Series 290

Instruction Manual
Marple Personal Cascade Impactors
Part Number 100065-00
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I. INTRODUCTION

Thermo Scientific's unique Series 290 Marple Personal Cascade Impactor is the first precision cascade impactor worn by the worker giving complete, accurate aerodynamic particle size distributions. The personal mounting bracket is attached to the lapel or pocket. The rugged Series 290 impactors combine compactness and light weight (7 oz. max.) with Andersen Instrument Inc.'s patented* radial slot design widely acclaimed for its accuracy, minimal internal losses and absence of particle bounce. Cascade impactors are available with 8,6, or 4 impactor stages all followed by a built-in filter holder. Impactor cut-points range from 21 to 0.5 microns.

The Series-290 are operated at a flow rate of 2 LPM by the 290-P Constant Flow Personal Sampling Pump, or similar pump attached to the belt and interconnected via tubing to the cascade impactor.

Development

The US Natl. Inst. for Occupational Safety and Health (NIOSH) recognized the need to develop an accurate size-fractionating wood dust sampler worn by the worker. To accomplish their objective, Mr. Michael A. McCauley and his colleagues at NIOSH selected the team of Andersen Instrument Inc. Instruments and Professor Virgil A. Marple and Dr. Kenneth Rubow of the University of Minnesota's Particle Technology Laboratory. The result: Series 290 Marple Personal Cascade Impactors. The Series 290 impactors were designed in accordance with the proven Marple theory of impactors (See Reference 1). The Model 294 four-stage unit is specifically designed for wood-dust sampling and has undergone extensive field testing (See Reference 3). Thermo Fisher Scientific has since acquired Anderson Instrument Inc.

* U.S. Patent No. 3,983,743

Applications

- Wood dust
- Coal dust
- Silica dust
- Respirable dust sampling
- Inhalation toxicology, aerobacteriology
- Indoor air pollution
- Low-cost multi-point sampling
- Aerosol research

II. AERODYNAMIC PARTICLE SIZING

The inlet visor and cowl prevent large wood chips, cigarette ashes, and other debris from entering the cascade impactor. The design concept of the Marple Samplers evolved from the following information:

The human respiratory tract is an aerodynamic classifying system for airborne particles. A sampling device can be used as a substitute of the respiratory tract as a collector of airborne particles. As such, it should reproduce to a reasonable degree the human respiratory system so that lung penetration by airborne particles can be predicted from sampling data. The sampling instrument should therefore classify the particles collected according to the aerodynamic dimension that, as Wells states, is the true measure of lung penetration. The fraction of inhaled particles retained in the respiratory system and the site of deposition vary with the size, shape, and density and all the physical properties of the particles that constitute the aerodynamic dimensions (Figure 1).

