Particle Instruments

Model 376060
Particle Size Selector

Instruction Manual

P/N 1930013, Revision F
October 2002

TSI®

Model 376060
Particle Size Selector

Instruction Manual

Manual History

The following is a manual history of the Model 376060 Particle Size Selector Instruction Manual, part number 1930013.

Revision	Date
A	June 1991
B	March 1992
C	January 1995
D	October 1996
	October 1998
E	August 2000
F	October 2002

This manual was first published in August 1988.

Revision B includes U.S. patent information, information for the Model 3010 CPC, and a reorganization of contents.

In revision C the manual was reformatted, a new photo was added for Figure 1-1, a column for 1.5 lpm was added to Table 2-1, Figure 3-2 was added, and TSI's new customer service numbers were added.

In revision D, TSI's "Limitation of Warranty and Liability" on page iii, page 1-1 was updated, Tables 2-1 and 2-2 were revised, and Table A-1 was revised.

In October 1998, TSI's area code was changed from 612 to 651.

In revision E, TSI's Limitation of Warranty and Liability was updated.

In revision F, TSI's phone numbers and address were updated.

Part Number 1930013 / Revision F / October 2002

U.S. Patent The Model 376060 Particle Size Selector is protected under U. S. Patent 5,072,626.

Address TSI Incorporated / 500 Cardigan Road / St. Paul, MN 55126 / USA

Fax No. (651) 490-3824

E-mail Address particle@tsi.com

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(effective July 2000)

Seller warrants the goods sold hereunder, under normal use and service as described in the operator's manual, shall be free from defects in workmanship and material for (12) months, or the length of time specified in the operator's manual, from the date of shipment to the customer. This warranty period is inclusive of any statutory warranty. This limited warranty is subject to the following exclusions:

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Knowing that inoperative or defective instruments are as detrimental to TSI as they are to our customers, our service policy is designed to give prompt attention to any problems. If any malfunction is discovered, please contact your nearest sales office or representative, or call TSI's Particle Instrument Division at 1-800-874-2811 (USA) or (651) 490-2811.

Contents

Chapters

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About This Manual

This instruction manual provides information for the installation and operation of the Model 376060 Particle Size Selector (PSS).

Organization

The chapters and appendixes of this instruction manual explain how to assemble, operate, and maintain the Particle Size Selector.

- **Chapter 1: Product Overview**
  Chapter 1 gives a brief description of the many features of the PSS.

- **Chapter 2: Unpacking and Assembling the Particle Size Selector**
  Chapter 2 gives a packing list and assembly instructions for the PSS.

- **Chapter 3: Operating the Particle Size Selector**
  Chapter 3 gives operating procedures and a short section explaining the principle of operation with particle penetration calculations.

- **Chapter 4: Maintenance and Service**
  Chapter 4 gives cleaning instructions for the PSS as well as instructions for returning the PSS to TSI.

- **Appendix A Operating Specifications**
  Appendix A gives operating specifications for the PSS.

- **Appendix B Technical Paper**
  Appendix A describes the theory of screen diffusion batteries.

Related Product Literature

- **Model 3010 Condensation Particle Counter Instruction Manual** (part number 1933010) TSI Incorporated

  This manual contains operating instructions for the Model 3010 Condensation Particle Counter, an instrument used with the Particle Size Selector.

Reusing and Recycling

As part of TSI Incorporated's effort to have a minimal negative impact on the communities in which its products are manufactured and used:

- This manual uses recyclable paper.
- This manual has been shipped, along with the instrument, in a reusable carton.

Getting Help

To obtain assistance with the Particle Size Selector, either refer to Chapter 4, "Maintenance and Service," for instructions or contact:

TSI Incorporated
Particle Instruments
500 Cardigan Road
St. Paul, MN 55126 USA
Fax: (651) 490-3824
Telephone: 1-800-874-2811 (USA) or (651) 490-2811
E-mail address: particle@tsi.com

Submitting Comments

TSI values your comments and suggestions on this manual. Please use the comment sheet on the last page of this manual to send us your opinion on the manual's usability, to suggest specific improvements, or to report any technical errors.

If the comment sheet has already been used, mail, fax, or e-mail your comments on another sheet of paper to:

TSI Incorporated
Particle Instruments
500 Cardigan Road
St. Paul, MN 55126
Fax: (651) 490-3824
E-mail address: particle@tsi.com

CHAPTER 1
Product Overview

The Model 376060 Particle Size Selector (PSS) is a separating device that selectively removes small particles from an aerosol, while passing larger particles.

The PSS consists of a set of fine-mesh diffusion screens in a housing placed on the aerosol inlet of a Models 3010, 3760, 3760A, and 3762 Condensation Particle Counter (CPC). The PSS raises the smallest detectable particle size limit for the CPC. Without the PSS, the CPC has a lower size limit of about .001 micrometers. By changing the number of screens in the PSS, the lower size limit can be raised to 0.05 µm, 0.1 µm, 0.2 µm or 20 other intermediate sizes.

Figure 1-1
Model 376060 Particle Size Selector Placed on the Inlet of a Model 3010 Condensation Particle Counter

The Model 376060 Particle Size Selector has a unique design protected under U.S. Patent 5, 072,626. Small particles with high diffusion coefficients rapidly diffuse to the wire screens where they are captured; larger particles with lower diffusion coefficients more readily pass through the screens.

The size cutoff of the PSS is the size of a particle that has a 50 percent chance of passing through the screens. Larger particles have a greater probability of passing through than smaller particles.

