EDGEWOOD ARSENAL
TECHNICAL REPORT

EATR 4574

AEROSOL FILTRATION BY FIBROUS FILTER MATS

by

Leonard A. Jonas
Carlye M. Lochboehler
William S. Magee, Jr.

November 1971

DEPARTMENT OF THE ARMY
EDGEWOOD ARSENAL
Research Laboratories
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FOREWORD

The work described in this report was authorized under Task 1W662710A09501, Physical Protection Against Chemical Agents, Physical Protection Concepts. The work was performed from January to June 1971. The results are recorded in notebook 8339.

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DIGEST

The physical properties and aerosol filtration characteristics of US Army Edgewood Arsenal Types 5, 6, 7, and 8 fibrous filter mats were studied. Bulk densities for the filters ranged from 0.197 to 0.243 gm/cu cm and their porosities (fractional void volumes) from 0.845 to 0.883. The pressure drops of the filters were expressed as a function of the product of the mat thickness and the superficial linear velocity in a simple linear polynomial in conformity with Darcy's law for fluid flow through porous media. Filtration by the filter mats of the fine aerosol dioctylphthalate (DOP) with mean diameter of 0.3 micron was expressed by the equation log DOP % penetration = $-0.01\Delta P\,\alpha + 2$ at any discrete superficial linear velocity, where α was the filtration efficiency factor per unit pressure drop. Functional relationships among the ΔP and α parameters with the linear flow velocity permitted the log DOP % penetration equation to be recast in terms of mat thickness and linear velocity in accord with Dorman's semiempirical filtration equations. The flow regimes of Dorman were found to be quite consistent with the experimental data, and the parametric relationships confirmed the concept of a discrete flow velocity at which the maximum aerosol penetration of a filter occurred.

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13. ABSTRACT

The physical properties and aerosol filtration characteristics of US Army Edgewood Arsenal Types 5, 6, 7, and 8 fibrous filter mats were studied. Bulk densities for the filters ranged from 0.197 to 0.243 gm/cu cm and their porosities (fractional void volumes) from 0.845 to 0.883. The pressure drops of the filters were expressed as a function of the product of the mat thickness and the superficial linear velocity in a simple linear polynomial in conformity with Darcy's law for fluid flow through porous media. Filtration by the filter mats of the fine aerosol dioctylphthalate (DOP) with mean diameter of 0.3 micron was expressed by the equation log DOP % penetration $= -0.01 \Delta P \ \alpha + 2$ at any discrete superficial linear velocity, where α was the filtration efficiency factor per unit pressure drop. Functional relationships among the ΔP and α parameters with the linear flow velocity permitted the log DOP % penetration equation to be recast in terms of mat thickness and linear velocity in accord with Dorman's semiempirical filtration equations. The flow regimes of Dorman were found to be quite consistent with the experimental data, and the parametric relationships confirmed the concept of a discrete flow velocity at which the maximum aerosol penetration of a filter occurred.

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AEROSOL FILTRATION BY FIBROUS FILTER MATS

I. INTRODUCTION.

Much current interest is centered on the control and reduction of air pollution. One means of accomplishing this is the removal of fine aerosol particles from the air by fibrous filter mats.

The published literature in the general field of aerosol filtration is exceedingly voluminous, and the problem existing with the new experimentalist is how to limit the references in order not to stagger the reader without slighting the important contributions of many workers in this field. Excellent background in aerosol filtration can be found in the work of Fuks,[1] Pich,[2] Dorman,[3] Green and Lane,[4] and Werner and Clarenburg,[5,6] and in the publications of Torgeson,[7] Chen,[8] and First and Silverman.[9]

In addition to the generalized studies of aerosol filtration, a body of literature[10,11] had accumulated on methods of generating aerosols and measuring their particle-size distribution, the choice of solid or liquid aerosol, instrumentation for the detection of aerosol penetration of filters, and the underlying theories on which the development of the instrumental methods was based.

II. PURPOSE.

The purpose of this study was to determine the penetration characteristics of a 0.3-micron-diameter liquid dioctylphthalate (DOP) aerosol through four types of US Army mask filter mats as a function of variables, such as flow velocity, filter thickness, and pressure drop, and to develop in accord with present theory those mathematical relations which quantitatively express the experimental data.

III. THEORY.

Dorman [3,12,13] has developed a means of analyzing aerosol filtration data in terms of a semiempirical formulation which takes into account the relative contributions of inertial,

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1 Fuks, N. A. The Mechanics of Aerosols. Academy of Sciences of the USSR, Institute of Scientific Information. 1955.

2 Pich, J. Chem. listy 59, 1497 (1965).

3 Dorman, R. G. Aerosol Science. Academic Press, New York, New York. 1966.

4 Green, H. L., and Lane, W. R. Particulate Clouds: Dusts, Smokes, and Mists. E & F. N. Spon, Ltd., London, England. 1957.

5 Werner, R. M., and Clarenburg, L. A. Ind. Eng. Chem. Process Des. Develop. 4, 288 (1965).

6 Clarenburg, L. A., and Werner, R. M. Ibid., p 293.

7 Torgeson, W. L. Mechanics and Kinetics of Aerosol Filtration. Environmental Research Corporation, St. Paul, Minnesota. 1968.

8 Chen, C. Y. Chem. Rev. 55, No. 3, 595 (1955).

9 First, M. W., and Silverman, L. A. M. A. Arch. Ind. Hyg. 7, 1 (1953).

10 Handbook on Aerosols. Atomic Energy Commission, Washington, DC. US Government Printing Office. 1950.

11 Handbook on Air Cleaning; Particulate Removal. Department of Industrial Hygiene, School of Public Health, Harvard University and Atomic Energy Commission, Washington, DC. US Government Printing Office. 1952.

12 Dorman, R. G. Aerodynamic Capture of Particles. Pergamon Press, Oxford, England. 1960.

13 Dorman, R. G. Int. J. Air Pollut. 3, 112 (1960).

diffusional, and interception mechanisms. Implicit to his work is the assumption that these three mechanisms contribute additively. Hence, the percentage penetration may be related to physical parameters of the system by the expression

$$\log \text{DOP \% penetration} = -\left(k_R \lambda V_L^{x} + k_D \lambda V_L^{-y} + k_I \lambda\right) + 2 \qquad (1)$$

where k_R, k_D, and k_I are, respectively, the inertial, diffusional, and interception parameters, V_L is the superficial linear velocity, and λ is the thickness of the filter. Dorman reported that x and y are found empirically to be in the ranges between 3/2 and 2 and between 1/2 and 2/3, respectively.

As demonstrated experimentally, a plot of log DOP % penetration versus V_L exhibits a maximum for the velocity equal to, say, $\bar{V}_L$. Knowing this, we find the analytic maximum for equation 1 by taking the derivative with respect to V_L and setting it equal to zero. From this, we obtain the relation

$$k_D = k_R \left(\frac{x}{y}\right) \bar{V}_L^{(x+y)} \qquad (2)$$

with which equation 1 can be reduced to the form

$$\log \text{DOP \% penetration} = -k_R \lambda \left[V_L^{x} + \left(\frac{x}{y}\right) \bar{V}_L^{(x+y)} V_L^{-y}\right] - k_I \lambda + 2. \qquad (3)$$

Plots of [2 - log DOP % penetration] versus $\left[V_L^{x} + \left(\frac{x}{y}\right) \bar{V}_L^{(x+y)} V_L^{-y}\right]$ being straight lines enable k_R and k_D to be calculated from the slope and k_I from the intercept.