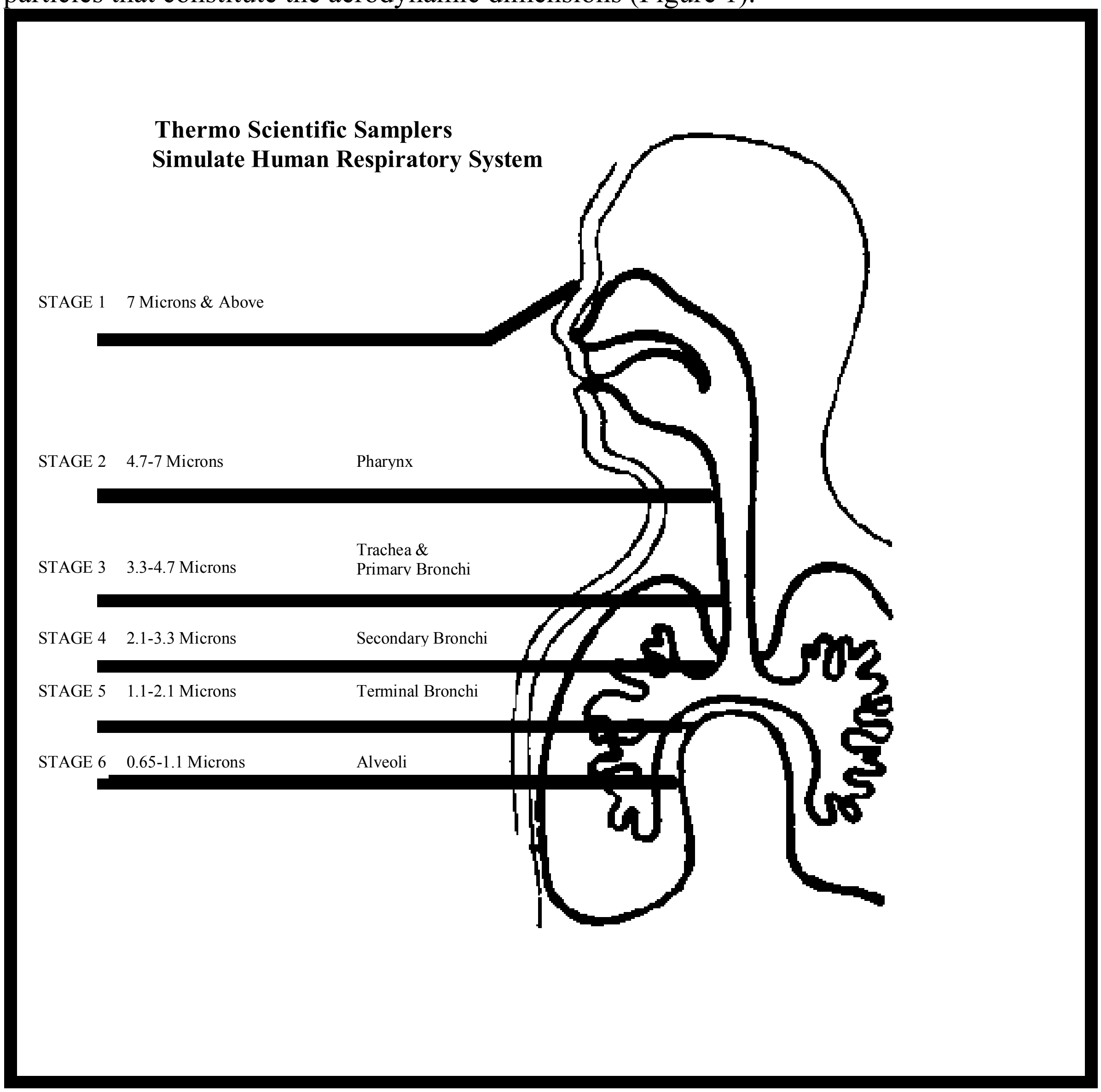

Figure 1: Sampler Simulation of Respiratory System

Methods that employ light scattering or filtration and microscopic sizing of particles do not reckon with density and some other properties that affect the movement of the particle in air, and therefore, do not give the desired information. Because the lung penetrability of unit density particles is known and since the particle sizes that are collected on each stage of the sampler have been determined, then as long as a standard model of this samplers is used according to standard operating procedure, the stage distribution of the collected material will indicate the extent to which the sample would have penetrated the respiratory system. With this information and with knowledge of the chemical, biological, and/or radiological properties of the material collected, the exact nature and extent of the health hazard can be assessed.

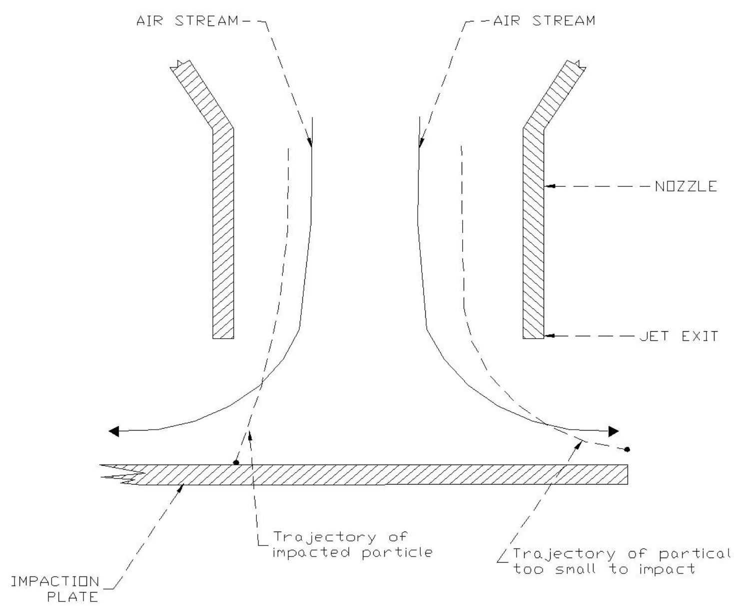

Figure 2: Jet Schematic of Marple Impactor Stage

The earliest and most fundamental work in inertial impaction theory was conducted in the early 1950's by Ranz and Wong. In this work, Ranz and Wong showed that the collection of a particle by an obstacle is a function of what is defined as the inertial impaction parameter:

$$K = \frac{C\rho U D_p^2}{18\mu D_c}$$

Where U is the relative velocity, ρ is the particle density, D_p is the particle diameter, μ is the gas viscosity, D_c is the diameter of the round jet, and C is the Cunningham slip correction factor.

Data from inertial impactors are normally presented as 50% effective cutoff diameters. For the Thermo Scientific impactors, containing round jets and flat collection surfaces, the 50% effective cutoff diameter would yield a value of 0.14 for the inertial impaction parameter K.

The Cunningham slip correction factor is equal to:

$C = 1 + 0.16 \times 10^{-4}/D_p$ for normal temperatures and pressures.

