposit should snap the fabric back to its cage more forcefully and cause greater drag toward the cleaned air side on particles shaken loose by the cleaning pulse.

SUMMARY

Fabric filter performance data for woven felt fabrics can be understood if particle penetration by fault mechanisms, such as pinhole bypass and seepage, are considered. Penetration straight through the dust cake and fabric may not be important by comparison. Using the fault mechanisms, observed trends in penetration with filtration velocity, particle diameter, and additional dust loading can be explained.

The experimental work described here using a pulse-jet filter operated over many filtration and cleaning cycles has shown that overall mass emissions increase substantially with increasing filtration velocity, and that the increase is due entirely to seepage. Particle emissions due to seepage through a pulse-jet filter are especially important and must be controlled at high filtration velocities.

APPENDIX

Each time the inlet dust feed was turned off, the downstream gas sample was switched from the "on" sampling filter to the "off" sampling filter. However, until clean gas displaced the dusty gas from the filter housing, dusty gas continued to flow through the bags. During this time, straight through penetration could occur, and the downstream "on" sampling filter should have been connected. The reverse situation occurred each time the inlet dust was fed. While clean gas flowed through the bags and until it was displaced by dusty gas from the filter housing, the downstream "off" sampling filter should have been connected.

The time necessary to displace dusty gas from the filter housing can be estimated by using a plug flow displacement model.

$$t = \frac{V}{Q} \tag{5-3}$$

Here, t is the time to displace dusty gas with clean gas, or vice versa, V is the gas volume in the ducts and filter housing, and Q is the volumetric gas flowrate which varies with filtration velocity. For all experiments, inlet dust was fed and not fed for alternate twenty second intervals. That fraction of the interval during which displacement occurred, F, was calculated by dividing the results of Equation 5-3 by twenty seconds. Results are in Table 5-3.

The data can now be corrected to account for the fraction of the cycle time during which displacement occurred and the incorrect sampling filter was connected. Let M'_{on} be the fraction of total downstream dust actually collected by the downstream sampling filter connected when the inlet dust feed was on; let M'_{off} be the analogue when the inlet dust feed was off. The fractions of dust which should have collected on the downstream sampling filters had no displacement occurred, M_{on} and M_{off}, can then be found from Equations 5-4 and 5-5.

$$M'_{on} = (1-F)\ M_{on} + F\ M_{off} \tag{5-4}$$

$$M'_{off} = F\ M_{on} + (1-F)\ M_{off} \tag{5-5}$$

The fractions of the total downstream dust sample actually collected while inlet dust was on and off, M'_{on} and M'_{off}, were determined experimentally at each filtration velocity. Using values of F from Table 5-3, Equations 5-4 and 5-5 were solved simultaneously for the two unknowns, M_{on} and M_{off}. Values of M'_{on} and M'_{off} as well as M_{on} and M_{off} are given in Table 5-3. The corrected values, M_{on} and M_{off}, were used for the calculations presented in Table 5-2.

TABLE 5-3. DISPLACEMENT CORRECTIONS TO DOWNSTREAM DUST MASS COLLECTED

Filtration Velocity	Displacement per		Fraction of Total Mass Actually Collected Downstream		Fraction of Total Mass Calculated as Collected, Without Displacement	
	time	cycle	Dust On	Dust Off	Dust On	Dust Off
cm/s	s	F	M'_{on}	M'_{off}	M_{on}	M_{off}
5	4.8	0.24	0.74	0.26	0.95	0.05
7.5	3.2	0.16	0.45	0.55	0.43	0.57
10	2.4	0.12	0.56	0.44	0.58	0.42
12.5	1.9	0.10	0.47	0.53	0.47	0.53

REFERENCES

1. D. Leith, S.N. Rudnick and M.W. First, High Velocity, High Efficiency Aerosol Filtration, EPA Report 600/2-76-020, Office of Research and Development, Washington (1976).

2. D. Leith and M.W. First, "Performance of a Pulse-Jet Filter at High Filtration Velocity - I. Particle Collection," J. of Air Poll. Control Assoc., 27:534 (1977).

3. P.W. Spaite and G. Walsh, "Effect of Fabric Structure on Filter Performance," Am. Ind. Hyg. Assoc. J., 24:357 (1963).

4. J.D. McKenna, J.C. Mycock and W.O. Lipscomb, "Performance and Cost Comparisons Between Fabric Filters and Alternate Control Techniques," J. of Air Poll. Control Assoc., 24:1144 (1974).

5. D.S. Ensor, R.G. Hooper and R.W. Scheck, Determination of the Fractional Efficiency, Opacity Characteristics, Engineering and Economic Aspects of a Fabric Filter Operating on a Utility Boiler, EPRI Report FP-297, Palo Alto, CA (1976).

6. J.H. Turner, "Extending Fabric Filter Capabilities," J. of Air Poll. Control Assoc., 24:1182 (1974).

7. C.E. Billings, M.W. First, R. Dennis and L. Silverman, Laboratory Performance of Fabric Dust and Fume Collectors, AEC Contract NYO-1590 (revised), Washington (1961).

8. R. Dennis, "Collection Efficiency as a Function of Particle Size, Shape, and Density: Theory and Experience," J. of Air Poll. Control Assoc., 24:1156 (1974).

9. R. Dennis and J. Wilder, Fabric Filter Cleaning Studies, EPA Report EPA-650/2-75-009, Office of Research and Development, Washington (1975).

10. D.G. Stephan, G.W. Walsh and R.A. Herrick, "Concepts in Fabric Air Filtration," Am. Ind. Hyg. Assoc. J., 21:1 (1960).

11. R. Dennis, R.W. Cass, D.W. Cooper, R.R. Hall, V. Hampl, H.A. Klemm, J.E. Langley and R.W. Stern, Filtration Model for Coal Fly Ash with Glass Fabrics, EPA Report EPA-600/7-77-084, Office of Research and Development, Washington (1977).

12. C.R. Holland and E. Rothwell, "Model Studies of Fabric Dust Filtration, 1. Flow Characteristics of Dust Cakes Uniformly Distributed on Filter Fabrics," Filtration and Separation, 14:30 (1977).

13. C.R. Holland and E. Rothwell, "Model Studies of Fabric Dust Filtration, 2. A Study of the Phenomenon of Cake Collapse," Filtration and Separation, 14:224 (1977).

14. E.M. Afify and M.H. Mohamed, "Collection Efficiency and Pressure Drop of Needle Punched Filters," J. of Eng. for Industry, 98:675 (1976).

15. S.N. Rudnick, Department of Environmental Health Sciences, Harvard School of Public Health, 665 Huntington Avenue, Boston, MA 02115, private communication.

16. D.W. Cooper and V. Hampl, "Fabric FIlter Performance Model" in Conference on Particulate Collection Problems in Converting to Low Sulfur Coals, EPA Report EPA-600/7-76-016, Office of Research and Development, Washington (1976).

17. D.C. Draemel, Relationship Between Fabric Structure and Filtration Performance in Dust Filtration, EPA Report EPA-R2-73-288, Office of Research and Monitoring, Research Triangle Park, NC (1973).

18. D. Leith, M.W. First and H. Feldman, "Performance of a Pulse-Jet Filter at High Filtration Velocity - II. Filter Cake Redeposition," J. of Air Poll. Control Assoc., 27:636 (1977).

SECTION 6

EFFECT OF MODIFIED CLEANING PULSES

INTRODUCTION

An attractive feature of pulse-jet filters is their ability to operate at higher filtration velocities (air to cloth ratios) than do filters cleaned by other means. To increase filtration velocity further is a tempting goal as the resultant decrease in installed cost can often more than compensate for the increased operating cost caused by higher pressure drop across the fabric (1). The filtration velocity associated with least annualized cost increases as the number of operating hours per year decreases, so that for a process operated one shift per day or less, relatively high velocities (100 mm/s) at relatively high pressure drops (~ 250 mm water) may be appropriate (1).