CHAPTER 2

Unpacking and Assembling the Particle Size Selector

Use the information in this chapter to unpack and assemble the Model 376060 Particle Size Selector (PSS).

Packing List

The following is the packing list for the PSS:

Table 2-1
Model 376060 PSS Components and Part Numbers

Quantity	Description	Part Number
1	Front Cone Assembly	
	1 Front Cone	1503182
	1 Finger Screw	1503188
	1 O-ring, 1-033	2501638
1	Back Cone Assembly	
	1 Back Cone	1503185
	1 O-ring, 1-110	2501637
11	Screens*	1407009
1	Instruction Manual	1930013

*An additional set of 12 screens (Model 376061) can be purchased separately.

If anything is missing or appears to be damaged, of if you wish to purchase additional screens, contact your TSI representative or contact TSI Particle Instrument Division at 1-800-874-2811 (USA) or (651) 490-2811.

Assembling the Particle Size Selector

The Model 376060 Particle Size Selector requires some assembly. Use the information in this section to assemble the PSS. If you have any difficulties, use the information in Chapter 4, "Service and Maintenance," to contact a technical representative at TSI Incorporated.

Assembly Instructions

The PSS can be assembled in two ways as shown in Figures 2-1 and 2-2.

The front cone in Figure 2-1 allows the combined PSS/CNC to maintain an aerosol inlet if you decide to attach transport tubing. The diameter of the inlet is 0.95 centimeter (3⁄8 inch). When sampling from ambient air, it is best to use the spacer (see Figure 2-2). This arrangement takes less space and leaves the screens exposed.

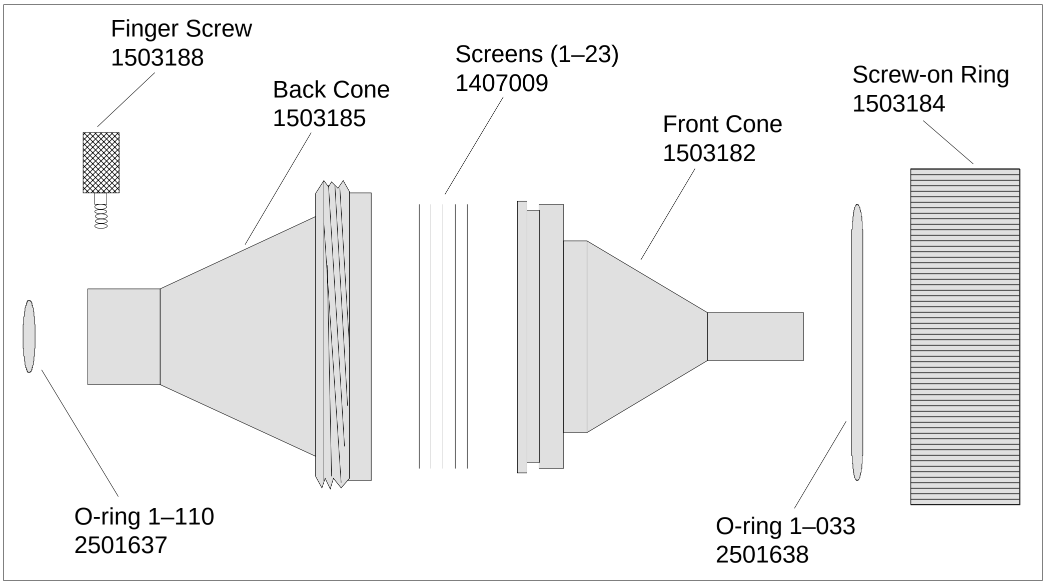

Figure 2-1
Assembling the Particle Size Selector with the Front Cone

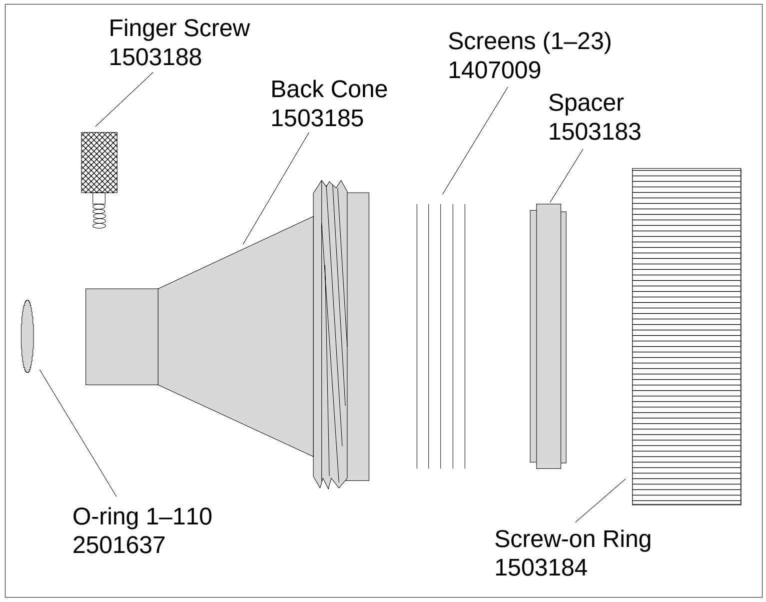

Figure 2-2
Assembling the Particle Size Selector with the Spacer

1. Using Table 2-2, select the number of screens necessary for the desired particle size cut. Place the screens so that the mesh orientation in the back cone is random. Be careful not to bend, crease or fray the screens.