Darcy's law [14] for flow of an incompressible fluid through a porous material of length λ, cross-sectional area A, volumetric flow rate q, fluid viscosity μ, and material permeability K expresses the pressure drop ΔP as

$$\Delta P = \frac{\mu q}{KA/\lambda} = \frac{\mu}{K} \lambda V_L = k_3 \lambda V_L \qquad (4)$$

where k_3 is the ratio μ/K. In these relations, cognizance has been taken of the facts that $V_L = q/A$ by definition and that both μ and K are constants of the fluid flow and porous material under study.

From equation 4 above and equation A12 in the appendix, we form the expression

$$\log \text{DOP \% penetration} = -0.01\, k_3 \lambda \alpha V_L + 2 \qquad (5)$$

Comparisons of the right-hand sides of equations 3 and 5 yield, after logarithms are taken, the equation

$$\log \alpha = -\log V_L + \log \left\{ k_R \left[V_L^{x} \; 3 \left(\frac{x}{y}\right) \bar{V}_L^{(x+y)} V_L^{-y}\right] + k_I \right\} - \log (0.01 k_3) \qquad (6)$$

The above set of equations forms the basis for analysis of our experimental data.

[14] Collins, R. E. Flow of Fluids through Porous Materials. pp 10-11. Reinhold Publishing Corporation, New, New York. 1961.

IV. EQUIPMENT.

The equipment used to test the filtration characteristics of the filter mats was a DOP aerosol test apparatus.[10] The apparatus, assembled on a laboratory bench and occupying a space 2 feet deep, 3 feet high, and 8 feet wide, consisted of three functional parts: (1) generator for the test aerosol, (2) holder for exposure of the filter mat to the aerosol, and (3) detector for measurement of that fraction of the challenge aerosol penetrating the filter. The aerosol was produced by an MIT-E1R9 generator which employed a total airstream of 100 liters per minute (ℓpm), dividing it into a 20 ℓpm portion which was preheated (150°C) and directed into a chamber at 168°-170°C where it passed over DOP liquid picking up the existing vapor and was subsequently quenched with the remaining 80 ℓpm air at room temperature. The temperature gradient in this quenching step caused formation of the fine DOP aerosol (mean diameter of 0.3 micron). The concentration of aerosol formed was established between 80 and 120 μg per liter of air by regulation of the temperature of the DOP liquid. The particle size of the aerosol was adjusted, as desired, by the temperature of a small filament heater in the 80 ℓpm quenching airstream which altered the temperature gradient. The desired mean value of 0.3μ diameter corresponded to a reading of 29° (±1°) on the MIT-E1R2 particle size meter, referred to as the Owl. The newly formed aerosol was next directed into a 5-gallon reservoir which served to age or store the DOP aerosol. The aerosol was drawn by vacuum from the reservoir through the remaining portions of the test apparatus when required. Excess aerosol generated was vented to a laboratory hood.

The sample filter mats were conditioned in the laboratory at the temperature (25°C) and relative humidity (50%) of the room. The mats were positioned in a cast iron mat holder which held them in place by means of a pressure seal and exposed an area of 100 sq cm to the challenge DOP aerosol.

The detection and measurement of that fraction of the challenge DOP aerosol penetrating the filter mat were accomplished with an NRL-E2R1 smoke penetration meter which employed small angle forward light scattering to measure the DOP aerosol. The meter was capable of detecting penetrating aerosol particles over a range of 0.001% to 100%.

V. PROCEDURE.

The generator cup was filled with liquid DOP to a depth of 2 inches. All electrical and heater switches were activated including an auxiliary heater, which in a 15-minute period aided in attaining the operating temperature (168°-170°C) for the DOP. When the operating temperature was reached, the air pressure valves were opened to generate the DOP aerosol. The aerosol particle size was checked with the Owl; and the temperature gradient adjusted until a mean 0.3μ-diameter aerosol was being formed.

The concentration range of 80 to 120 μg of DOP per liter of air was determined as follows: A 5-1/4 by 5-1/2-inch cut of Type 6 filter mat, having reached equilibrium at the temperature and relative humidity of the room, was placed in the filter mat holder and exposed to air without DOP for 15 minutes at a flow of 32 ℓpm. The mat was removed from the holder and, after an additional 10-minute waiting period, the initial weight of the mat was obtained to the nearest tenth of a milligram on an analytical balance. The same mat was then replaced in the holder and exposed to the DOP aerosol concentration for 15 minutes at 32 ℓpm. After another 10-minute waiting period, the final weight was determined. The mean concentration was calculated by dividing the net increase in filter weight due to DOP by the volume of air passed through the filter. After the desired concentration range was obtained, the system was purged with pure air prior to actual testing of the filter mats.

Pressure drop and DOP % penetration were determined in the following manner for one through six layers of Type 5 filter material over a linear velocity range of 50 through 797 cm/min and for one layer of Types 6, 7, and 8 filter materials over a linear velocity range of 80 through 850 cm/min.

The filter mat was placed in the pad holder and the pressure drop across the filter mat at the specific flow velocity was noted from a pressure manometer. Next, the mat was exposed to the predetermined DOP aerosol concentration by drawing the aerosol through the mat at the same flow velocity. The DOP % penetration was read directly as the maximum deflection of the microammeter needle on the NRL penetrometer. The system was again purged before each pressure drop and DOP penetration determination.

VI. RESULTS AND DISCUSSION.

The four filter mats studied, Types 5 through 8, were each composed of both aerosol filtering fibers and coarse matrix fibers. The fine filtering fibers in Types 5, 6, and 7 were blue Bolivian crocidolite asbestos beaten to separate the mineral clusters and in Type 8, AAA glass fibers, having a range of diameters between 0.50 and 0.74 micron. Matrix fibers in the various filter mats consisted of mixtures of fibers such as cotton, rayon, hemp, and wood pulp. Density values for the various fibers ranged from 1.15 to 3.25 gm/cu cm.[15] The compositions used for the formation of the filter mats are shown in table I.

Table I. Composition of Fibrous Filter Mats

Fiber		Percent composition of filter			
Type	Density	Type 5	Type 6	Type 7	Type 8
	gm/cu cm				
Cotton floc	1.52	58.2	25.6	-	-
Viscose rayon	1.51	34.0	-	42.0	46.3
Manila hemp	1.48	4.9	6.4	4.3	9.8
Blue Bolivian crocidolite asbestos	3.2-3.3	2.9	20.0	11.7	-
Duralba wood pulp	1.15	-	-	42.0	23.9
AAA glass	1.25	-	-	-	20.0
Causticized esparto	1.33	-	48.0	-	-

[15] Hall, A. J. The Standard Handbook of Textiles. p 94. Chemical Publishing Company, New York, New York. 1965.

Weight per unit area and mat thickness values were determined for each of the four filter types. From these data, physical properties such as the bulk density, mean fiber density, volume fiber fraction, and porosity (volume void fraction) were calculated. The mean fiber density for the filter was calculated as the weighted mean in accord with

$$\bar{d}_f = \sum_{1}^{n} (d_{fiber} \times \text{fiber fractional composition}) \tag{7}$$

where n was the number of different fibers in the composition of the filter. The porosity ϵ of the filter mat was calculated from the relationship

$$\epsilon = \frac{\dfrac{1}{\text{Bulk density}} - \dfrac{1}{\bar{d}_f}}{\dfrac{1}{\text{Bulk density}}} \tag{8}$$

since the reciprocal of the bulk density represented the specific volume (cu cm/gm) of the filter mat which included both the specific volume of the filter fibers and their interfiber space volumes. The fraction of a total filter volume filled by fibers (σ) was

$$\sigma = 1 - \epsilon \tag{9}$$

The physical properties of the filter mats are shown in table II.