However, as filtration velocity increases penetration increases as well for both pulse-jet cleaned filters (2,3) and for filters cleaned by other means, (4-7) and in some cases the penetration increase may become unacceptable. Although data are few, bag life may decrease as well at high filtration velocities (8).

In a conventional cleaning pulse, compressed air enters the bag rapidly and pushes the bag outward, away from its supporting cage. Upon approaching full inflation, the bag decelerates rapidly to a state of metastable rest, during which residual pulse air flows through the fabric and flushes out dust loosened by this deceleration.

At the end of a conventional pulse, the backflow of pulse air stops and normal filtration resumes. The bag accelerates back toward its supporting cage and hits it smartly causing a rapid deceleration analogous to that observed as the bag snaps open. This causes additional dust agglomerates and particles to become loosened. These, together with the agglomerates and particles that were loosened but not blown free by the cleaning phase of the pulse, may now be flushed through the bag to the cleaned air side by the filtration gas. Dust penetration by this mechanism has been called seepage (3).

Effective cleaning requires interaction between the cleaning pulse and the fabric. The bag must be flexible enough to inflate rapidly as the pulse begins. It should not stretch radially so that the bag may decelerate rapidly as it reaches full inflation. However, these same qualities, flexibility and radial distortion resistance, will also allow the bag to return to its cage rapidly as filtration resumes and this aggravates seepage.

Recently it was shown that almost all the dust that penetrates through a pulse-jet filter does so by seepage, and that seepage increases with increasing filtration velocity (3). This occurs for several reasons. First, higher filtration velocity increases the fraction of dust feed by a cleaning pulse that redeposits on the bags, and decreases the fraction of freed dust that falls to the hopper (9). This causes a thicker dust deposit to build up, with more dust available to seep through. Second, higher filtration velocity drives the cleaned fabric back to its cage faster, causing it to hit with greater impact. This drives through more dust.

Dennis and Wilder (10) placed a 1.7 liter damping tank after the outlet of the pulse valve in their single bag, pilot pulse-jet filter and studied the effect of this tank on both penetration and pressure drop. They found that for filtration velocities between 30 and 50 mm/s, penetration was reduced by a factor of about five when damped pulses were used; however, pressure drop increased about 20%. Some of the air released by a cleaning pulse was taken up momentarily by the tank, and the transient reverse pressure gradient across the bag was somewhat reduced. For this reason, bag cleaning was less effective; the greater residual dust holding was thought to account for the higher pressure drop found. Reduced fabric stretching and reduced transient pressure gradients across the bag were thought to account for the reduced penetration.

Ideally, a cleaning pulse should: (1) inflate the bag quickly so that it will decelerate rapidly when it snaps fully open, (2) provide time after inflation for pulse air to flow through the bag and flush loosened dust into the housing, and (3) return the fabric to its cage support gently to prevent seepage and excessive fabric wear. A conventional cleaning pulse of sufficient duration produced by a coventional pulse-jet solenoid valve should satisfy the first two objectives, but does not satisfy the last. Dennis and Wilder's damped pulses (10) should satisfy the last two objectives but not the first.

To satisfy all three objectives simultaneously, conventional cleaning pulses were modified in a way that retained rapid air delivery to each bag at the pulse beginning but that gently returned the bag to its cage. Modified pulses described here began normally but at the pulse end, pressure trailed off gradually allowing each pulsed bag to deflate gradually and return gently to its cage.

To test the effectiveness of modified cleaning pulses, a three bag pilot filter fitted with polyester felt bags 2.44 m tall and 114 m in diameter was used (9). A schematic drawing of the apparatus is given in Figure 6-1. The test dust was fly ash with cumulative size distribution by count given in Figure 6-2. Mass concentrations of fly ash upstream and downstream of the fabric filter were found by sampling isokinetically, onto glass filter papers.

Cleaning pulses, either conventional or modified, were delivered sequentially to each bag once per minute. The valve arrangement for the pulse-air manifold is shown schematically in Figure 6-3. Compressed air entered through a regulator which controlled pressure at 6.8 atmospheres gauge. From the regulator, the compressed air passed into a reservoir from which it flowed through a normally open solenoid valve, A, into a 1.6 L pulse air chamber. This chamber could be fitted with an extension which doubled its volume. Chamber pressure was measured on a Bourdon gauge and by a transducer connected to an oscilliscope.

The volumes of compressed air used for a conventional pulse, a modified pulse, and a modified pulse with chamber extension were measured by connecting the outlet from each pulse to a spirometer. The volume of compressed air per pulse was found to be 8.6 liters for a conventional pulse, 10.9 liters for a modified pulse, and 20.7 liters for a modified pulse with extended chamber volume, all measured at ambient pressure.

For conventional pulse operation the appropriate pulse valve, B_1, B_2, or B_3, Figure 6-3, received an electrical signal to "open" for 75 milliseconds. A photograph of the relationship between chamber pressure and time for a conventional pulse as shown on the oscilliscope is given in Figure 6-4. It shows that pulse valve B_1 began to open about 20 ms after receiving an electrical impulse. Although the electrical on-time was set at 75 ms, the valve continued to pass air for about 220 ms. This occurred because the pneumatic valve took about 150 ms to build up enough air pressure behind its diaphram to close, although once closure began it was rapid. Pressure vs. time traces for valves B_1, B_2, and B_3, were virtually identical.

To generate a modified cleaning pulse, one of the pulse valves (B_1, B_2, or B_3) was opened and 240 ms later solenoid valve A, Figure 6-3, was closed causing pressure in the chamber to drop as air bled from it to the pulsed bag. This gradual reduction in pulse pressure allowed the bag to move back to its supporting cage gently. After about 560 ms, the pulse valve closed and pressure within the chamber stabilized. Some time later, solenoid A was reopened, refilling the chamber with compressed air for the next pulse. A photograph of the oscil-