   Note: *Do* not *install a damaged or dirty screen. Refer to "Routine Maintenance" in Chapter 4 for instructions on cleaning PSS screens and housing.*

2. Secure the screens by installing either the back cone or spacer and the screw-on ring. Store the unused screens and parts in a safe place for later use.

3. Push the back cone of the PSS onto the aerosol inlet of the CPC as far as it will go.

4. Tighten the back cone with the finger screw. Be sure that the O-ring seals the connection between the PSS and the CPC inlet.

Table 2-2
Number of PSS Screens Required for Various CPC Flowrates

Number of	Particle Size Cut (50%) µm					
Screens	0.3 lpm	1.0 lpm	1.41 lpm	1.50 lpm	2.83 lpm	3.00 lpm
1	0.032	0.017	0.015	0.014	0.010*	0.010*
2	0.056	0.030	0.025	0.024	0.017*	0.017
3	0.079	0.041	0.034	0.033	0.024	0.023
4	0.102	0.052	0.043	0.042	0.030	0.029
5	0.123	0.062	0.052	0.050	0.036	0.034
6	0.147	0.072	0.059	0.058	0.041	0.040
7	0.170	0.083	0.068	0.066	0.047	0.045
8	0.192	0.092	0.076	0.074	0.052	0.050
9	0.216	0.102	0.084	0.081	0.057	0.055
10	0.240	0.112	0.092	0.089	0.062	0.060
11	0.267	0.122	0.099	0.096	0.067	0.065
12	0.291	0.132	0.108	0.103	0.072	0.070
13	0.316	0.143	0.116	0.111	0.078	0.075
14	0.344	0.152	0.123	0.119	0.082	0.080
15	0.372	0.162	0.132	0.126	0.087	0.085
16	0.400	0.172	0.140	0.135	0.092	0.089
17	0.430	0.184	0.147	0.143	0.097	0.094
18	0.460	0.194	0.156	0.150	0.102	0.099
19	0.490	0.204	0.164	0.158	0.106	0.103
20	0.522	0.216	0.172	0.166	0.112	0.108
21	0.552	0.225	0.180	0.174	0.117	0.112
22	0.582	0.237	0.188	0.182	0.122	0.119
23	0.616	0.249	0.198	0.190	0.128	0.123

*Particle sizes below 50% detection efficiency of CPC.

CHAPTER 3

Operating the Particle Size Selector

This chapter gives information you need to operate the Model 376060 Particle Size Selector (PSS): operating instructions and a short section explaining the principle of operation with calculations of the particle penetration through the PSS. You can also refer to Appendix A which contains the operating specifications for the PSS.

Operating Instructions

When using a PSS on the inlet, the CPC operates normally. It detects particles larger than the selected cut-size, as determined by the number of screens.

Use the operating instructions in the CPC manual to operate the CPC.

Principle of Operation

This section describes the principle of operation for the Particle Size Selector and gives calculations of the particle penetration through the PSS. Also, refer to Appendix A for a technical paper on the theory of a screen-type diffusion battery.

The motion of aerosol particles smaller than 0.2 micrometer in diameter is strongly affected by random collisions with gas molecules. This is known as diffusion. A particle undergoing diffusion follows a random, irregular path. Its position at any given time depends on its most recent collisions with molecules. Smaller particles with less momentum are more strongly affected than larger particles with greater momentum. Particles larger than several tenths of a micrometer are not significantly affected by diffusion at normal temperatures and pressures.

As particles undergoing diffusion pass through a fine-mesh screen, some particles collide with the screen wires. Surface-attractive forces between particles and wires make the particles stick to the screen. Because of diffusion, small particles are more likely to collide with the screen than large particles. Thus the penetration of small particles is lower than for large particles. The screen-hole size (20 micrometers) is quite large compared to the size of most airborne particles and so the normal screen collection method (interception and sieving) is not applicable.

Figure 3-1 shows the theoretical penetration of particles through the PSS using 5, 11, and 23 screens. The theoretical calculations are from Cheng and Yeh [1980]. A sample program in QBASIC is reprinted in Figure 3-2. This program was used to generate the curves in Figure 3-1 and may be used to calculate other useful information. The governing equation is shown below.

The penetration of particles is given as:

$$P = \exp(-4.52\ nPe^{-2/3})$$

where: n = number of screens

Pe = Peclet number = $2aU_o/D$ (dimensionless)

a = Screen wire radius (cm)

U_o = Undisturbed flow velocity $= 66.666Q / \pi d_f^2 (dm / s)$

d_f = Fluid flow cross-sectional diameter (cm)

Q = Volumetric flowrate (L/min)

D = Diffusion coefficient of particle = $kTC/6\pi\mu a_p$

k = Boltzman constant (1.38 x 10^{-16} erg/K)

T = Absolute temperature (K)

C = Cunningham slip correction (dimensionless)

a_p = Particle radius (cm)

μ = Fluid viscosity (poise)