Table II. Filter Mat Physical Properties

Filter type	Weight per unit area	Thickness*	Bulk density	Weighted mean fiber density	Fiber fraction, σ	Porosity (volume void fraction)
	gm/sq cm	cm	gm/cu cm	gm/cu cm		
5	0.0128	0.062	0.206	1.565	0.131	0.869
6	0.0214	0.103	0.208	1.772	0.117	0.883
7	0.0245	0.101	0.243	1.561	0.155	0.845
8	0.0203	0.103	0.197	1.369	0.144	0.856

* Measured with Randall and Stickney thickness gauge.

The pressure drop across the filter, resulting from forced airflow through the filter, was determined as a function of both the number of layers and the superficial linear velocity for Type 5 filter mats. Because of the high pressure drop across one layer of the Types 6, 7, and 8 filters, pressure drop was determined only as a function of linear velocity. Pressure drop measurements in millimeters of water were made for as many as six layers of

Type 5 filters. For the Type 5 filter, the superficial linear velocity range tested was 50 to 2983 cm/min; for Types 6, 7, and 8, from 80 to 850 cm/min. The data are shown in tables III and IV. Pressure drop versus number of Type 5 layers is plotted in figure 1 and shown as a family of straight line curves depending upon the superficial linear velocity of flow.

Table III. Pressure Drop as a Function of Layers of Type 5 Filters

Linear velocity	Pressure drop, ΔP					
	1 Layer	2 Layers	3 Layers	4 Layers	5 Layers	6 Layers
	mm of water					
50	1	2	3	4	5	6
100	2	4	6	9	11	12
150	3	7	10	12	16	19
200	4	9	13	16	20	24
300	7	13	20	26	32	38
400	8	16	25	34	41	51
500	10	20	32	43	53	64
600	12	23	35	49	59	70
700	13	27	42	55	66	-
797	14	27	43	56	69	83
983	16	31	49	64	79	93
1014	17	33	53	67	81	97
1492	28	52	76	92	126	152
2029	35	70	104	135	163	195
2506	47	90	125	166	216	249
2983	52	106	152	199	246	292

Table IV. Pressure Drop as a Function of Linear Velocity

Linear velocity, V_L	Pressure drop, ΔP		
	Type 6	Type 7	Type 8
cm/min	mm of water		
80	10	10	7
100	13	14	10
150	21	22	15
200	28	30	20
300	43	44	30
400	56	58	39
500	70	70	48
600	82	84	56
650	88	89	60
700	95	95	65
750	100	100	67
800	103	106	72
850	111	111	75

The above data for Type 5 mats were recalculated in terms of pressure drop as a function of sq cm/min (product of the filter mat thickness λ and the superficial linear velocity V_L) and plotted as a single straight line in figure 2 (including all the data shown by the family of straight lines of figure 1). The points shown are the experimental data; and the smooth line, the Univac 1108 computer regression line (coefficient of correlation R of 0.99840). The regression line equation for the Type 5 filter mat was

$$\Delta P \text{ (mm of water)} = 0.268\lambda V_L \text{ (sq cm/min)} \quad (10)$$

or in cgs units

$$\Delta P \text{ (gm/cm-sec}^2\text{)} = 0.438\lambda V_L \text{ (sq cm/sec)} \quad (11)$$

which is in accord with Darcy's law, shown in equation 4, where the slope μ/K is equal to 0.438.