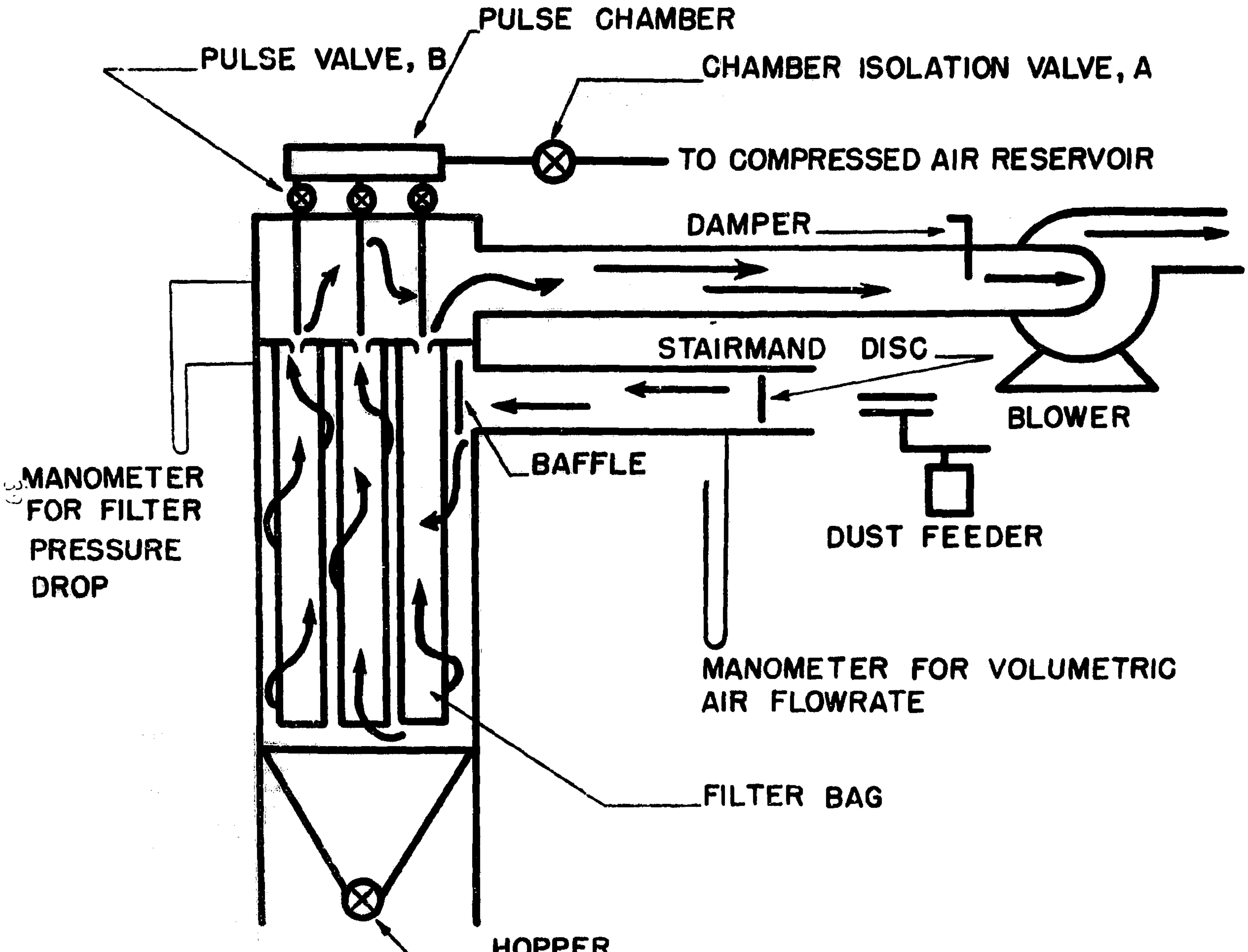

Figure 6-1. Schematic of fabric filter apparatus with pulse chamber.

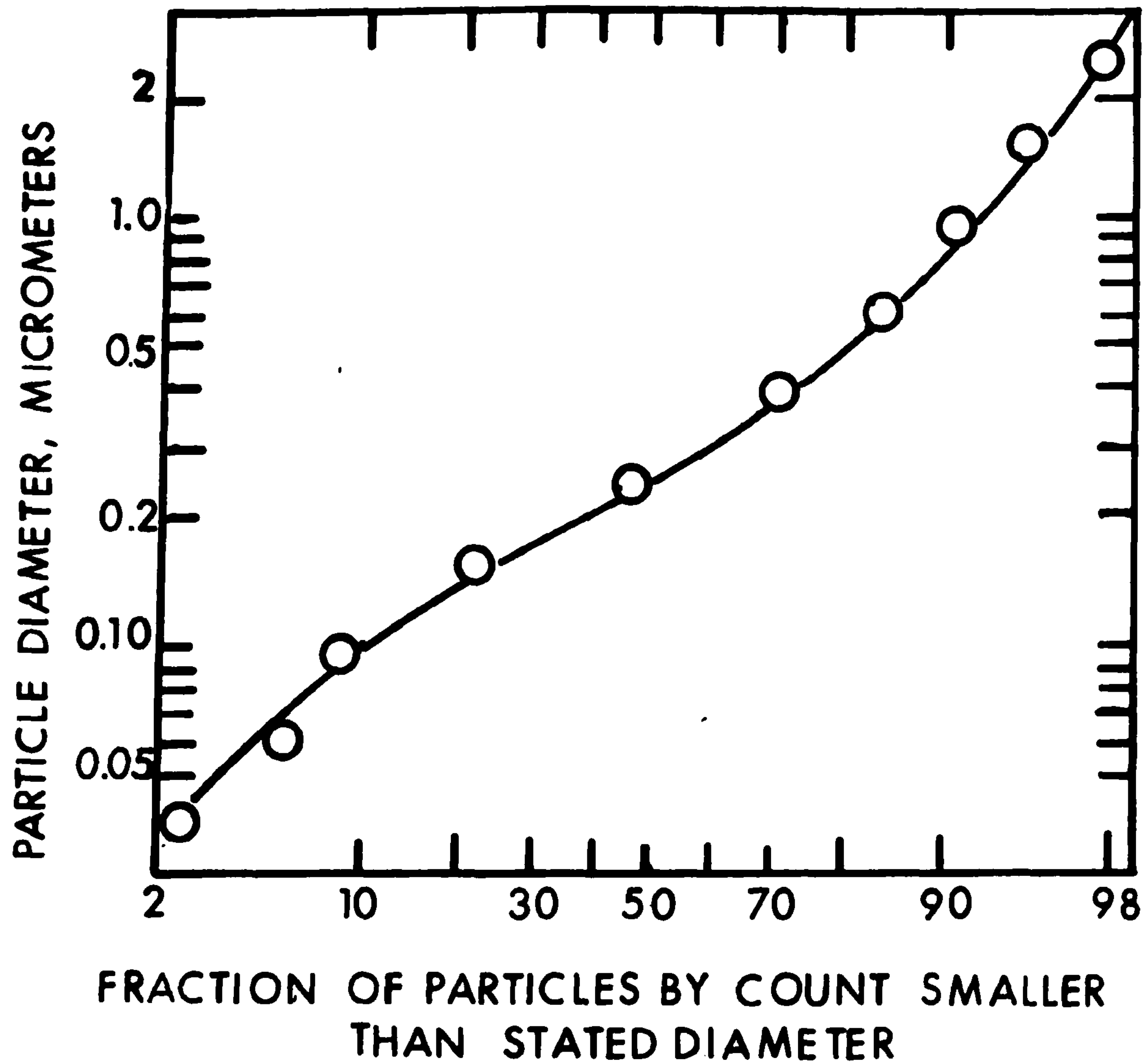

Figure 6-2. Cumulative size distribution by count for fly ash.