This factor corrects for the fact that as particle diameters approach the mean free path length of the gas molecules, they tend to "slip" between gas molecules more easily and are therefore more easily able to cross the bulk flow stream lines. The collection efficiency is therefore slightly greater than would be predicted by inertial impaction theory for particle diameters on the order of 1 or 2 microns. The overlapping of particle size between stages, which is naturally inherent in all cascade impaction devices, is minimized in Thermo Scientific samplers by design. Ranz and Wong (1952) stated that as a particle passes through a jet, its nearness to the axis of the jet is one of the factors that determines whether or not the particle will reach the impaction surface. In contrast to competitive samplers, which have larger rectangular jets in each stage, Thermo Scientific Samplers have small, round jets. Travel of the particle is thus confined near the axis of the jets. The average distance of the particles from the axis of the jets is less than in other impactors. Ranz and Wong (1952) also stated that round jets have sharper cutoffs than rectangular jets. Thermo Scientific Samplers, therefore, on a theoretical basis, should have a sharper cutoff. Figure 2 shows how impaction occurs at the orifice collector interfaces.

Another inherent advantage of Thermo Scientific Marple Impactors over its competitors is that single circular orifice and multiple rectangular orifice impactors by design must operate with higher orifice velocities. This results in more turbulent flow, greater re-entrainment, and a skewing of the size distribution toward the lower end (i.e., the indicated size distribution being smaller than it really is).

III. GENERAL IMPACTOR NOTES

This instruction manual applies to the following Series 290 Marple Personal Cascade Impactors:

MODEL NO.	Cascade Impactors
298	Eight-Stage Marple Personal Cascade Impactor
296	Six-Stage Marple Personal Cascade Impactor
294	Four-Stage Marple Personal Cascade Impactor

Kits	
298K	Eight-Stage Marple Personal Cascade Impactor Kit
296K	Six-Stage Marple Personal Cascade Impactor Kit
294K	Four-Stage Marple Personal Cascade Impactor Kit

Each Series 290 "Cascade Impactor" comes fully assembled with the following parts:

Table I: Impactor Parts

298	296	294
Inlet Visor	Inlet Visor	Inlet Visor
Inlet Cowl	Inlet Cowl	Inlet Cowl
10-32 Thumb Nuts(2)	10-32 Thumb Nuts(2)	10-32 Thumb Nuts(2)
Impactor Stages 1,2,3,4,5,6,7,8	Impactor Stages 3,4,5,6,7,8	Impactor Stages 1,2,3,5A
Filter Hold-Down Plate	Filter Hold-Down Plate	Filter Hold-Down Plate
Filter Screen	Filter Screen	Filter Screen
Base with hose fitting	Base with hose fitting	Base with hose fitting
Mounting Bracket, with clip	Mounting Bracket, with clip	Mounting Bracket, with clip
10-32 Thumb Screws(2)	10-32 Thumb Screws(2)	10-32 Thumb Screws(2)

For in-line sampling, the optional Model 290-IA In-Line Inlet Adapter is provided. The Series 290K "Kits" also include the Model 290-P Constant Flo Personal Sampling Pump and a length of interconnecting tubing. For operation of the Model 290-P, please consult the separate Model 290-P Instruction Manual provided with the Series 290K Kits.

Ordering More Collection Substrates and Filter Media
The following special Series 290 impactor collection substrates and back-up filter media are available:

Model C-290-MY	Collection Substrates, 34 mm dia., Mylar media, box of 100
Model C-290-SF	Collection Substrates, 34 mm dia., Film TM media, box of 100
Model F-290-P5	Filter Media, 34 mm dia., polyvinyl chloride media, 5 micron pore size, box of 100

Accessories

Model 290-IGT	Impaction Greasing Template
Model 29OG	Impaction Grease
Model 290-ORL	Large "O" rings, for Series 290,Viton, pack of 10
Model 290-ORS	Small "O" rings, for Series 290,Viton, pack of 10

IV. IMPACTORS

1. Description

The Marple Personal Cascade Impactor is a multi-orifice, multi-stage cascade impactor used to measure the concentration and particle size distribution of all liquid and solid particulate matter. The flow enters the inlet cowl and accelerates through the six radial slots in the first impactor stage. Particles larger than the cut-point of the first stage impact on the perforated collection substrate. Then, the air-stream flows through the narrower slots in the second impactor stage, smaller particles impact on the second collection substrate, and so on. The width of the radial slots are constant for each stage but are smaller for each succeeding stage. Thus, the jet velocity is higher for each succeeding stage, and smaller particles eventually acquire sufficient momentum to impact on one of the collection substrates. After the last impactor stage, remaining fine particles are collected by the built-in 34 mm filter.

2. Impactors

The Series 290 Marple Personal Cascade Impactor is constructed with aluminum stages that are held together by two screws with o-ring gaskets. Each impactor stage contains multiple precision drilled orifices. When air is drawn through the sampler, multiple jets of air in each stage direct any airborne particles toward the surface of the agar collection surface for that stage. The size of the jet orifices is constant within each stage, but are smaller in each succeeding stage. The range of particle sizes collected on each stage depends on the jet velocity of the stage and cutoff of the previous stage. Any particle not collected on the first stage follows the air stream around the edge to the next stage.

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Figure 3: Marple Personal Cascade Impactor

3. Pump Selection

The sampling pump for the Marple Personal Cascade Impactor must have two features:

- It must have a constant flow controller, which maintains the pre-selected flow rate constant as the pressure drop through the back-up filter increases with particulate loading.
- It must have a sufficient vacuum capability to maintain the pre-selected flow rate over the entire sampling period.