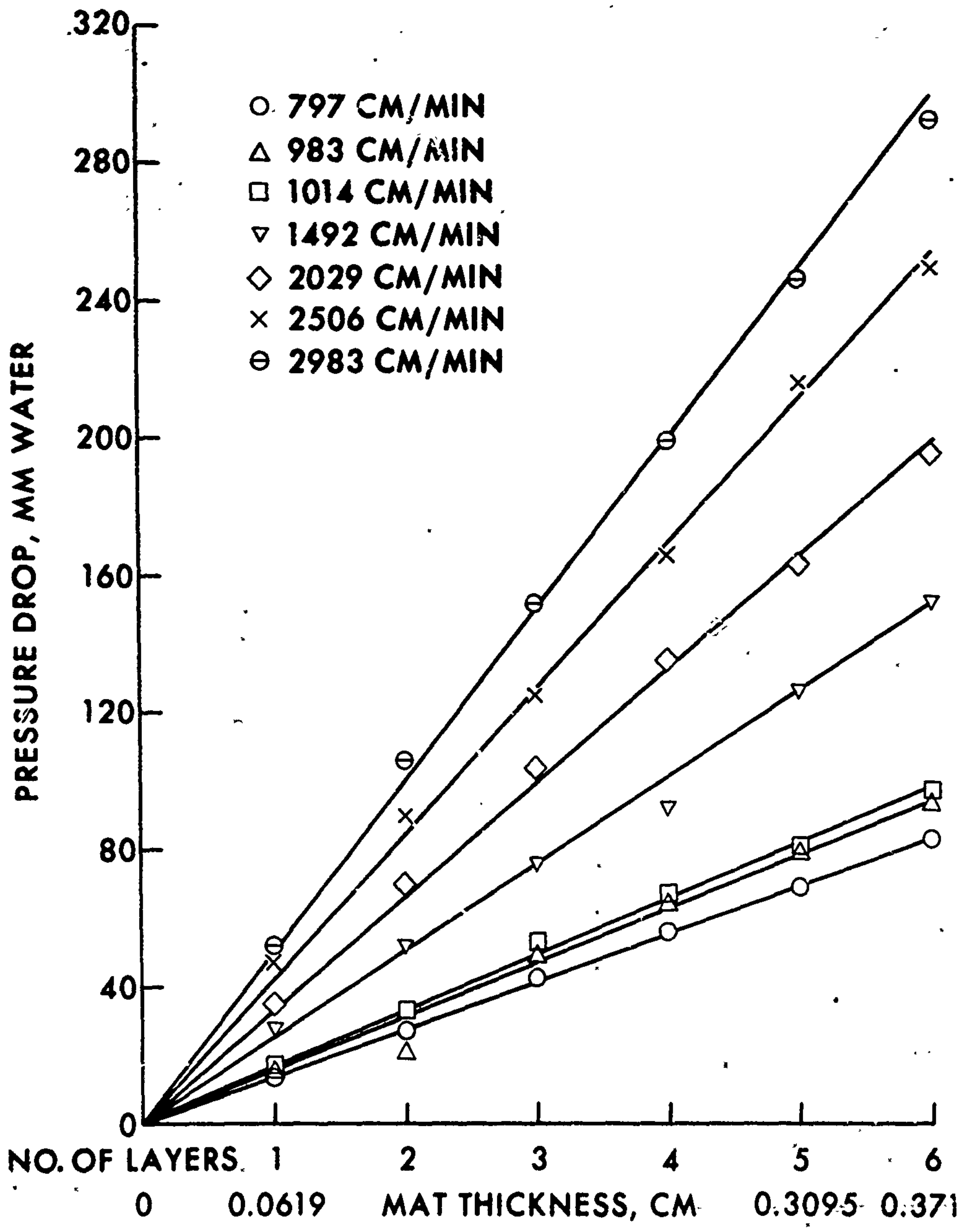

Figure 1. Pressure Drop Versus Mat Thickness at Velocities for Type 5 Filters

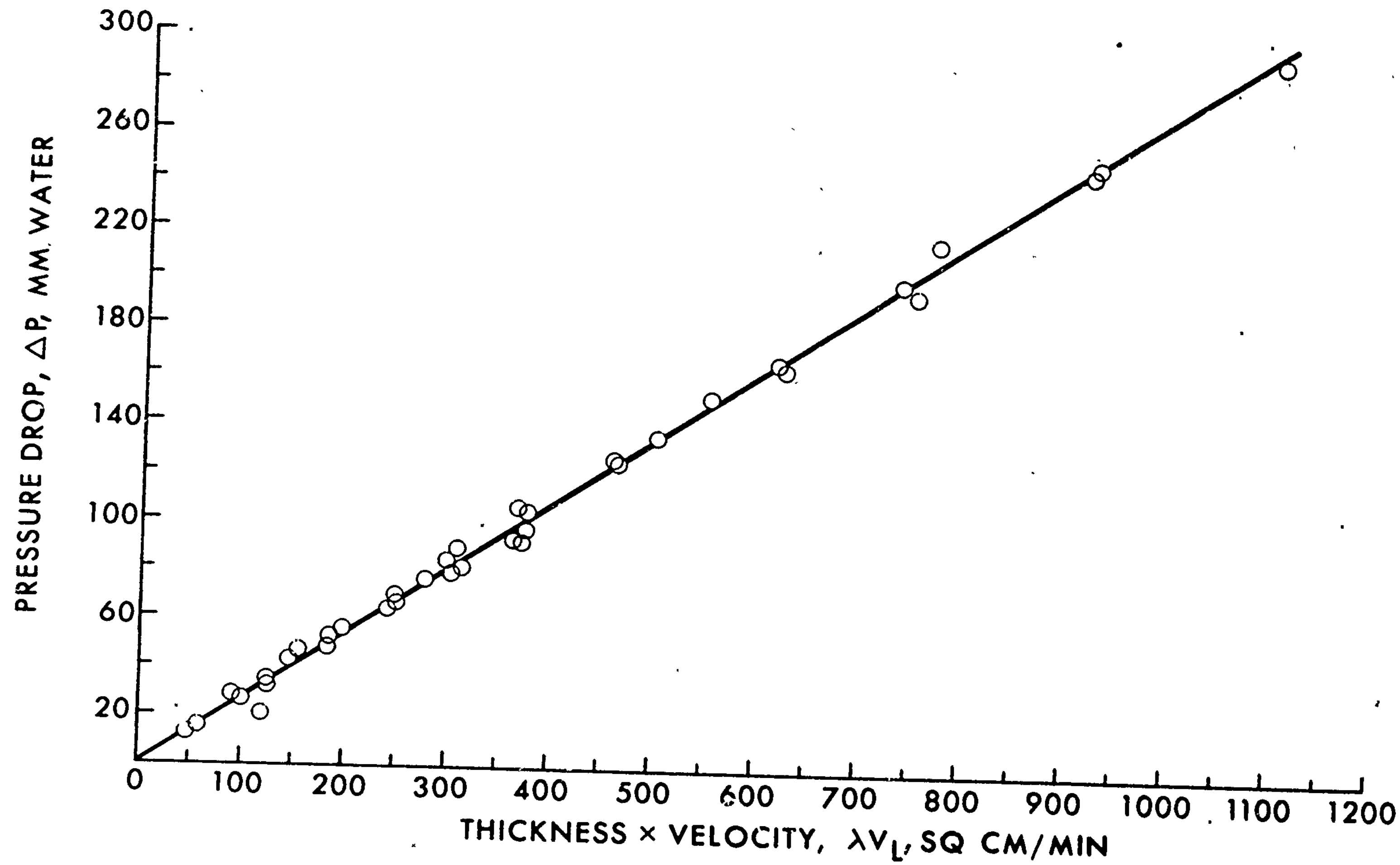

Figure 2. Pressure Drop as a Function of Mat Thickness *Times* Linear Velocity for Type 5 Filters

The pressure drop versus λV_L relations for Types 6, 7, and 8 filter mats was also determined by multiplying the filter thickness values shown in table II by the V_L values in table IV and then plotted as the straight line curves in figure 3. The individual points are the data values; the smooth lines, the computer derived regression equations. The equations derived were as follows:

For Type 6: ΔP (mm of water) = $1.297\lambda V_L$ (R = 0.99856)

For Type 7: ΔP (mm of water) = $1.335\lambda V_L$ (R = 0.99829)

For Type 8: ΔP (mm of water) = $0.883\lambda V_L$ (R = 0.99815)

As shown for Type 5, the slope (μ/K) of Darcy's equation varies for each filter. However, since the fluid viscosity μ was constant, the variations in slope were attributable to differences in the material permeability factor K for each of the filters studied.

The aerosol filtration characteristics of the various filter mats were studied using DOP aerosols with a mean diameter of 0.3 micron and measuring the percentage penetration of the DOP through the mats. The penetration of Type 5 mats was tested as a function of pressure drop by using multilayers of mats at any one flow velocity and by using single layers and varying the velocity. These data are shown in table V. Figure 4 shows that for these data a plot of the log DOP % penetration is an inverse linear function of pressure drop and results in a family of straight line curves for the various flow velocities. The equations of these straight line curves for the six linear velocities plotted (ranging from 50 to 797 cm/min) are shown in table VI in accordance with the equation form

$$\log \text{DOP \% penetraton} = -0.01\alpha\Delta P + 2$$

which is derived in the appendix and noted as equation A12, where the slope of the log DOP % penetration versus ΔP plot is equal to -0.01α.

Table V. DOP % Penetration of Type 5 Filter Mats as a Function of Layers and Linear Flow Velocity

Linear velocity	DOP % penetration through					
	1 Layer 0.0619 cm	2 Layers 0.1238 cm	3 Layers 0.1857 cm	4 Layers 0.2476 cm	5 Layers 0.3095 cm	6 Layers 0.3714 cm
cm/min						
50	17.000	2.390	0.330	0.055	0.006	-
100	18.000	3.150	0.462	0.070	0.013	0.001
150	19.000	3.360	0.798	0.170	0.029	0.006
200	19.000	4.116	0.756	0.210	0.033	0.007
300	21.000	3.990	0.819	0.200	0.041	0.008
400	26.000	5.000	1.092	0.240	0.059	0.007
500	25.000	5.500	1.071	0.200	0.043	0.006
600	24.500	5.000	1.176	0.255	0.065	0.015
700	24.500	5.000	1.197	0.245	0.057	0.012
797	22.000	5.000	1.008	0.235	0.040	0.009