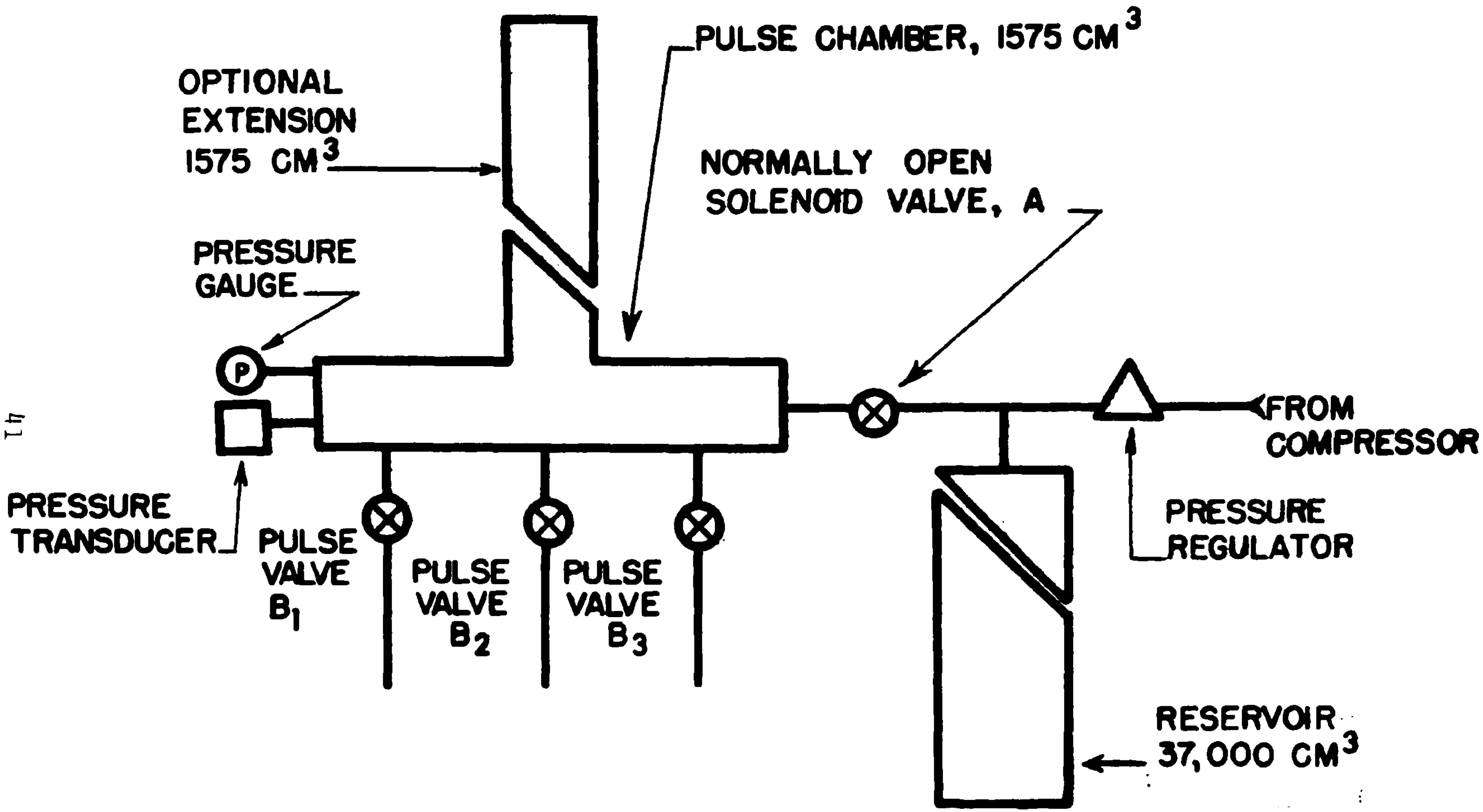

Figure 6-3. Valve arrangement for pulse air chamber.

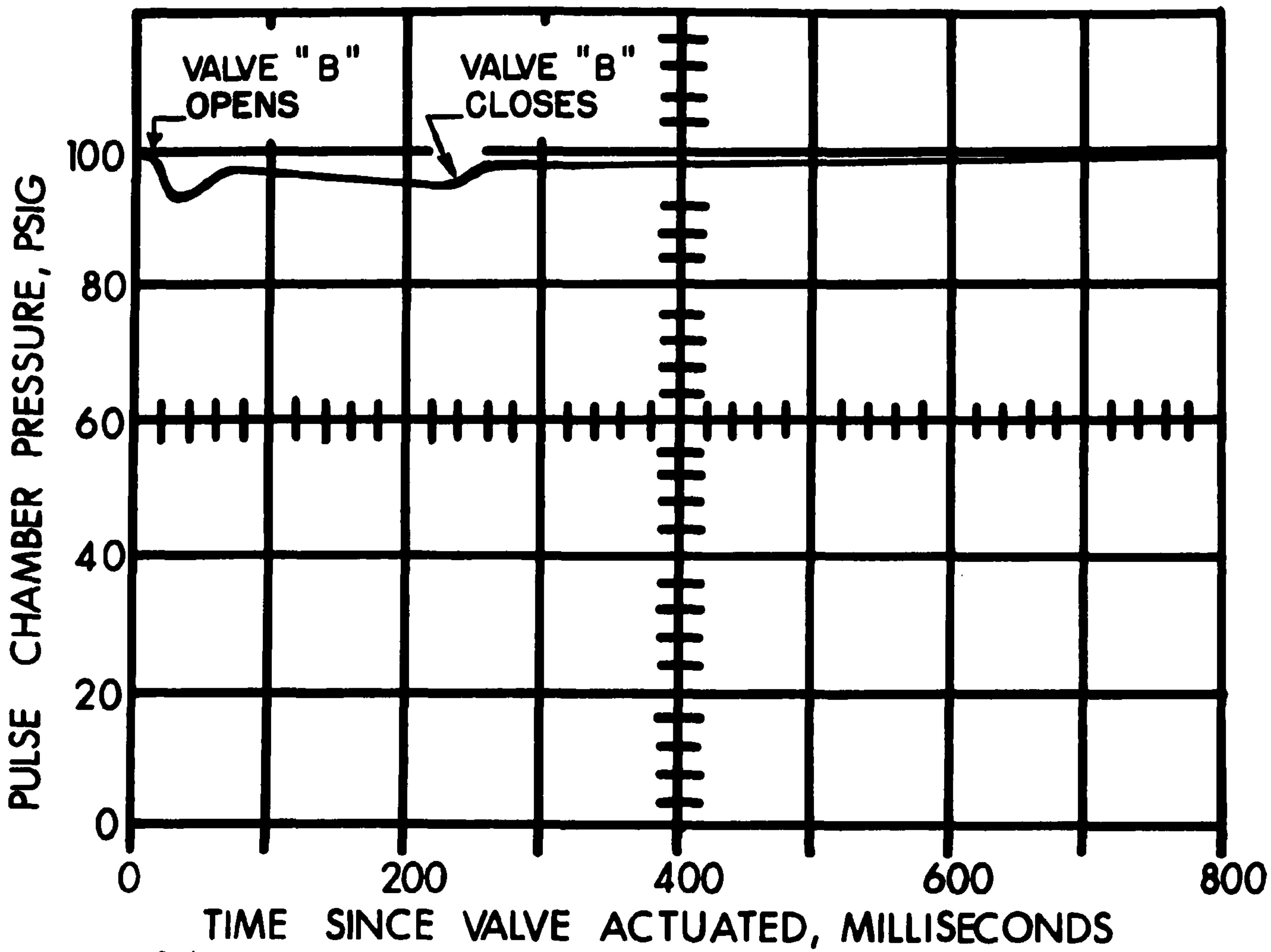

Figure 6-4. Tracing of oscilliscope display = pulse pressure vs. time for normal pulse.

liscope pressure-time trace for a modified pulse is given in Figure 6-5.

The declining portion of the pressure-time relationship for the modified pulse, and by inference the speed with which the bag returns to its cage, are determined by the pulse valve flow characteristics and the volume of the chamber. To determine the effect of chamber size on filter performance, its volume was doubled by adding an extension. The pressure-time trace for this arrangement is given in the oscilliscope photo shown in Figure 6-6.

The effects of pulse modification on dust penetration and filter resistance were determined for a range of operating conditions. Before taking data the fabric filter was operated at constant conditions until the bags reached pressure drop equilibrium. This process took some hours; the length of time necessary depended upon the degree to which experimental conditions differed from test to test. Tests were run at filtration velocities of 50, 75, 100, 125 and 150 mm/s, using both conventional and modified pulses, and for normal and extended chamber volumes, so that twenty different operating and cleaning situations could be studied. All tests were replicated and run in random order with approximately the same inlet dust mass flux 0.33 $kg/m^2/hr$, so that the amount of dust fed between pulses would be the same regardless of filtration velocity.

Increased relative humidity has been shown to reduce both pressure drop and penetration in a woven fabric filter cleaned by shaking the bags (11). Bench scale tests on Nomex and Dacron felts also show a decrease in pressure drop with increased humidity (12). Although it was not possible to control the humidity of the air passing through the present apparatus, relative humidity was measured for each test. Because replicates were taken, the data could be sorted into "higher" and "lower" relative humidities for each replicated experimental condition. The variation in relative humidity between replicates ranged from less than 1% to 32%.

RESULTS

Table 6-1 shows the fractional mass penetration, equilibrium pressure drop in mm water column, and per cent relative humidity measured for each test.