The constant flow feature is essential (1) to avoid changing, or smearing, the impactor stage cut-points which are flow rate dependent (see Section VI) to obtain accurate particle mass concentrations.

Figure 4 gives the pressure drop of the 294, 296, and 298 versus flow rate, with a clean Model F-290-P5 five micron PVC back-up filter. The pump selected should have a vacuum capability at least 1.5 to 2 times that shown in Figure 4 at the selected flow rate.

The Model 290-P Constant Flow Personal Sampling Pump has both required features at a flow rate of 2 LPM, or less. The Model 112 Constant Flow Air Sampler (0-10 LPM), which is used for area sampling (AC powered), has the required features over the flow range 2 to 5 LPM, for any sampling period. The Model 112 has a constant flow vacuum capability in excess of 600 inches of water over 2 to 5 LPM.

For multi-point measurements with a single pump, Thermo Scientific provides 2 LPM critical orifices with a diaphragm vacuum pump. Contact our Applications Engineers for more information.

The flow rate of the pump is accurately set with the convenient Model 715 two-by-two™ Calibration Mass Flow Meter.

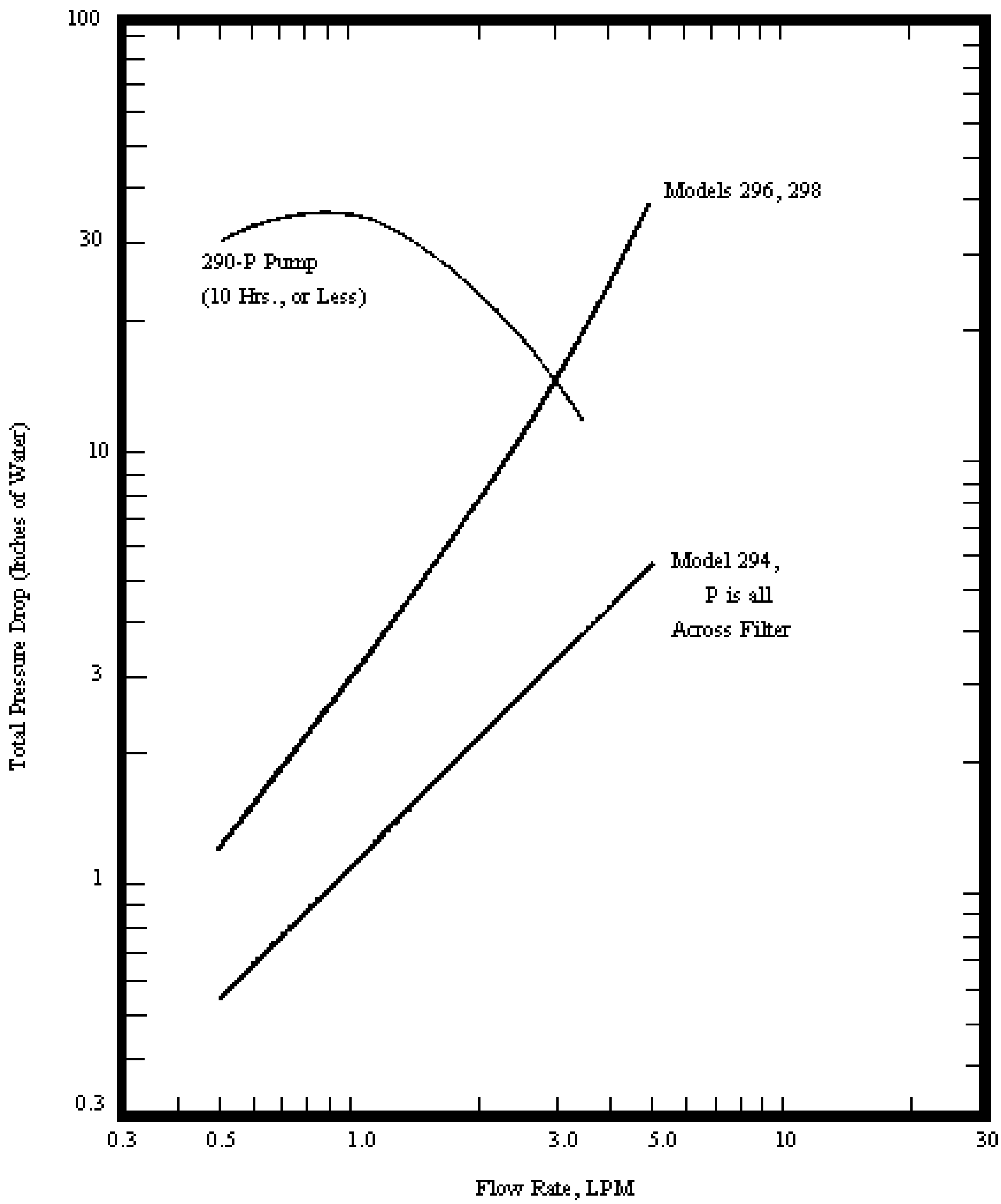

Figure 4: Pressure Drop Across Series 290 with Clean 34 mm 5 micron PVC Back-up Filter

4. *Carrying Case*
The Marple Impactor includes a carrying case for ease and portability.

