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PARTICLE COLLECTION EFFICIENCIES ON CYLINDRICAL WIRES

G.A. Sehmel

Atmospheric Physics Section
ATMOSPHERIC SCIENCES DEPARTMENT

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18		Battelle, Pacific Northwest Laboratories	
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23		THE ABSTRACT	
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25		Collection efficiencies of monodispersed 4 to 27 μ m uranine	
26		particles were determined for 0.020 to 0.064 in. diameter wires	
27		for air velocities from 8.6 to 33.1 ft/sec. The wires were coated	
28		with tacky films. The collection efficiencies are a complex func-	
29		tion of particle size, wire diameter, Reynolds number, Stokes' num-	
30		ber, and wire surface area covered by previously impacted par-	
31		ticles. For low surface coverages from 0.1 to 10% an asymptotic	
32		correlation is shown as a function of Stokes' number. This asymp-	
33		tote is near the upper experimental limit of published collection	
34		efficiency data. When greater than about 10% of the available	
35		surface is covered with particles, the collection efficiencies are	
36		less than those indicated in published correlations. The dis-	
37		agreement in published impaction efficiencies may be caused by	
38		failure to account for the decrease in impaction efficiency as the	
39		surface area coverage increases.	
40			
41			
42		INTRODUCTION	
43			
44		Particulate pollution can be controlled at the source by fil-	
45		tering the gases before exhaust gases are released. Improved	
46		understanding of filtration processes are continually needed to	
47		improve filter performance. Fibrous filters consist of many indi-	
48		vidual fibers which can be approximated as cylinders. Cylindrical	
49		particulate collectors are also important as a discrete particu-	
50			
51			
52		* This paper is based on work performed under United States Atomic	
53		Energy Commission Contract No. AT(45-1)-1830.	

Working Size Type Area: 8 1/2 x 11 in. (To be shot at 90°)
 Final Size Type Area: 30 x 47 in.
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late sampling method. Particulate impaction on cylinders also approximate the loss of air pollution on some vegetation geometries. This paper presents the experimental particle impaction data and correlations for predicting the collection efficiency on cylindrical wires. The particle collection efficiency is the fraction of particles approaching the wire per unit projected wire area which is retained by the wire. This means that the collection efficiency could be much less if the particles were not retained after impaction. As will be shown, this re-entrainment can be significant.

Particle impaction efficiencies have been calculated theoretically (1,3) and particle collection efficiencies have been experimentally (2,4,5,6,8,9,10) determined. The predicted agreement is qualitative between the different theories and several investigators. The general shape and relative values of the efficiencies show good agreement when average values are considered. However, there is much data scatter around the experimental averages and one must be rather arbitrary in the selection of which curve to use.

The equations of motion have been used to calculate particle trajectories used in calculating impaction efficiencies. These analyses show that the impaction efficiency should be a function of the Stokes' number as well as the Reynolds number. The Stokes' number is

$$\text{Stk} = S/D, \quad (1)$$

where D is the wire diameter and S is the stopping distance

$$S = \frac{\rho_p d^2 u}{18 \mu}. \quad (2)$$

The quantity ρ_p represents particle density, d is particle diameter, u is the air velocity, and μ the air viscosity. The Reynolds number $Re = D\rho u/\mu$ where ρ is the air density.

EXPERIMENTAL

The experimental procedures used for determining particle collection efficiencies have been previously described (8) for use with 0.035 in. diameter wires. Those data have been extended to wire diameters of 0.020 and 0.064 in. To determine collection efficiencies, monodispersed uranine particles from a spinning disc generator were passed vertically upward through a 2.8 in. inside diameter tube. Contained within the tube were three centrally located wires at one-half inch spacing in a horizontal plane.

Particles not collected on the wires were collected one inch downstream on a filter within a slip joint in the tube. After particle collection, the filter was cut into concentric annuli, and the annuli analyzed for the particle flux approaching the wire. The total particle flux was determined from water wash solutions of the wires and the filter. The wash solutions were analyzed fluorimetrically and the results used to calculate a particle mass balance.

Two different coatings on the wires were used to prevent particle re-entrainment and to determine if a significant difference occurred for the two coatings. The first coating was a smooth thin layer of petroleum jelly applied when melted. The second coating was applied from a warm solution of 2 g gelatin, 11 ml glycerin, and 12 ml water. The coatings were approximately 15 μm to 50 μm thick for the petroleum jelly and 25 μm to 50 μm thick for the gelatin-glycerin.