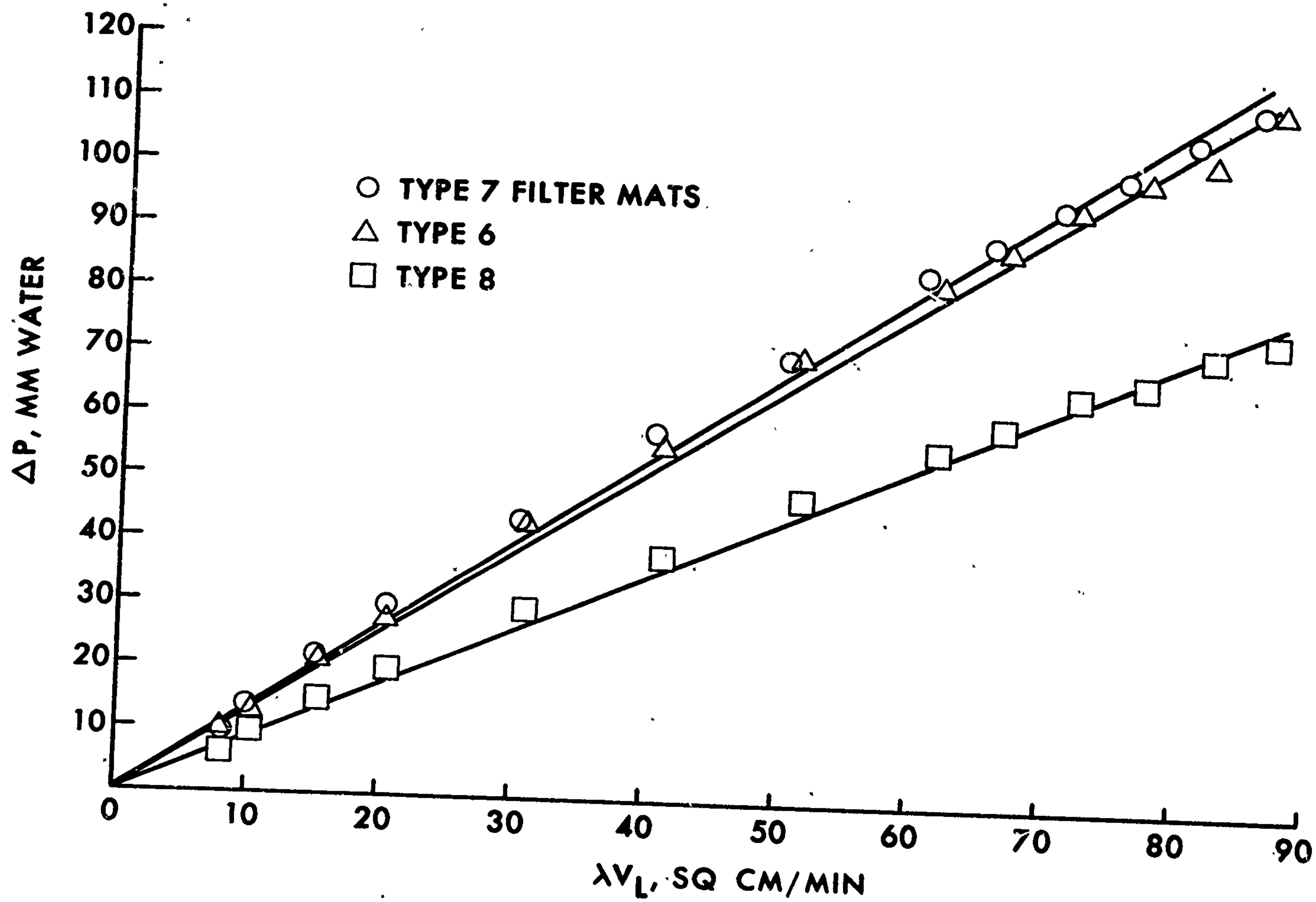

Figure 3. Pressure Drop as a Function of Thickness *Times* Velocity

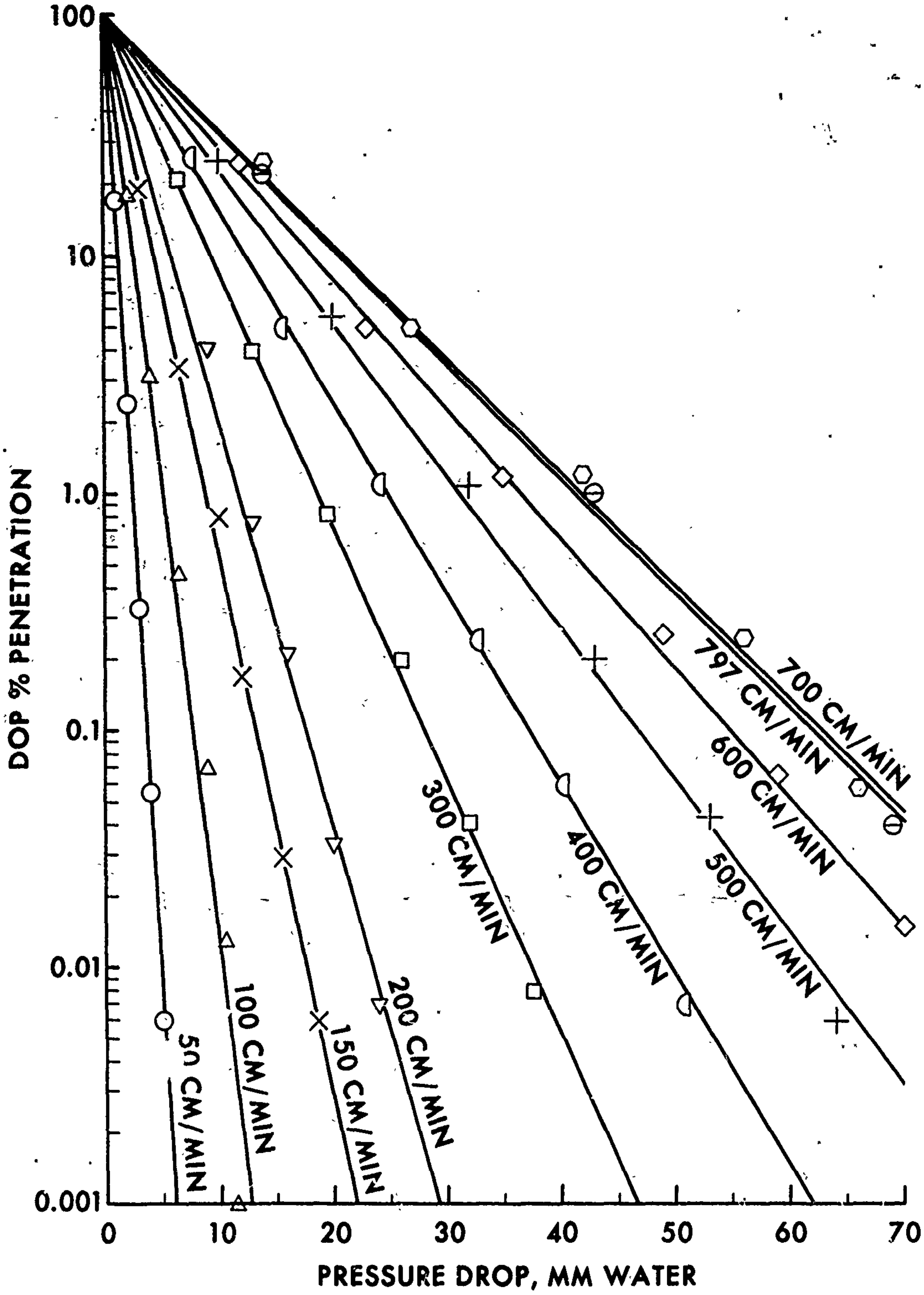

Figure 4. DOP Penetration as a Function of Pressure Drop at Various Velocities for Type 5 Filters

Table VI. Filtration Efficiency as a Function of Velocity for Type 5 Mats

Linear velocity, V_L	Aerosol penetration equation	Filtration efficiency, α
cm/min		
50	log DOP % penetration = -0.8807 ΔP + 2	88.1
100	log DOP % penetration = -0.3651 ΔP + 2	36.5
150	log DOP % penetration = -0.2276 ΔP + 2	22.8
200	log DOP % penetration = -0.1676 ΔP + 2	16.8
300	log DOP % penetration = -0.1059 ΔP + 2	10.6
400	log DOP % penetration = -0.0797 ΔP + 2	7.97
500	log DOP % penetration = -0.0628 ΔP + 2	6.28
600	log DOP % penetration = -0.0544 ΔP + 2	5.44
700	log DOP % penetration = -0.0475 ΔP + 2	4.75
797	log DOP % penetration = -0.0483 ΔP + 2	4.83

Figure 5 shows that a plot of the log DOP % penetration versus velocity has a maximum for each of the six layers displayed, the maxima being 450, 550, 580, 540, 520, and 570 cm/min for the one to six layers, respectively.