5. *Specifications for Marple Personal Cascade Impactor*

Size and Weight

Model No.	**294**	**296**	**298**
Over-all Height of Impactor, cm	7.2	8.0	8.6
Width, cm	5.7	5.7	5.7
Depth, cm	4.0	4.0	4.0
Net Weight, gm	200	200	250
Shipping Weight,			
kg	0.5	0.5	0.5
lb.	1.0	1.0	1.0

- Flow Rate: 2 liters per minute (LPM) nominal; 0.5 to 5 LPM max. range; 1 to 3 LPM recommended
- Construction: Precision-machined aluminum; impactor stages nickel plated

Particle Size Cut-Points: See Section VI

- Collection Substrates: 34mm diameter; available in Film TM or Mylar

- Back-Up Filter: 34 mm diameter, PVC filter media
- Outlet Fitting: 1/8 in. NPT with 0.25 in. (6.3 mm) I.D. tube barb
- Inlet Fitting (Optional): On Model 290-IA In-Line Inlet Adapter: 1/4 in. NPT

6. Assembly

The Marple Personal Cascade Impactors are assembled in the following:

Table II: Assembly Listing for Marple Impactor

298	296	294
Inlet Visor (1)	Inlet Visor (1)	Inlet Visor (1)
Inlet Cowl (2)	Inlet Cowl (2)	Inlet Cowl (2)
10-32 Thumb Nuts	10-32 Thumb Nuts	10-32 Thumb Nuts
Impactor Stage 1		Impactor Stage 1
Collection Substrate		Collection Substrate
Impactor Stage 2		Impactor Stage 2
Collection Substrate		Collection Substrate
Impactor Stage 3	Impactor Stage 3	Impactor Stage 3
Collection Substrate	Collection Substrate	Collection Substrate
Impactor Stage 4	Impactor Stage 4	
Collection Substrate	Collection Substrate	
Impactor Stage 5	Impactor Stage 5	Impactor Stage 5A
Collection Substrate	Collection Substrate	Collection Substrate
Impactor Stage 6	Impactor Stage 6	
Collection Substrate	Collection Substrate	
Impactor Stage 7	Impactor Stage 7	
Collection Substrate	Collection Substrate	
Impactor Stage 8	Impactor Stage 8	
Collection Substrate	Collection Substrate	
Filter Hold-Down Plate ("F")	Filter Hold-Down Plate ("F")	Filter Hold-Down Plate ("F")
Filter	Filter	Filter
Filter Screen	Filter Screen	Filter Screen
Impactor Base	Impactor Base	Impactor Base
Exit Hose Fitting	Exit Hose Fitting	Exit Hose Fitting
Personal Mounting Bracket w/ Alligator Clip	Personal Mounting Bracket w/ Alligator Clip	Personal Mounting Bracket w/ Alligator Clip
10-32 Thumb Screws	10-32 Thumb Screws	10-32 Thumb Screws
1/4" I.D. "Tygon" Tubing	1/4" I.D. "Tygon" Tubing	1/4" I.D. "Tygon" Tubing
290-P Constant Flo Sampling Pump (or equivalent)	290-P Constant Flo Sampling Pump (or equivalent)	290-P Constant Flo Sampling Pump (or equivalent)

NOTES: (1) Has "Smiling Face"
(2) Has 1 in. dia. inlet hole

Each impactor stage is numbered along its edge. In assembly, all numbers should line up along one of the two threaded studs in ascending order from inlet to exit. No number should be upside down. Note that in assembly the two threaded studs orient the impactor stages so that the slots in each stage are staggered from the slots in adjacent stages. The impactor collection substrates are placed in the recess on the top surface of each impactor stage so that the slots in the stage are exposed; i.e, the perforations in the substrates go over the impactor slot. A tweezers is recommended to avoid hand contact. Thus, the particles accelerating through a slotted jet in an impactor stage impact on the solid surface of the collection substrate laying over the top of the adjacent downstream stage.

After proper assembly of the stages, collection substrates, and filter, attach the two thumb nuts to the two threaded studs and hand tighten until the stages "bottom out" on each other. The cascade impactor unit is now sealed.

The large "O" ring (Model 290-ORL) in each stage provides the seal between the stages and the exterior. The small "O" ring (Model 290-ORS) in the inner hub of each stage is used to hold down the collection substrate. The small "O" rings may be removed if the substrates will not rotate during sampling, as in stationary or area sampling. To avoid possible sticking, the small "O" rings need not be used with the Model C-290-SF Film TM Collection Substrates.

a. Personal Sampling

The alligator clip on the personal mounting bracket is clipped to the lapel or pocket flap. Alternatively, the clip can be rotated 1800 so that it points downward and clipped to the edge of the pocket. For firmer mounting, a piece of cardboard or equivalent rigid material can be cut to fit the inside of the pocket with the clip biting over both edge-s of the pocket and the cardboard.