Figure 6-7 is a plot of penetration against filtration velocity with pulse type as parameter. An analysis of variance performed on the data after taking logarithms showed that penetration increased significantly with increased filtration velocity. However, at all velocities tested penetration was significantly lower with modified pulses than with conventional pulses. The

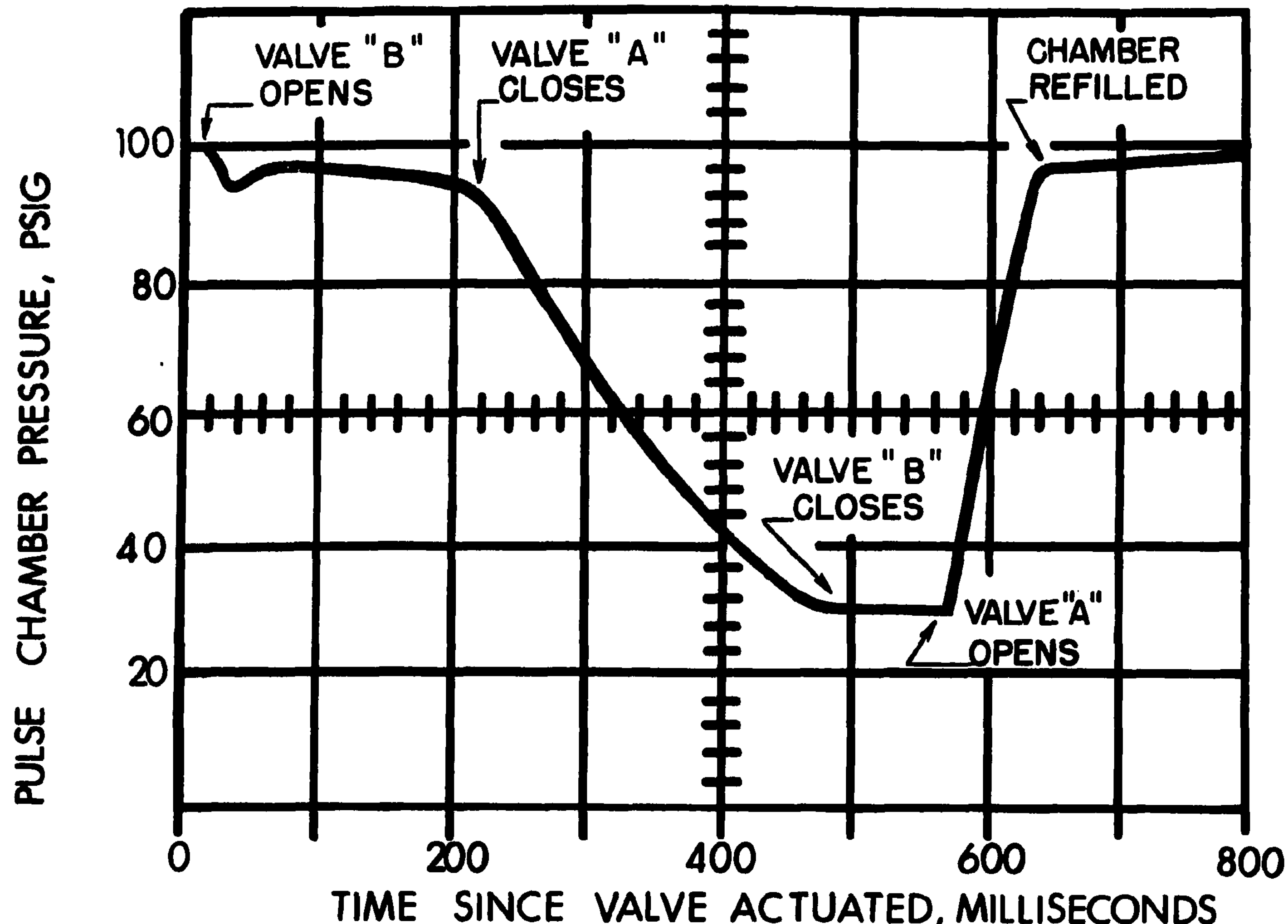

Figure 6-5. Tracing of oscilliscope = pulse pressure v.s. time for modified pulse.

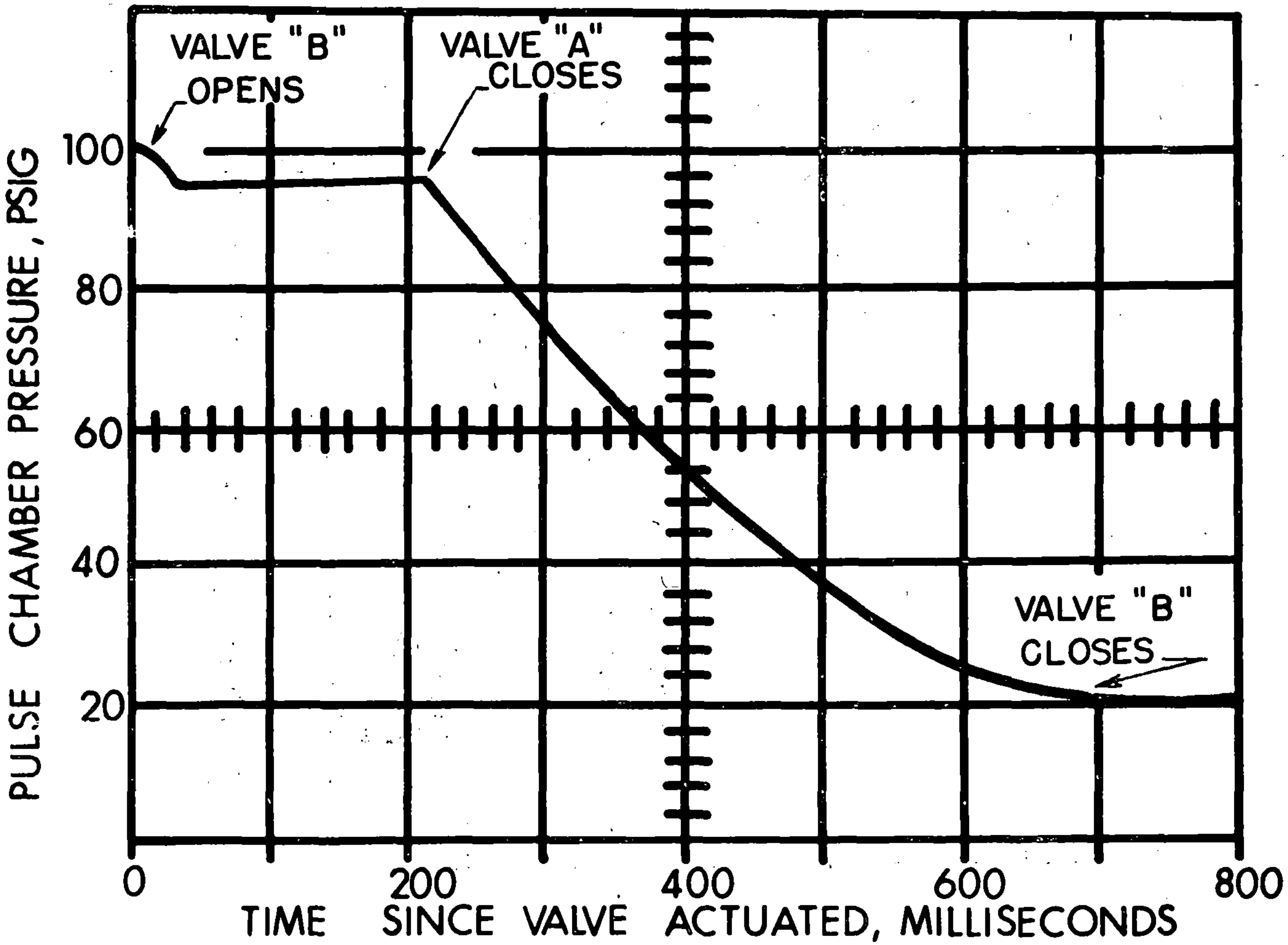

Figure 6-6. Tracing of oscilliscope display = pulse pressure vs. time for modified pulse with twice normal chamber volume.