Because of the high aerosol filtration per layer, the Types 6, 7, and 8 mats were only studied by varying the flow velocity through single layers. These data are shown in table VII and plotted in figure 6. Again the plot shows the characteristic maxima in the penetration of DOP aerosols as a function of velocity, the maxima occurring at 560, 640, and 670 cm/min for Types 6, 7, and 8 mats, respectively. The velocity at which the maximum DOP % penetration occurs was indicated by $\bar{V}_L$ and obtained by direct inspection of the log DOP penetration versus velocity plots.

Should the plot of log DOP penetration versus velocity for some filters show either an apparent absence of a maximum or a broad plateau which prevents unique determination of $\bar{V}_L$ by inspection, the following alternative method for determination of $\bar{V}_L$ was devised. From equation 6 we see that for x = 2 and y = 2/3

$$\frac{d \log \alpha}{d \log V_L} = -1 + \frac{2k_R\left[V_L^2 - \bar{V}_L^{8/3} V_L^{-2/3}\right]}{\left[k_R\left(V_L^2 + 3\bar{V}_L^{\,8/3} V_L^{-2/3}\right) + k_I\right]} \qquad (12)$$

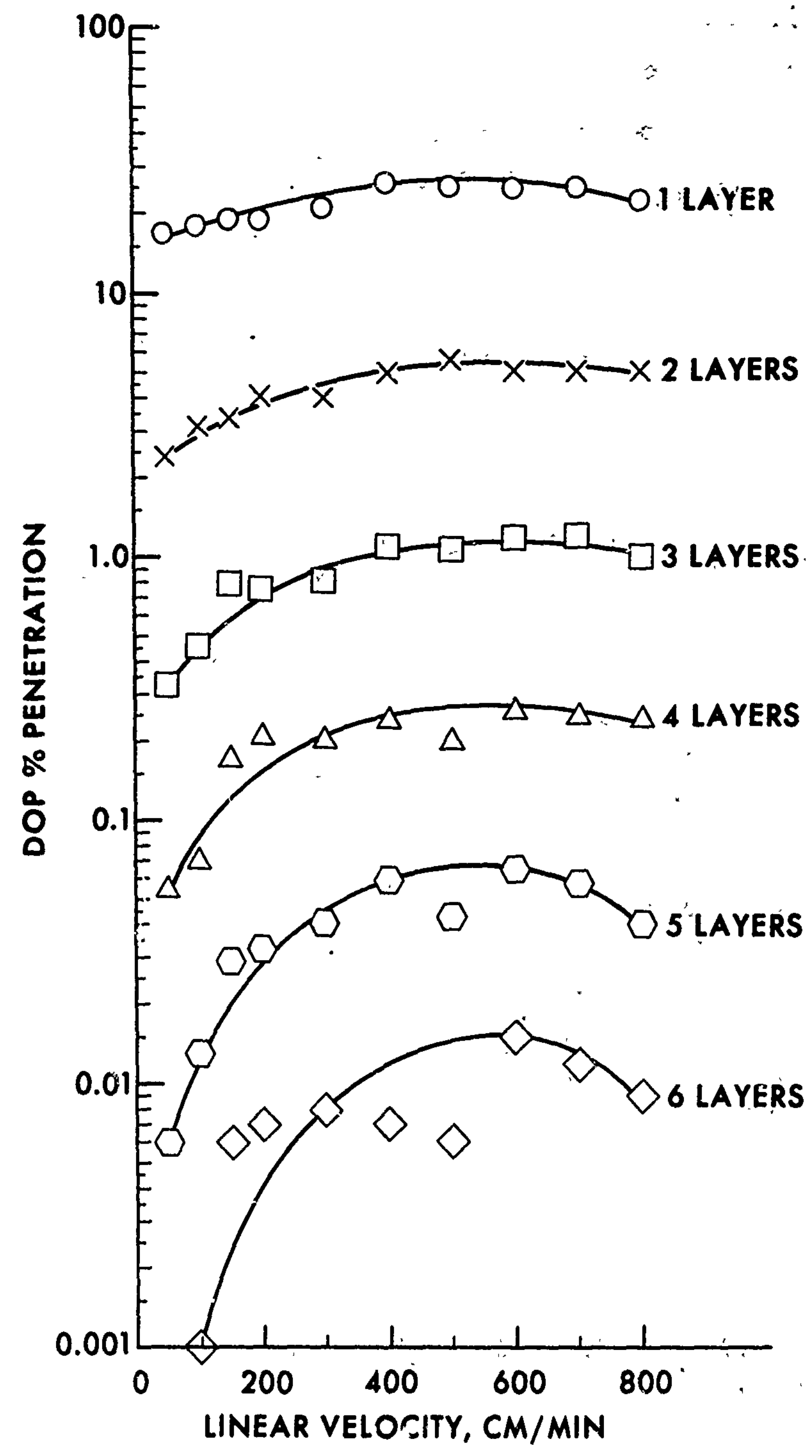

Figure 5. DOP Penetration as a Function of Linear Velocity for Various Layers of Type 5 Filter

Table VII. DOP % Penetration of Filter Mats as a Function of Linear Flow Velocity

Linear velocity	DOP % penetration through		
	Type 6	Type 7	Type 8
cm/min			
80	0.005	0.000	0.000
100	0.017	0.003	0.001
150	0.033	0.013	0.008
200	0.046	0.018	0.013
300	0.062	0.023	0.015
400	0.071	0.035	0.018
500	0.087	0.039	0.021
600	0.079	0.045	0.022
650	0.079	0.044	0.034
700	0.084	0.046	0.027
750	0.073	0.038	0.030
800	0.072	0.034	0.021
850	0.054	0.027	0.020