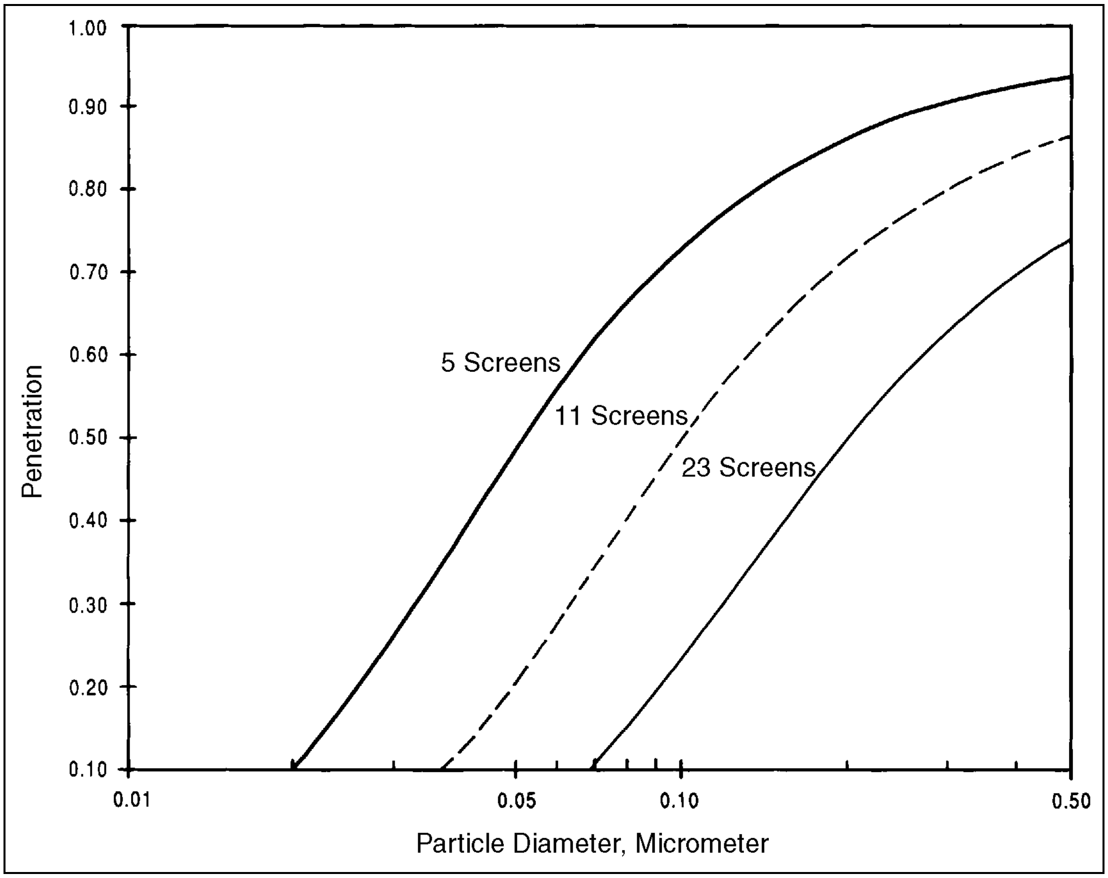

Figure 3-1
Theoretical Penetration of Particles Through the PSS Using 5, 11 and 23 Wire-Mesh Screens

```
'  DIFFSCRN.BAS
'  Calculates the penetration of particles though a diffusion screen
'  Output is a file containing penetration vs. particle size & number of screens
'
'  Reference: Cheng and Yeh, J AEROSOL SCI 11:313-320 (1980).
'  Version 1.0 P. Keady  22-Jul-1988 - original in BASICA
'          2.0 R. Caldow  2-Apr-1993 - data output modified, changed to qbasic
'          2.1 R. Caldow  6-Dec-1994 - added selection of number of screens
'  **************************************************************************

'******* Change parameters here as needed: **************************
pi = 3.141593              ' constant
lambda = 6.53E-06          ' cm, mean free path of air molecules
K = 1.38E-16               ' erg/K, Boltzman's constant
mu = .000183               ' poise, air viscosity
T = 293                    ' K, absolute temperature
Df = 3.81                  ' cm, fluid flow cross-sectional (wetted screen area) diameter
A = .001                   ' cm, fiber radius
Q = 1                      ' lpm, volumetric flow rate
nscr = 55                  ' number of screens for which to calculate
'**********************************************************************

DIM dp(21), graphtable(22, nscr + 1)

top:
INPUT "Enter Output Filename:"; filename$
IF filename$ = "" THEN GOTO top
filename$ = LEFT$(filename$, 8) + ".PSS"
OPEN filename$ FOR OUTPUT AS #1

FOR n = 1 TO 21: READ dp(n): NEXT n
FOR n = 1 TO 21: graphtable(n + 1, 1) = dp(n): NEXT n

FOR n = 1 TO nscr
  graphtable(1, n + 1) = n
  FOR m = 1 TO 21
    D = dp(m) * .0001
    C = 1 + 2.492 * (lambda / D) + .84 * (lambda / D) * EXP(-.435 * D / lambda)
    DC = (K * T * C) / (6 * pi * mu * D * .5)
    U = 66.666 * Q / (pi * Df ^ 2)
    p = EXP(-4.52 * n * (2 * A * U / DC) ^ -.66667)
    graphtable(m + 1, n + 1) = p * 100
  NEXT m
  PRINT USING "Processing screen ## of ##"; n; nscr
NEXT n

PRINT #1, "Assumptions:"
PRINT #1, USING " Lambda = ##.##^^^^ CM, MEAN FREE PATH OF AIR MOLECULES"; lambda
PRINT #1, USING " K =      ##.##^^^^ ERG/K, BOLTZMANS CONSTANT"; K
PRINT #1, USING " Mu =     ##.##^^^^ POISE, AIR VISCOSITY"; mu
PRINT #1, USING " T =      ##.##^^^^ Kelvin, ABSOLUTE TEMP"; T
PRINT #1, USING " Df =     ##.##^^^^ CM, FLUID FLOW CROSS SECTIONAL DIAMETER"; Df
PRINT #1, USING " A =      ##.##^^^^ CM, FIBER RADIUS"; A
PRINT #1, USING " Q =      ##.##^^^^ LPM, VOLUMETRIC FLOW RATE"; Q
PRINT #1,
PRINT #1, "Top row is Dp in µm, First column is number of screens"
PRINT #1, "Output is an array of penetration in %"

PRINT USING "Saving & to disk..."; filename$
FOR n = 1 TO (nscr + 1)
  FOR m = 1 TO 22
    PRINT #1, USING "###.###"; graphtable(m, n);
  NEXT m
  PRINT #1,
NEXT n

CLOSE
END
DATA .01,.015,.02,.03,.04,.05,.06,.07,.08,.09
DATA .1,.15,.2,.3,.4,.5,.6,.7,.8,.9,1
```