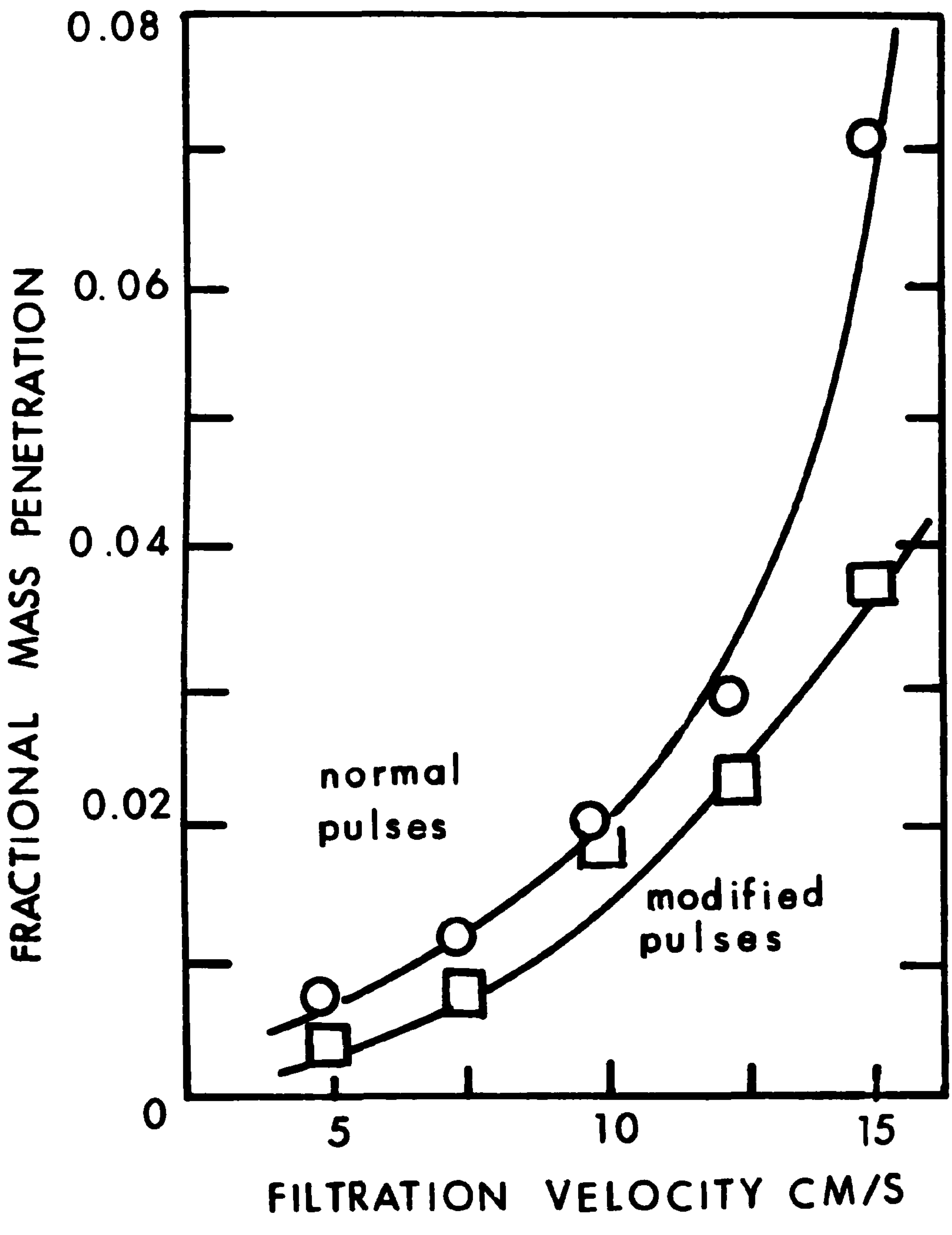

Figure 6-7. Penetration vs. filtration velocity, pulse type as parameter.

Table 6-1

Fractional Mass Penetration/Pressure Drop, MM Water Gauge/% Relative Humidity

Filtration Velocity cm/s	Relative Humidity H/L	Normal Pulses: Std. Pulse Volume	Normal Pulses: 2 x Std. Volume	Modified Pulses: Std. Pulse Volume	Modified Pulses: 2 x Std. Volume
5	Lower	0.011/35 mm/38%	0.008/35 mm/38%	0.007/35 mm/33%	0.000/75 mm/59%
	Higher	0.006/65 mm/48%	0.005/65 mm/54%	0.007/65 mm/44%	0.001/70 mm/59%
7.5	Lower	0.011/82.5 mm/38%	0.014/75 mm/33%	0.007/103 mm/52%	0.009/70 mm/49%
	Higher	0.012/225 mm/60%	0.011/97.5 mm/50%	0.007/275 mm/56%	0.007/180 mm/56%
10	Lower	0.016/80 mm/43%	0.023/115 mm/36%	0.033/150 mm/29%	0.032/160 mm/26%
	Higher	0.027/260 mm/53%	0.019/145 mm/51%	0.003/230 mm/67%	0.007/300 mm/62%
12.5	Lower	0.029/160 mm/52%	0.083/400 mm/40%	0.041/150 mm/38%	0.040/195 mm/37%
	Higher	0.005/500 mm/62%	0.003/385 mm/64%	0.005/465 mm/64%	0.009/280 mm/69%
15	Lower	0.178/680 mm/49%	0.072/475 mm/51%	0.048/250 mm/55%	0.035/625 mm/37%
	Higher	0.006/385 mm/70%	0.027/615 mm/60%	0.036/685 mm/58%	0.033/695 mm/43%

penetration reduction due to pulse modification is increasingly effective as velocity increased. Pulse chamber volume within the range studied had no significant effect on penetration for either normal or modified pulses. Penetration is plotted against filtration velocity with relative humidity as parameter in Figure 6-8. The penetration increase with increasing velocity is significantly more rapid at low relative humidity.

As expected, pressure drop increased rapidly with filtration velocity as is shown in Figure 6-9. An analysis of variance performed on the logarithms of the pressure drop data showed that this increase was significant. There was not a significant pressure drop difference between normal and modified cleaning pulses, or between normal and twice normal pulse volumes.

Relative humidity is the parameter against which pressure drop and filtration velocity are plotted in Figure 6-9. For both relative humidity conditions, pressure drop increased with velocity. However, contrary to observations for collection of fly ash on woven bags cleaned by shaking (11), pressure drop in the pulse-jet filter was significantly higher at higher relative humidity.

DISCUSSION

Pulse form modification is an effective way to reduce dust seepage through a pulse-jet filter, especially at higher filtration velocities. At the highest filtration velocity tested, 15 cm/s, pulse modification lowered fractional penetration by 46%.

Pulse cleaning effectiveness is associated with fabric deceleration as the bag snaps fully open, and with pulse duration sufficient to assure that loosened dust is flushed from the fabric into the filter housing. Because the initial part of a modified and a conventional pulse are the same, they should inflate and flush bags equally well. Modified pulses backflush bags longer than normal pulses because additional backflow occurs while pulse pressure falls during the final stage of the modified pulse. However, if enough backflow occurs to move loosened dust away from the fabric, additional pulse air brings diminished returns as has been shown by Dennis and Wilder (10). For these reasons, pressure drops across bags cleaned by conventional and modified pulses were about the same.

There was no difference in penetration between bags cleaned by modified pulses from the 1.6 L pulse chamber and modified pulses from the 3.2 L chamber. This implies that chamber size might be decreased further to save on compressed air, while retaining the form and effect of modified pulses.