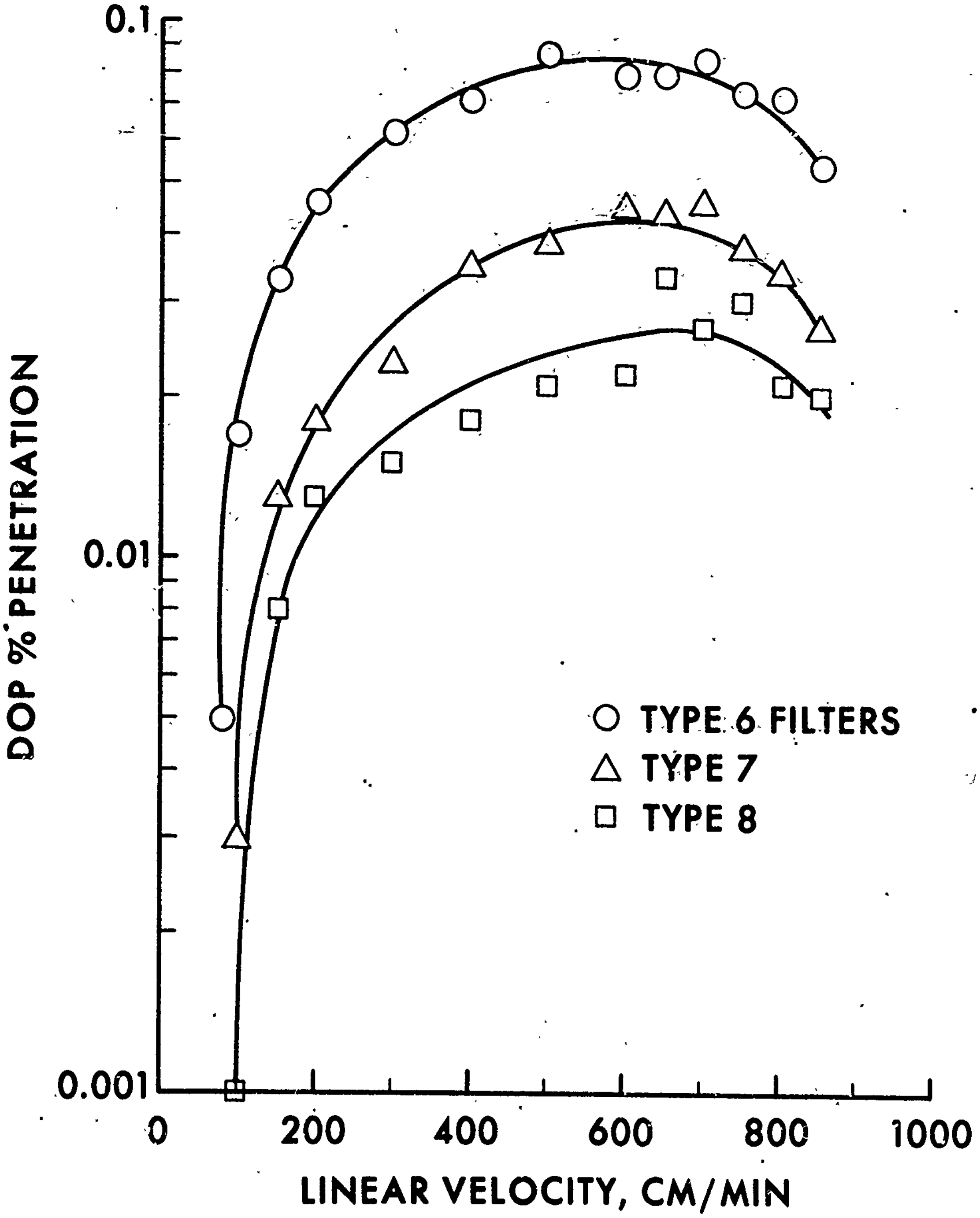

Figure 6. DOP Penetration as a Function of Linear Velocity

with the second term > 0 if $V_L > \bar{V}_L$, = 0 if $V_L = \bar{V}_L$, and < 0 if $V_L < \bar{V}_L$. Thus, the magnitude of the slope, i.e. $\frac{d \log \alpha}{d \log V_L}$, decreases as V_L increases. The experimental results in table VI are plotted as log α versus log V_L in figure 7 and demonstrate this increasing magnitude of slope with increasing V_L. The value of $\bar{V}_L$ is the abscissa value for the point of tangency of this curve with a straight line with slope equal to minus unity. This uniquely determines $\bar{V}_L$ as seen from equation 12.

The filtration data shown in tables V and VII were replotted in figure 8 according to the Dorman procedure as expressed in equation 3 with x = 2 and y = 2/3. These values are chosen for a best fit and, as stated by Dorman,[13] with some theoretical justification for the latter value. Straight line curves were obtained for the Types 5, 6, 7, and 8 filter mats. Since the slope of these lines equals λk_R, the y-axis intercept equals λk_I, and k_D equals $3k_R\bar{V}_L{}^{8/3}$ (from equation 2), the three Dorman parameters were calculated for the various filter mats and are shown in table VIII.

Table VIII. Dorman Parameters for Aerosol Filter Mats

Dorman parameter	Filter mat			
	Type 5	Type 6	Type 7	Type 8
Inertial k_R	1.51×10^{-6}	4.67×10^{-6}	3.72×10^{-6}	3.82×10^{-6}
Diffusional k_D	53.9	298	354	402
Interception k_I	8.99	24.0	27.3	27.8

VII. CONCLUSIONS.

The experimental study of Edgewood Arsenal Types 5, 6, 7, and 8 fibrous filter mats showed that the pressure drops across the filters were linear functions of the product of mat thickness and superficial linear velocity differing only in slope, in accordance with Darcy's law of fluid flow through porous media. The experimental data on DOP penetration through the filters were satisfactorily described as functions of pressure drop and superficial linear velocity in accordance with an equation derived by assuming aerosol removal is a first order removal process. The derived equation was completely compatible with Dorman's flow velocity equation whose parameters for the diffusion, interception, and inertia régimes provided excellent characterization for the DOP filtration properties of the filters. On a single layer basis, the aerosol filtration capabilities of Types 6, 7, and 8 were quite similar, being somewhat less efficient than that of the Type 5 filter.