Figure 3-2
DIFFSCRN.BAS Printout

CHAPTER 4

Maintenance and Service

Use the information in this chapter to clean the Model 376060 Particle Size Selector (PSS) and to contact technical personnel and Customer Service at TSI, Incorporated.

Routine Maintenance

The Particle Size Selector requires periodic cleaning of the screens and housing. Use this procedure to disassemble and clean the PSS screens and housing:

1. Disassemble the PSS by reversing the order in which you assembled it in Chapter 2. See "Assembling the Particle Size Selector" in Chapter 2.

2. If the screens appear dirty, clean them in an ultrasonic bath with a mild cleaning solution or solvent for 10 to 30 minutes. When clean, rinse and dry them carefully.

3. Clean the housing with a mild detergent. Lightly coat the O-rings with vacuum grease. (Do not install a damaged or creased screen; replace it with P/N 1407009, available from TSI.)

Technical Contacts

- ❑ If you have any difficulty installing the Particle Size Selector on a CPC, or if you have technical or application questions about these instruments, contact TSI Incorporated at 1-800-874-2811 (USA) or (651) 490-2811.
- ❑ If you are returning the Particle Size Selector, contact TSI Particle Instrument Division at 1-800-874-2811 (USA) or (651) 490-2811.

Returning the Instrument

If you are returning the PSS for service, call TSI Particle Instrument Division at 1-800-874-2811 (USA) or (651) 490-2811 for specific return instructions. The following information will be needed when you call:

- ❑ The instrument model number
- ❑ The instrument serial number
- ❑ A purchase order number
- ❑ A billing address
- ❑ A shipping address.

APPENDIX A

Operating Specifications

Table A-1 contains the operating specifications for the Model 376060 Particle Size Selector (PSS).

Table A-1
Model 376060 PSS Specifications

Screens	11 stainless-steel, type 316, 20-µm openings, 20-µm wires
Front cone .... inlet fitting	0.95-cm [0.375-in.] outside diameter
Construction .... material	Housing made of anodized and irridited aluminum, delrin; O-rings made of buna-N
Weight	approximately 127 g [4.5 oz]
Length	with front cone: 9.6 cm [3.8 in.] with spacer: 6.0 cm [2.4 in.]
Diameter	6.35 cm [2.5 in.]

APPENDIX B
Technical Paper

THEORY OF A SCREEN-TYPE DIFFUSION BATTERY*

Y. S. Cheng and H. C. Yeh

Inhalation Toxicology Research Institute, Lovelace Biomedical and Environmental Research Institute, P.O. Box 5890, Albuquerque, NM 87115, U.S.A.

Abstract – A theoretical analysis of collection efficiency for screen-type diffusion batteries was made. The structure of stacks of screens can be approximated by a fan model of filter elements. The penetration equation was derived from the theory of diffusional deposition through a fan model filter. The theoretical equation is in good agreement with experimental data and, thus, useful in the calibration of the instrument.

NOMENCLATURE

a	fiber radius (cm)
a_p	particle radius (cm)
C	Cunningham slip correction (dimensionless)
c	exit particle concentration
c_0	inlet particle concentration
D	diffusion coefficient of particle $= kTC/6\pi\mu a_p$ ($cm^2\ sec^{-1}$)
d_p	particle diameter (cm)
d_f	fluid flow cross-sectional diameter (cm)
d_s	screen diameter (cm)
G	sedimentation parameter $= 2\rho_p C a_p^2 g/9\mu U_0$ (dimensionless)
h	thickness of screen (cm)
i	stage number
Kn	Knudsen number $= \lambda/a$ (dimensionless)
k	Boltzmann constant $= 1.38 \times 10^{-16}$ erg K^{-1}
L	thickness of filter stacks $= nh$ (cm)
m, m_{th}, m_{exp}	slope (dimensionless)
m_s	mass of screen (g)
n	number of screen
P	penetration of a filter (dimensionless)
Pe	Peclet number $= 2aU_0/D$ (dimensionless)
Q	volumetric flow rate ($l.\ min^{-1}$)
R	interception parameter $= a_p/a$ (dimensionless)
St	Stokes number $= 2\rho_p C a_p^2 U_0/9\mu a$ (dimensionless)
T	absolute temperature (K)
U_0	undisturbed flow velocity $= 66.666Q/\pi d_f^2$ ($cm\ sec^{-1}$)
α	solid volume fraction of a filter $= 1-\varepsilon$
ε	porosity of a filter
ρ_p	particle density ($g\ cm^{-3}$)
ρ_s	screen density ($g\ cm^{-3}$)
μ	fluid viscosity (P)
η	single fiber efficiency
λ	mean free path of the gas molecular $= 6.53 \times 10^{-6}$ cm for air at 1 atm and 23°C