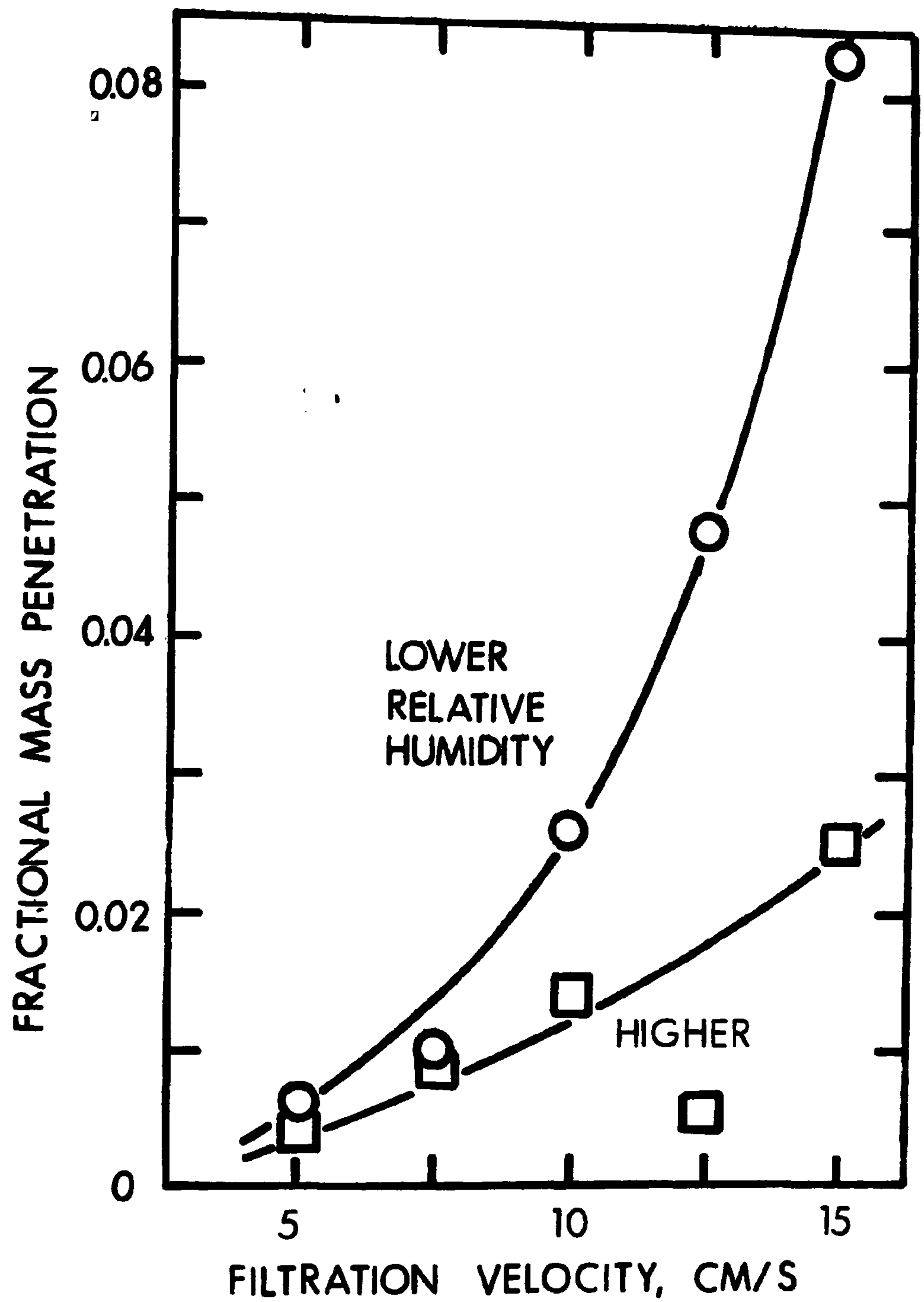

Figure [illegible]-8. Penetration vs. filtration velocity, relative humidity as parameter.

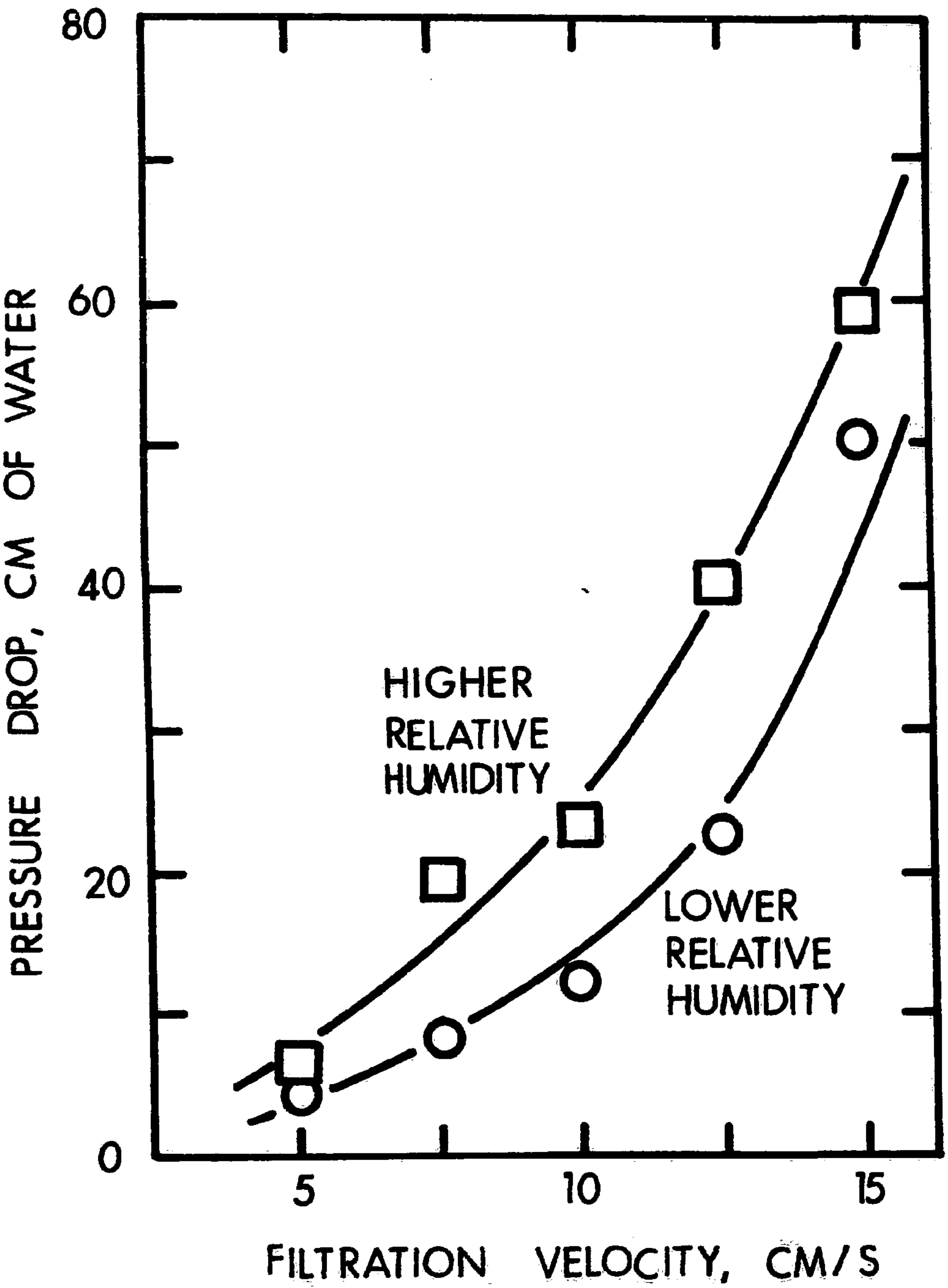

Figure 6-9. Pressure drop vs. filtration velocity, relative humidity as parameter.

For a dust particle or agglomerate to be separated from the fabric, interparticle adhesive forces must be overcome by the deceleration force acting on dust as the bag snaps open at the beginning of a cleaning pulse, or snaps back onto its cage at the end of the pulse. In the former case, the dust flies into the housing from which it can fall to the hopper; in the latter case, the dust separated from the fabric penetrates the filter by seepage. It has been demonstrated that increased relative humidity leads to stronger particle-to-particle and particle-to-fiber bonds, (12), (13) which should make separation of the dust deposit from the fabric more difficult. Fly ash may have adsorbed sulfuric acid, which absorbs water at high relative humidities, thereby strengthening interparticle bonds.