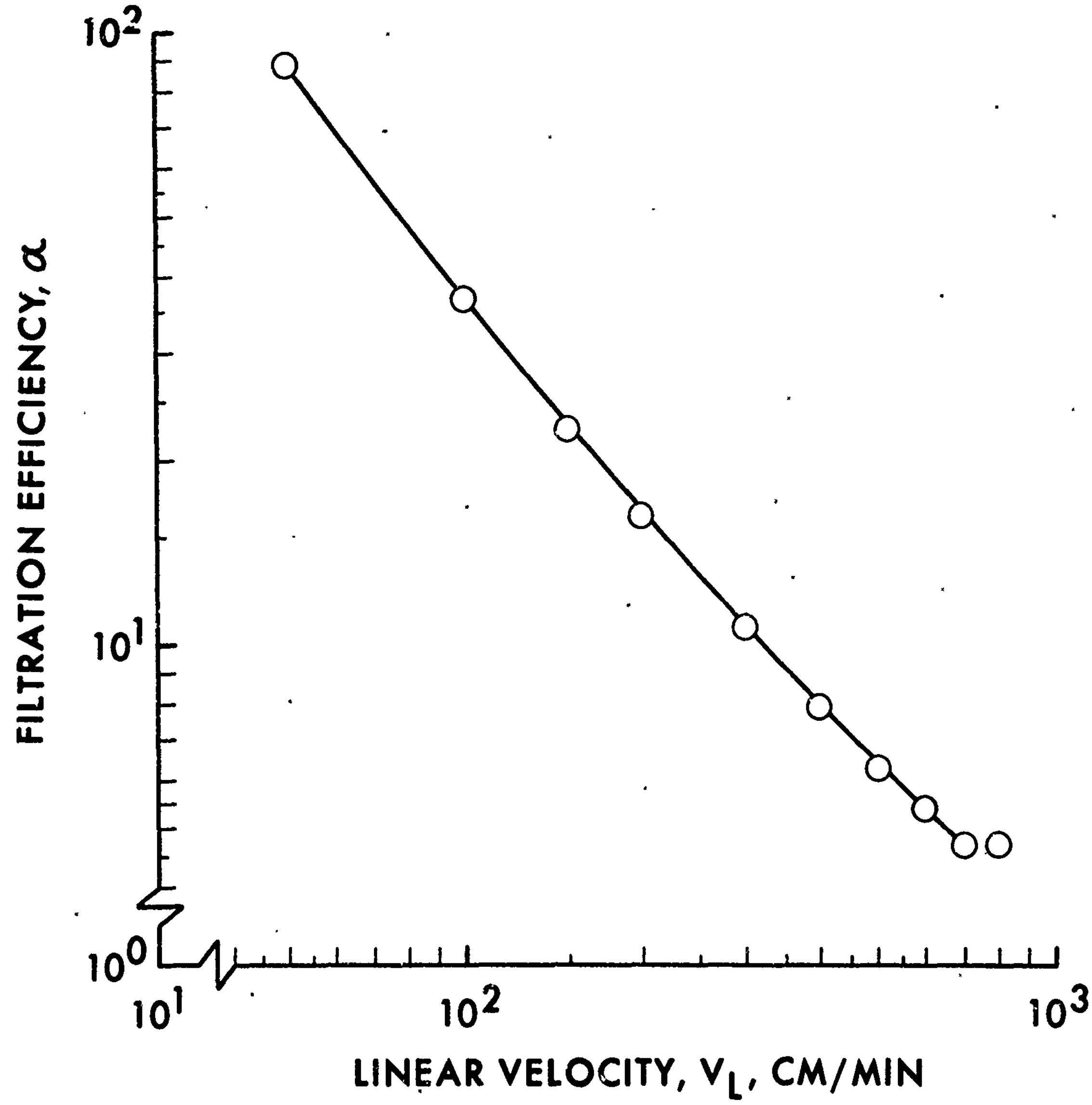

Figure 7. Filtration Efficiency as a Function of Velocity for Type 5 Filter Mat

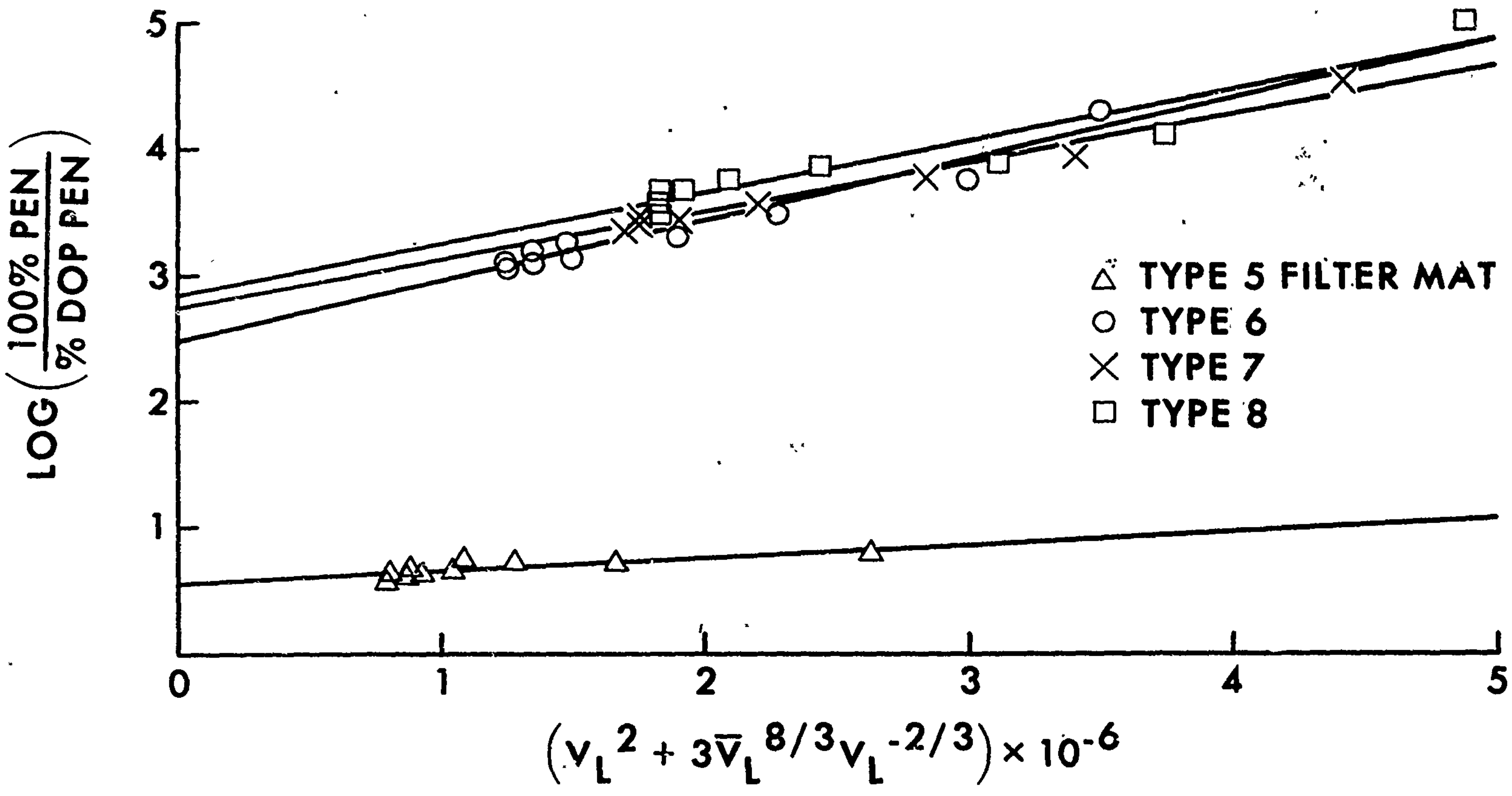

Figure 8. Log (100% Penetration/% DOP Penetration) Versus ($V_L^2 + 3\bar{V}_L^{8/3} V_L^{-2/3}$) for Various Filter Mats

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APPENDIX

DERIVATION OF AEROSOL FILTRATION EQUATION

Assume that aerosol filtration by a filter mat can be represented as a first order removal process. Then

$$-\frac{dn}{d\lambda}\, \alpha n \qquad \text{(A1)}$$

where n is the number density of aerosol particles (number/cu cm) and λ is the filter thickness. The constant of proportionality k changes equation 1 to

$$-\frac{dn}{d\lambda} = kn \qquad \text{(A2)}$$

$$-\int_{n_1}^{n_2} \frac{dn}{n} = k \int_{\lambda_1}^{\lambda_2} d\lambda \qquad \text{(A3)}$$

$$-\ln \frac{n_2}{n_1} = k\lambda \qquad \text{(A4)}$$

since $\lambda_2 - \lambda_1$ constitutes the boundaries of the filter thickness and therefore λ_1 can be set as zero.

From Darcy's law, equation 4, we see that the pressure drop ΔP is a linear function of filter thickness for a fixed velocity, then

$$\Delta P = k_1\lambda \qquad \text{(A5)}$$

Thus,

$$-\ln \frac{n_2}{n_1} = k_2\Delta P \qquad \text{(A6)}$$

where k_2 is equal to k/k_1 and n_2/n_1 is the fractional density of DOP particles penetrating the filter. It follows, therefore, that

$$\frac{n_2}{n_1} = \frac{\text{DOP \% penetration}}{100} \qquad \text{(A7)}$$

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and thus from equation A6

$$- \ln \frac{\text{DOP \% penetration}}{100} = k_2 \Delta P \tag{A8}$$

or

$$- \ln \text{DOP \% penetration} + \ln 100 = k_2 \Delta P \tag{A9}$$

from which

$$\log \text{DOP \% penetration} = - \frac{k_2}{2.303} \Delta P + 2 \tag{A10}$$

Defining

$$a = k_2/(2.303 \times 10^{-2}) \tag{A11}$$

then

$$\log \text{DOP \% penetration} = - 0.01\, a \Delta P + 2 \tag{A12}$$