INTRODUCTION

A diffusion battery is a useful instrument in measurement of size distributions of ultrafine particles ($d_p \leq 0.1\ \mu m$). It usually consists of series of small circular or rectangular conduits. Penetration of particles through the battery depends on their diffusivity and, hence, their size. The flow field and diffusional deposition in circular tubes as well as parallel plates are well understood from both theoretical and experimental studies (Soderholm, 1979). Recently, a new design of a 10 stage diffusion battery consisting of stacks of stainless steel screens was developed and is commercially available (Sinclair and Hoopes, 1975; Sinclair *et al.*, 1979). Screen-type diffusion batteries are compact in size, simple in construction, and screens can easily be cleaned and replaced when they are contaminated or worn out. However, the flow

* Research performed under U.S. Department of Energy Contract Number EY-76-C-04-1013.

field is external flow around an array of crossed cylinders and the theory for channel flow is not applicable. No theoretical analysis has been published and therefore data interpretation relies mainly on experimental calibration and/or comparison with comparable data from a diffusion battery of collimated holes.

In this report, an equation of penetration based on diffusional theory of filtration was derived. Agreement between theory and experimental data was good. The use of the theory for extending the calibration of the diffusion battery to different operation conditions are discussed.

DIMENSIONS OF FILTERS

The commercially available screen-type diffusion battery (Model 3040, TSI Inc., St. Paul, Minnesota) consists of 10 stages. Each stage contains one or more screens in series. The first stage contains one screen, the second contains two screens so that the number of screens from the first stage down to stage i, is given by:

$$n = \frac{i(1+i)}{2} \tag{1}$$

and the total screen number for 10 stages is 55.

Screens are made of 635-mesh type 304 stainless steel (Fig. 1). The screen wire is 20 μm in diameter and openings are also 20 μm (TSI, Inc. Instruction Manual Model 3040 Diffusion Battery, 1977). Screen diameter is 5.08 cm (2 in.) and the fluid flow cross-sectional diameter is 3.81 cm (1.5 in.). The porosity ε or the solid volume fraction α of screens can be estimated by measuring the volume of solid and total volume of screen

$$\alpha = 1 - \varepsilon = \frac{\text{volume of solid}}{\text{total volume}} = \frac{4m_s}{\pi d_s^2 h \rho_s}. \tag{2}$$

Density of stainless steel type 304 is 7.93 g cm^{-3} provided by the manufacturer (Industrial Screening and Filtration Media Catalog No. 2000, Tetko, Inc., Elmsford, New York). From direct measurement, the average mass and thickness per screen are 0.277 g and 50 μm, respectively. Thus, α is calculated to be 0.345 using equation (2).

THEORY OF FILTRATION

The theory for deposition of particles through fibrous filters has been investigated and recently reviewed by Yeh (1972), Davies (1973) and Kirsch and Stechkina (1978). From conservation of mass, penetration of particles through a filter element is given by (Fuchs, 1964; Dorman, 1966):

$$P = \frac{c}{c_0} = \exp\left(\frac{-2\alpha L}{\pi(1-\alpha)a}\eta\right). \tag{3}$$

For very small particles, effects of inertia, gravitational settling and interception can be neglected, then Brownian diffusion is the dominant mechanism for particle collection. In the continuous flow regime, single fiber efficiencies of diffusion deposition in filter elements of different geometrical arrangements have been derived (Stechkina and Fuchs, 1966; Davies, 1973):

$$\eta = BPe^{-2/3}. \tag{4}$$

The constant B, which is a function of geometric arrangement, is given by

$$B = 2.9(-0.5\ln\alpha + \alpha - 0.25\alpha^2 - 0.75)^{-1/3}$$

for parallel staggered cylinder model, (5a)

$B = 2.7$ for fan model, (5b)

$B = 1.5\text{–}2.0$ for real filter. (5c)

A real filter consists of an array of fibers in random orientation and equation (5c) given by Davies (1973) applies. In addition, some fiber models of definite configuration were developed to study flow patterns as well as deposition efficiencies. For parallel staggered rows of parallel cylinders, the flow pattern can be approximated by Kuwabara's cell model (Kuwabara, 1959; Kirsch and Fuchs, 1967). Equations (4) and (5a) were derived using Kuwabara's cell model by Stechkina and Fuchs (1966). The fan model consists of rows of parallel cylinders where axes of different rows are at random angles. Equation (5b) was obtained by fitting the fan model to the experimental data (Kirsch and Fuchs, 1968).