RESULTS

Particle collection efficiencies are different for coated versus non-coated wire surfaces. Initial experiments with non-coated wires showed a wide variation in collection efficiencies which were also less than anticipated from published results. The low values of collection efficiencies reflected that particle re-entrainment had occurred. Consequently, the wires were coated to prevent re-entrainment. The uranine particles [density of 1.5 g/cm^3 , (7)] reacted differently on the two types of coatings. The particles retained their original shape on the petroleum jelly coated wires. After collection, the particle concentration on some of these wires was qualitatively determined using a microscope. The relative particle concentration was a maximum along the frontal edge of the wire (0° angle) and decreased to a negligible concentration at 90° . No particles were observed from 90° to 180° on the wires examined. In contrast, the uranine particles collected on the gelatin-glycerin coating soon lost their identity and were absorbed and diffused throughout the coating from 0° to 180° . Although the particle behavior on the coatings was different, differences in collection efficiencies between the coatings were not consistently different when a small fraction of the wire was covered by particles. Surface coverage will be defined as the total projected areas of particles collected on the wire divided by the projected wire area.

The experimental particle collection efficiencies are shown in Fig. 1 as a function of the Stokes' number. The collection efficiencies are from near zero to greater than unity. Values greater than unity are caused by the interception effect which is

important for larger particles. As shown in the figure, collection efficiencies were obtained for most combinations of five particles diameters (4,6,9,14 and 27 μ m) and three air velocities (8,6,16.2, and 33.1 ft/sec). For these air velocities, the air turbulence intensities measured with a hot wire anemometer are given in Table I.

First Line of Title TABLE I

Second Line of Title TURBULENCE INTENSITY

Air Velocity ft/sec	Air Turbulence Intensity - (%)
8.6	9.8
16.2	7.4
33.1	6.5

The collection efficiencies show a wide range in value for any Stokes' number. Obviously the Stokes' number by itself is not the sole correlating parameter. For instance at small Stokes' numbers, the collection efficiency is very low which would suggest that a large turbulence intensity could significantly increase the collection efficiency. The effect of turbulence and other factors will be determined, but first the data spread of Fig. 1 should be compared with literature values of the collection efficiency.

The data in Fig. 1 are represented by an asymptote for the upper collection efficiency for any Stokes' number. Also shown is a lower limit ascribed to surface coverage effects. It is the contention of the present work that an increase in surface coverage can significantly decrease the observed collection efficiency. To visually observe this decrease, the data for which surface coverage is less than 10 percent is also shown in Fig. 2. The scatter below the asymptote is decreased from the scatter shown in Fig. 1. The decreased scatter is attributed to the smaller surface coverages in Fig. 2. Also shown are several data points for collection efficiencies at an air velocity of 16.2 ft/sec and a wire diameter of 0.064 in. Since these data lie above the asymptote, it is not known if the asymptote is real or if experimental error occurred for these data.

The asymptote as well as the lower limit of surface coverage effects are also shown in Fig. 3 in comparison with literature values. Since the curves for the asymptote and limit of surface coverage effect encompass the spread of the literature collection efficiencies, the conclusion is that empirical correlations of the present data should also explain most of the variations in

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FIGURE 1

COLLECTION EFFICIENCIES FOR CYLINDRICAL WIRE COLLECTORS

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Final Size Type Area: 14×47 Picas

Final Trim Size: $6\frac{1}{8} \times 9\frac{1}{8}$ inches

FIGURE 2.

COLLECTION EFFICIENCIES FOR CYLINDRICAL WIRE COLLECTORS WITH SURFACE COVERAGE LESS THAN 10%

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FIGURE 3

COMPARISON OF THEORETICAL AND EXPERIMENTAL COLLECTION EFFICIENCIES FOR CIRCULAR CYLINDERS

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the literature values.

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CORRELATIONS

A weighted least squares technique was used to correlate all the present experimental collection efficiency data for which the surface coverage was less than 0.10. The weighting was $1/E^2$ in order to increase the prediction accuracy at small Stokes' number. In developing the correlation, the first and second order of interactions were statistically tested for all variables except for the Stokes' number. In this case, the statistical significance was tested to the fourth power. In the final correlations, all terms are significant at the 99 percent level.

The dimensional correlation for the collection efficiencies is based upon a natural logarithmic transformation:

$$E = A_0 + A_1(\ln \text{ Stk})^2 + A_2(\ln \text{ Stk})^3 + A_3(\ln \text{ Stk})^4 \\ + A_4(\ln \text{ Re}) + A_5(\ln \text{ Re})^2 + A_6(\ln \text{ ROR}) \\ + A_7(\ln \text{ Re})(\ln \text{ cov}) + A_8(\ln \text{ Stk})(\ln \text{ ROR}) \\ + A_9(\ln \text{ Turb}) + A_{10}(\ln \text{ Turb})^2$$

where the dimensionless numbers are

E = collection efficiency, fraction
 Stk = Stokes' number, stopping distance/wire diameter
 Re = Reynolds number of wire
 cov = coverage, fraction
 ROR = particle diameter/wire diameter.