The hose is connected to the plastic elbow fitting on the impactor and the inlet to the personal sampling pump. The elbow normally is turned downward. The pump is clipped to the belt.

b. Area Sampling

The is an excellent cascade impactor for stationary ambient sampling in an occupational area, inhalation toxicology chamber, aerosol research facility, or process stream. In this case, the personal mounting bracket is removed from the impactor base by unloosening the two thumb screws. If no large debris is present in the aerosol, the inlet visor and inlet cowl also can be removed. The exit hose fitting is rotated so it points either sideways or upwards, and the base of the cascade impactor is set on a horizontal surface. For rigid stationary mounting, it can be mounted to a suitable base using the two threaded holes in the impactor base. The Model 290-P Constant Flo Personal Sampling Pump (or equivalent), Model 112 Constant Flow Air Sampler (0-10 LPM), or other compatible vacuum supply is connected via tubing to the impactor.

c. In-Line Sampling

The versatile Series 290 also can be used as an in-line particle size fractionator for extracting a sample from inhalation toxicology chambers, aerosol chambers, process streams, or stacks (at temperatures not exceeding 1500F). In this case, the inlet visor and cowl are removed and replaced by the optional Model 290-IA In-Line Adapter. The sampled aerosol is connected to the 290-IA via the 1/4 NPT inlet part in the In-Line Adapter. The exit plastic hose fitting can be replaced with piping attached directly to the 1/8 NPT exit port in the impactor base.

The Series 290 can be operated in any orientation, without significant internal losses due to particle sedimentation if the sampling flow rate is approximately 1.0 LPM, or greater.

7. Cleaning and Collection Substrates

Since the cascade impactor is used for sampling particulate matter, all internal surfaces of the stages should be free from dirt. To clean, disassemble the cascade impactor and wash each part in water with detergent or in alcohol. Alternatively, the parts can be cleaned in an ultrasonic bath. Rinse and dry completely. Hold stages up to a light to make sure all slots are free of foreign matter. The slots also can be cleaned with shim stock.

When sampling solid particles, the Model C-290-MY Mylar Collection Substrates are used with impaction grease to avoid possible particle bounce. The Model C-290-SF -Film Collection Substrates have a sticky surface on one side for collection of solid particles without bounce. When sampling liquid aerosols, bare C-290-MY Mylar substrates are recommended. For sticky, non-bouncing solid aerosols the bare C-290-MY Mylar substrates can be effectively employed without encountering particle bounce, but in this case the sampling flow rate should not exceed 2 LPM.

Application of Impaction Grease: Although several low vapor pressure (vacuum) greases are suitable, Model 29OG Impaction Grease is a good choice.
The Model 29OG is high vacuum grease. The grease is applied as a suspension or solution of 10 to 20 percent grease in toluene. The mixture is applied with a brush, eyedropper or the Model 290IGS Impaction Grease Sprayer to the substrates. The Model C-290-IGT Impaction Grease Template is recommended for proper application of the grease. Place the substrate on the bottom plate of the template with the two locating pins through opposite perforations. Place the top plate (with six slots) on top, located by the two pins. Apply the solution within the six slots in the template. Note that the outer edge and center of the substrates must be devoid of grease or else the substrate will stick to the upstream impaction stage. Allow the solvent to evaporate. After drying, a cloudy white film is visible. The final greased substrate should be tacky, but not slippery, with a film thickness about equal to the diameter of the particles to be captured, i.e., 1 to 10 microns thick.

V. SAMPLING

Although the following instructions directly apply to personal sampling, they also are applicable to area or in-line sampling. An impactor data/work sheet similar to that shown in Figure 6 is recommended for measurement quality assurance.