In the screen-type diffusion battery, each screen consists of two rows of parallel cylinders intersecting at 90° angles (Fig. 1). For stacks of screen axes of different rows will be randomly oriented and thus can be best described by the fan model. Given the dimensions of a, α and $L = n \cdot h$, penetration through n screens can be calculated from equations (3), (4) and (5) where

$$P = \exp(-AnPe^{-2/3}) \tag{6}$$

with A having the following relationships for the three models

$$A = \frac{2B\alpha h}{\pi(1-\alpha)a} = \begin{cases} 10.56 & \text{for parallel staggered cylinder model,} \\ 4.52 & \text{for fan model,} \\ 2.51\text{–}3.35 & \text{for real filter.} \end{cases} \tag{7}$$

For diffusional deposition to be the dominant mechanism, Stokes number St, sedimentational parameter G and interception parameter R should all be very small. The size range for the model 3040 diffusion battery is from 0.005 to 0.2 μm. Maximum values of St, G and R for unit density 0.2 μm dia. particles at 6 l. min^{-1} sampling rate are 2×10^{-3}, 2.5×10^{-5} and 1×10^{-2}, respectively. Hence, effects of inertia, sedimentation and interception can be neglected for particles smaller than 0.2 μm in diameter. The assumption of continuous flow around cylinders is valid, since the calculated Knudsen number, Kn, is 6.53×10^{-3} much smaller than 1. Consequently, equation (6) should apply.

COMPARISON WITH EXPERIMENTAL DATA

Experimental calibration curves for the TSI model 3040 screen-type diffusion battery given by Sinclair *et al.* (1979) were used to compare with the derived theory. In their study, monodisperse NaCl and DOP particles of 0.015 to 0.11 μm in diameter were generated using an electrical classifier (Model 3071, TSI Inc., St. Paul, Minnesota) and passed through the diffusion battery with flow rates of 6 and 4 l. min^{-1}. Results are tabulated in Table 1. Figures 2 and 3 show penetration vs screen number, n. Equation (6) with $A = 4.52$ for the fan model were also plotted and shown as the straight lines in Figs 2 and 3. Agreement between theory and experimental data was evident. From experimental data, the slope m_{exp} of the calibration lines can be calculated by fitting the data:

$$m_{exp} = \frac{-\log P}{n}. \tag{8}$$

Table 1. Experimental calibration of the screen-type diffusion battery by Sinclair *et al.* (1979)

Flow rate, Q (l. min^{-1})	Particle diameter, d_p (μm)	m_{exp}	m_{th}
6	0.107	0.0101	0.00967
6	0.085	0.0142	0.0126
6	0.052	0.0223	0.0229
6	0.026	0.0533	0.0546
6	0.015	0.112	0.111
4	0.085	0.0162	0.0165
4	0.050	0.0315	0.0313
4	0.026	0.0662	0.0716

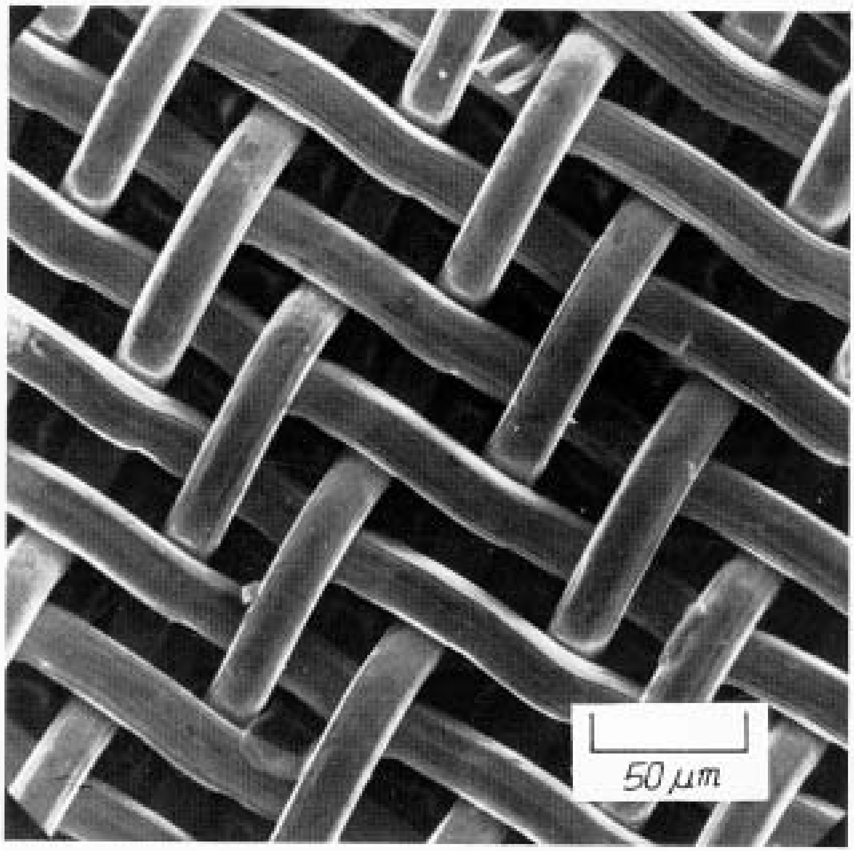

Fig. 1. A scanning electron micrograph of the screen used in the screen-type diffusion battery.

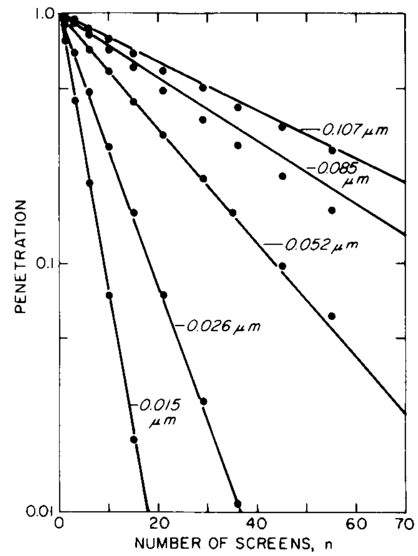

Fig. 2. Penetration of aerosol particles through the screen-type diffusion battery at 6 l. min^{-1}. The circles are experimental data. The straight lines are given by equation (6) with A = 4.52.