One correlation was developed for the case if the turbulence intensity were not known and a second correlation was developed for the case when turbulence intensity is known. The constants for these two correlations are given in Table II.

Although these simple correlations have a high multiple correlation, the correlations do not completely explain all the variations in collection efficiency. The fit of the data can best be seen in Fig. 4 and 5 in which the predicted collection efficiencies are shown as a function of the experimental collection efficiencies.

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FIGURE 4

COMPARISON OF PREDICTED TO EXPERIMENTAL WIRE
COLLECTION EFFICIENCIES (WITHOUT CONSIDERING
TURBULENCE INTENSITY)

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TABLE II

CORRELATION CONSTANTS

	Without Turbulence Intensity	With Turbulence Intensity
First Line of Text	$A_0 = 4.48815$	$A_0 = 7.38574$
	$A_1 = -6.71645E-02$	$A_1 = -7.43736E-02$
Second Line of Text	$A_2 = -1.06849E-02$	$A_2 = -9.79891E-03$
	$A_3 = 1.27069E-03$	$A_3 = 9.86443E-04$
	$A_4 = 4.69039E-01$	$A_4 = 6.11157E-01$
	$A_5 = 3.01188E-02$	$A_5 = 2.41199E-02$
	$A_6 = 1.55092$	$A_6 = 1.71240$
	$A_7 = -1.35877E-03$	$A_7 = -1.34442E-03$
	$A_8 = 1.06201E-01$	$A_8 = 1.23029E-01$
	$A_9 = 0$	$A_9 = -2.58047$
	$A_{10} = 0$	$A_{10} = 6.11230E-01$

CONCLUSIONS

A considerable amount of scatter has existed in literature values of the particle collection efficiency which has not been adequately described by the average curves reported in the literature. Since the present data scatter as a function of Stokes' number is similar to that of the literature, generalized correlations to predict collection efficiency were developed in terms of the Stokes' number, Reynolds number, surface coverage by particles, particle to wire diameter, and turbulence intensity. Although these correlations cannot be checked against the literature collection efficiencies because of insufficient experimental detail in the literature articles, the recommendation is that the present correlations be used to predict particle collection efficiencies for any particle collection on cylindrical wires.

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REFERENCES

1. Brun, R.J., W. Lewis, P.J. Perkins, J.S. Serafini. Impingement of Cloud Droplets on a Cylinder and Procedure for Measuring Liquid-Water Content and Droplet Sizes in Supercooled Clouds by Rotating Multicylinder Method, NACCA-1215, Lewis Flight Propulsion Laboratory, Cleveland, Ohio, 1955.
2. Chamberlain, A.C. Deposition of Particles to Natural Surfaces, Symposia of the Society of Microbiology, Number XVII, Airborne Microbes, pp. 138-164, 1967.
3. Davies, C.N., C.V. Peetz. Impaction of Particles on a Traverse Cylinder, Proc. Roy. Soc., Ser. A., London, 234, 269, 1956.
4. Gregory, P.H. Deposition of Airborne Lycopodium Spores on Cylinders, Ann. Appl. Biol., 38, 357, 1951.
5. May, K.R., R. Clifford. The impaction of Aerosol Particles on Cylinders, Spheres, Ribbons, and Discs, Ann. Occup. Hyg., 10, 83, 1967.
6. Ranz, W.E., J.B. Wong. Impaction of Dust and Smoke Particles, Ind., Eng. Chem., 44 (6), 1371, 1952.
7. Sehmel, G.A. The Density of Uranine Particles Produced by a Spinning Disc Aerosol Generator, Amer. Ind. Hyg. Assoc. J., 28, 491, 1967.
8. Sehmel, G.A. Particle Collection Efficiencies for 0.035-In. Diameter Wires, pp 43-51, in ed. T.T. Mercer, P.E. Morrow, W. Stöber, Assessment of Airborne Particles, Charles C. Thomas, publisher, Springfield, Illinois, 1972.
9. Starr, J.R. Inertial Impaction of Particulates Upon Bodies of Simple Geometry, Ann. Occup. Hyg., 10, 349, 1967.
10. Wong, J.B., W.E. Ranz, H.F. Johnstone. Inertial Impaction of Aerosol Particles on Cylinders, J. Appl. Phys., 26 (2), 244, 1955.

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