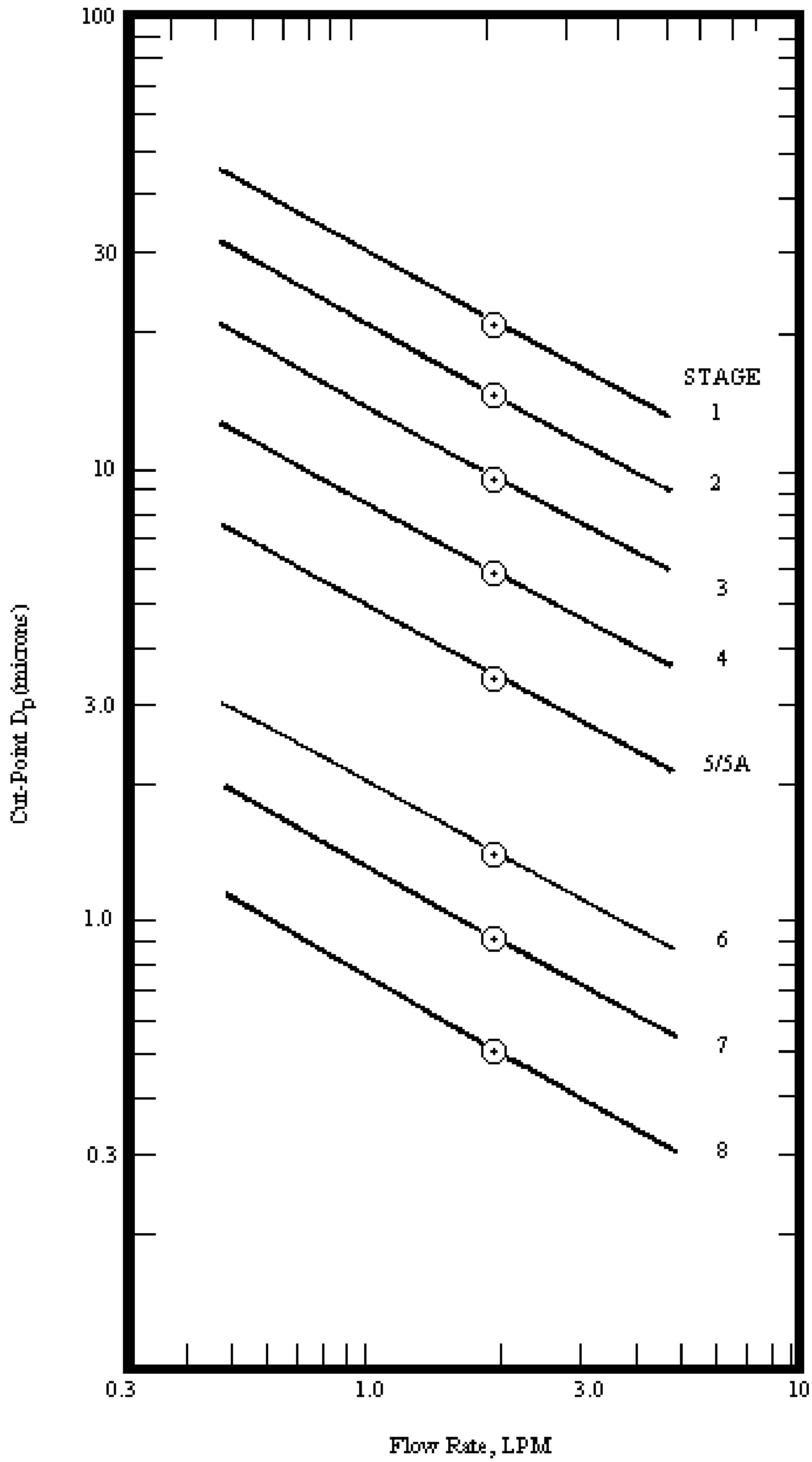

Figure 6: Series 290 Impactor Cut-Points vs. Flow Rate for Air at 25°C and 1 atm

1. From Figure 5**,** select the sampling flow rate based on the particle cut-points desired and the vacuum capability of the sampling pump (See Figure 4).

2. If the collection substrates are to be greased, use the procedure in Section IV.7. Pre-weigh all collection substrates and back-up filters in a clean laboratory environment. Record the weights. A micro-balance with a sensitivity of 0.001 or 0.01 mg is required. The substrates and filter should be equilibrated with the lab environment for approximately 24-hours at a relative humidity of 50%, or less, before weighing and passed over a static eliminator if they have a static electricity charge.

3. Assemble the cascade impactor as described in Section IV.5.

4. Connect tubing to sampling pump and set the desired sampling flow rate on the pump. Record the flow rate.

5. Go into field, attach cascade impactor to the lapel or pocket, pump to the belt, and the interconnecting tubing to both.

6. Turn pump on. Record sampling starting time and other required data on the data/work sheet.

7. After the desired sampling period, turn pump off and record sampling termination time (or elapsed time). If desired, the final flow rate can be checked to insure that constant flow was maintained throughout sampling. The Model 715 two-by-two TM Portable Calibration Mass Flow Meter is ideal for this application.

8. For best results, return to lab with fully assembled impactor transported in the up right position and sealed on the inlet to prevent sample contamination. Alternatively, the substrate can be removed in the field and placed in marked/sealed containers for transporting to the lab. In the lab, disassemble stages and remove collection substrates, maintaining their proper identification while doing so. Weigh all collection substrates and back-up filter, as in Step 2. Record the final weights.

9. Reduce the data as described in Section VI.

VI. DATA REDUCTION AND PRESENTATION

1. Impactor Cut-Points

Use of cascade impactor data requires knowledge of the cut-points of the impactor stages. Table 8-1 gives the experimentally determined cut-points at the design flow rate of 2 liters per minute (LPM) (See Reference 2).

Table III: Series 290 Impactor Cut Points at 2 LPM

Impactor Stage No.	Cut-Point* D_p (Microns)
1	21.3
2	14. 8
3	9.8
4	6
5 or 5A	3.5
6	1.55
7	0.93
8	0.52
Back-Up Filter	0

The internal losses in the Series 290 are minimal and usually are neglected in data reductions. Reference 2 gives internal losses and detailed performance data. Appendix B gives correction factors.

Although 2 LPM is the design flow rate for which most performance data is directly applicable, the cut-points for other flow rates in the 0.5 to 5 LPM range are calculated from equation VI-1 and are given in Figure 5. If the flow rate is too high, particle bounce and internal impaction losses can increase. If the flow rate is too low, internal sedimentation losses can increase. Therefore, the recommended flow range is 1 to 3 LPM for the Series 290 Marple Personal Cascade Impactors.