Because the dust deposit is more firmly anchored to the fabric at higher relative humidity, seepage penetration should decrease. The data confirm this trend. At the same time, stronger interparticle bonds caused by increased relative humidity should make the dust deposit more difficult to clean from the fabric. A dust deposit with higher areal density would account for the higher pressure drops at high relative humidity found in these experiments.

Data for woven fabrics cleaned by shaking (11) and for bench scale new felts (12) show that pressure drop decreases with increasing relative humidity, opposite to the trend found here. Higher interparticle forces could cause a more porous dust deposit structure (12), one more resistant to compaction with continuous dust addition. Theory (15) confirms that for the same amount of deposited dust, a thicker, more porous structure should have less pressure drop than a thinner, more dense one. However, in the pulse-jet filter cleaning is not wholly effective at removing deposited dust. The effect of increasing the amount of dust retained on the bag at high humidity may be more important than the effect of the more porous structure which that dust forms.

SUMMARY

Pulse-jet filters show higher seepage penetration at higher filtration velocities. This seepage occurs when the bags return to and strike their rigid support cages at the end of a cleaning pulse, as loosened dust is driven from the bags into the cleaned gas stream. Seepage can be reduced by cleaning the bags with pulses which are identical with conventional pulses at the beginning, but which gradually decrease in pressure at the pulse end, allowing the bags to return gently to their cages. Modified pulses are increasingly effective at reducing dust penetration as filtration velocity increases. At the highest velocity tested, 15 cm/s, modified pulses reduced penetration by 46% but had no effect on pressure drop.

Increased relative humidity caused significantly lower penetration but increased pressure drop. Because increased humidity causes an increase in interparticle bond strength, dust collected at high humidity may be bound more tightly in place and be less likely to seep through the fabric, causing reduced penetration. However, when dust is tightly bound it becomes more difficult to separate from the fabric. At high humidities, an equilibrium dust deposit with higher areal density may build up on the bags causing higher pressure drop.

REFERENCES

1. Leith, D. and M.W. First, "Pressure Drop in a Pulse-Jet Fabric Filter", Filtration and Separation, 14 (5):473 (1977).

2. Leith, D., S.N. Rudnick and M.W. First, High Velocity, High Efficiency Aerosol Filtration, EPA Report EPA 600/2-76-020, Office of Research and Development, Washington, D.C., 1976.

3. Leith, D. and M.W. First, "Performance of a Pulse-Jet Filter at High Filtration Velocity, III. Penetration by Fault Processes", J. Air Poll. Control Assoc., 27(8): 754 (1977).

4. Spaite, P.W. and G. Walsh, "Effect of Fabric Structure on Filter Performance", Am. Ind. Hyg. Assoc. J., 24:357 (1963).

5. Ensor, D.S., R.G. Hooper and R.W. Scheck, Determination of the Fractional Efficiency, Opacity Characteristics, Engineering and Economic Aspects of a Fabric Filter Operating on a Utility Boiler. EPRI Report FP-297, Palo Alto, CA, 1976.

6. McKenna, J.D., J.C. Mycock and W.O. Lipscomb, "Performance and Cost Comparisons Between Fabric Filters and Alternate Control Techniques", J. Air Poll. Control Assoc., 24: 1144 (1974).

7. Turner, J.H., "Extending Fabric Filter Capabilities", J. Air Poll. Control Assoc., 24:1132 (1974).

8. Hobson, M.J., "Review of Baghouse Systems for Boiler Plants", in Proceedings, the User and Fabric Filtration Equipment II, Air Pollution Control Association, 4400 Fifth Ave., Pittsburgh, PA (1975).

9. Leith, D., M.W. First, and H. Feldman, "Performance of a Pulse-Jet Filter at High Filtration Velocity, II. Filter Cake Redeposition", J. Air Poll. Control Assoc., 27 (7):636 (1977).

10. Dennis, R. and J. Wilder, Fabric Filter Cleaning Studies, EPA Report EPA-650/2-75-009, Office of Research and Development, Environmental Protection Agency, Washington, D.C. (1975).

11. Durham, J.F. and R.E. Harrington, "Influence of Relative Humidity on Filtration Resistance and Efficiency:, Paper 4e presented at 63rd Annual Meeting of American Institute of Chemical Engineers, Chicago, IL, 1970.

12. Ariman, T. and D.J. Helfritch, "How Relative Humidity Cuts Pressure Drop in Fabric Filters", Filtration and Separation, 14:127 (1977).

13. Corn, M. and F. Stein, "Re-entrainment of Particles from a Plane Surface", Am. Ind. Hyg. Assoc. J., 26:325 (1965).

14. Löffler, F., "Investigating Adhesive Forces Between Solid Particles and Fiber Surfaces", Staub (English Translation), 26:19 (1966).

15. Stephan, D.G., G.W. Walsh and R.A. Herrick, "Concepts in Fabric Air Filtration", Am. Ind. Hyg. Assoc. J., 21:1 (1960).

SECTION 7

CURRENT PROGRAM

Many factors affect fabric filter performance in addition to those considered here. Dust characteristics including concentration, particle size, shape, chemical and physical properties; fabric characteristics such as materials of construction, fiber shape and size; and, fabric construction techniques, gas properties such as temperature, relative humidity and filtration velocity, filter design including bag geometry, bag spacing, gas inlet location, cleaning type, intensity and frequency, and other factors all may have important effects. Currently the Harvard Air Cleaning Laboratory is investigating several areas in which important gains in performance may be realized, particularly at high filtration velocities.

Management of the gas flow pattern within the filter housing may bring about significant reductions in pressure drop and penetration because of the manner in which gas flow influences bag cleaning efficiency and dust redeposition. When the gas flow direction inside the filter housing is upward, as occurs when the gas inlet is near the bottom of the housing, some of the dust freed by a cleaning pulse remains air suspended in the vicinity of the filter bag and redeposits, thereby increasing pressure drop. When the gas flow direction is downward, as is the case with a gas inlet near the housing top, dust pulsed from the bags tends to be swept toward the dust hopper and redeposition is diminished. Regardless of the inlet location, a downwardly directed gas circulation pattern within the housing can be induced by drawing some of the gas from the filter bottom, passing it through a fan, and then reintroducing it at the housing top.

The effect of gas flow pattern on performance should be most important at high filtration velocities which aggravate redeposition and cause an excessively thick dust deposit.

Currently, the relationships between natural and forced gas flow patterns within the housing, filter penetration and pressure drop are being examined. Improvements in filter performance realized through this program should apply regardless of the particularities of the dust, filter fabric, or gas properties found in any single application. Additional reports such as this will be issued in which current progress will be described.

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16. ABSTRACT The report gives results of an economic analysis of pulse-jet filtration. It shows that, if the device is operated continuously, the filtration velocity associated with least total annualized cost is about 3 cm/s (6 ft/m). As annual operating time decreases, operating costs decrease; however, fixed cost remains about the same. Although the analyses depend on the particular values for cost factors used in the economic model, the least cost trend of increased velocity with decreased operating time should stand, regardless of the values used. As filtration velocity increases, penetration also increases. Experiments determined that essentially all penetration through the filter is due to seepage, and that almost no particles penetrate straight through without stopping. Higher velocities also cause more dust redeposition on the fabric bags, leading to a thicker dust deposit and higher pressure drop. High pressure drop also drives the bags back onto their cages more forcefully. Modified pulses produce a gradual reduction in pulse pressure at the end of the cleaning pulse, permitting a pulsed bag to return to its cage more slowly and gently than with the normal, square-wave cleaning pulse which ends abruptly. Pulses so modified were especially effective in reducing penetration at high filtration velocities. Pressure drop was unaffected by pulse modification. Compressed air use increased 27%.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Air Pollution Control	13B
Filtration	Stationary Sources	07D
Pulsation	Fabric Filters	14B
Jets	Pulse-jet Filters	20D
Fabrics		11E
Economic Analysis		05C

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