Theoretically, the slope m_{th} for the fan model is calculated from equation (6) with $A = 4.52$.

$$m_{th} = 1.96 Pe^{-2/3}. \tag{9}$$

Experimental values of m_{exp} were then plotted as function of Peclet number, Pe, in log–log scale as shown in Fig. 4. Experimental data are in agreement with equation (9) within an error of ±5.8% (S.D.). The theoretical values of the slope for other models are also calculated. The calculated value for a staggered row model is 134% higher, while the values for a real filter are 26–45% lower than the experimental data. The results indicate that the fan model is a better description than is a real filter treatment. A working equation which relates slope, m, to particle diffusivity, D, and sampling flow rate, Q (l. min^{-1}), is given by:

$$m = 96.0\left(\frac{D}{Q}\right)^{2/3}. \tag{10}$$

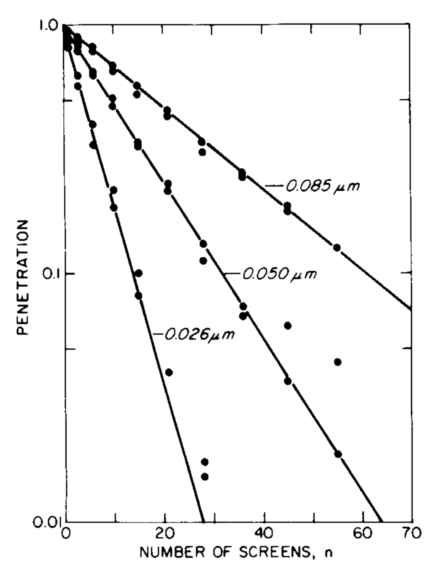

Fig. 3. Penetration of aerosol particles through the screen-type diffusion battery at 4 l. min^{-1}. The circles are experimental data. The straight lines are given by equation (6) with A = 4.52.

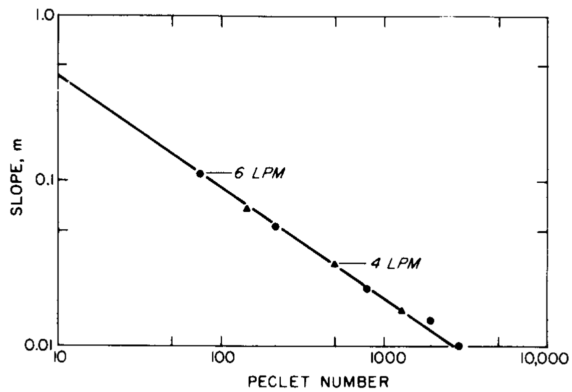

Fig. 4. Plot of slope of screen-type diffusion battery penetration curves vs Peclet number. The circles and triangles are experimental data. The straight line is $m = 1.96Pe^{-2/3}$.

The values of m_{exp} vs particle diameter for flow rates of 4 and 6 l. min^{-1} are shown in Fig. 5. Again, agreement is obtained and equation (10) can be used for sampling flow rates other than 4 and 6 l. min^{-1}.

CONCLUSIONS

A theoretical analysis of penetration of ultrafine particles through a screen-type diffusion battery was made. Stacks of screens can be best described as a filter element of a fan model. The theory for diffusional deposition through a fan model filter element applies. Under normal operational condition for ultrafine particles for which the effect of inertia, sedimentation and interception are negligible, penetration is given by $\ln P = -4.52nPe^{-2/3}$.

Comparison between theoretical and existing experimental data in the literature is in good agreement. More data under different operational conditions are required to confirm the theory. Present results provide a basis for understanding the performance of the wire mesh diffusion battery. The derived equation is useful in the calibration as well as data analysis of samples collected by the instrument and may be extended to different operational conditions such as high temperature or high altitude sampling.

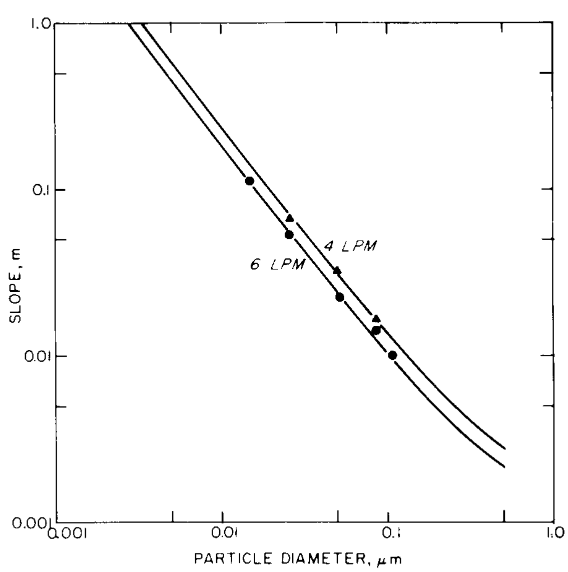

Fig. 5. Plot of slope of screen-type diffusion battery penetration curves vs aerosol particle diameter at flow rates of 4 and 6 l. min^{-1}. The circles and triangles are experimental data. The solid lines are theoretical values calculated from equation (10).

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