*Aerodynamic equivalent particle diameter for spherical particles of unity mass density in air at 25ºC and 1acfm.

Barometric pressure and ambient temperature changes over 10 to 35ºC have a negligible effect on the impactor cut-points.

Although Table III and Figure 8 have accurate cut-points for almost all applications, for completeness we give the following theoretical relationship for the cut-point of an impactor stage (See Reference 1):

$$D_p = (St)^{1/2} * w * (9\mu L / C\rho_p Q)^{1/2} \qquad \text{Equation VI-1}$$

Where:

St = the square root of the Stoke's Number, which depends on the jet throat length, jet Reynold's number and jet-to-plate distance, dimensionless (If jet-to-plate distance = 1, jet throat length = 1, and jet Reynold's number = 3000, then $(St)^{1/2} = 0.72$)

W = slot width, cm

μ = gas viscosity, gm/cm-sec

L = slot length, cm

ρ_p = particle mass density, gm/cc

C = Cunningham slip correction, dimensionless
Q = volumetric flow rate in the impactor stage, cc/sec.

From Equation VI-1, we can see that $D_p \propto Q^{-1/2}$. Figure 5 was generated from the experimental data at 2 LPM using this proportionality.

The gas viscosity, μ, varies with gas composition and temperature. The value μis 186 micropoise, or 186 x 10^{-6} g/cm-sec, for air at 25'C and 1 atm.

If desired, the particle density ρ_p can be obtained from standard mass density measurements for the particulate sample. For example, ρ_p = 2.54 for silica. The cut-offs in Table III and Figure 5 are for ρ_p = 1. Normally, correction is not made for non-unity particle mass density, in which case the cut-offs become the equivalent aerodynamic particle diameter. From Equation VI-1, we can see that $D \propto \rho_p$. Thus, if we want to plot the actual particle size distribution p at, for example, a mass density of 3.0, we would divide the cutpoints D_p in Table III by 1.73.

The Cunningham Correction C varies primarily with the particle size D_p. For large particles (greater than nominally 5 microns), C is very close to unity. Since C also depends on the mean free path of the gas, it also depends on gas pressure, temperature and composition.

2. Particle Mass Concentration
An important use of the Series 290 Marple Personal Impactor is calculation of the particle mass concentration C (mg/m^3) in each impactor size range and the total mass concentration C_{tot} (mg/m^3) of all particles sampled. Figure 6 is a useful Impactor Data/Work Sheet for both recording and reducing the data. It shows how to calculate C and C_{tot}.

3. Particle Size Distribution
<u>General</u>
A major use of Series 290 impactor data is determination of the complete particle size distribution of the sampled aerosol. Given the complete particle size distribution, the particle mass concentration in <u>any</u> size range can be calculated, including the inhalable, thoracic, and respirable fractions.

Figure 6 gives the methodology and formulas for calculating the two most popular types of particle size distributions.

<u>Differential Particle Size Distribution</u>
Below is a plot on log-log graph paper of: $\Delta C_i / \Delta_i \log_{10} D_p n$ vs. GMD_i

This plot is essentially a bar chart giving the particle mass concentration ΔC_i in each particle size band versus the geometric mean diameter GMD_i, where $GMD_i = (D_i * D_{i-1})^{1/2}$. This size distribution is the differential of the cumulative particle. size distribution. The differential particle size distribution gives the details, or "fine" structure, of the particle size distribution.

Cumulative Particle Size Distribution
This is a plot on log-normal (or log-probability) graph paper of

$$\sum_{i=j-1}^{N} W_j / W_{tot} \quad \text{vs.} \quad D_{p(i)}$$

(normal) (log)

The value W_i is the particle mass on impactor stage i, and W_{tot} is the sum of the particle masses on all stages plus back-up filter. The total number of all stages is N.

The cumulative particle size distribution gives total particle mass smaller than particle size D_p as a function of D_p. This type of particle size distribution gives us an over-all picture of the size of the particles and is the integral of the differential particle size distribution. On log-normal paper the particle size distribution of many aerosols is a straight line, or nearly so, which can be completely described by two numerical parameters obtained from the straight line graph:

1. The Mass Median Diameter MMD
The MMD of the log-normal distribution is the particle size D_p where $\sum_{i=j-1}^{N} W_j / W_{tot} = 50\%$. Thus 50% of the particle mass is borne by particles larger than the MMD, and 50% of the particle mass is borne by particles smaller than the MMD. The MMD gives an overall measure of the size of the particles.

2. The Geometric Standard Deviation σ_g
σ_g is the ratio

$$MMD / D_p(16\%)$$

where D p,16% is the particle size for which 16% of the mass is borne by particles smaller than $D_p(16\%)$. σ_g is a measure of the "spread" in the particle size distribution. if $\sigma_g = 1$, all of the particles are of the same size; i.e., the aerosol is "monodisperse."

4. Example Calculation
Appendix A gives an example data-presentation calculation using the Figure 6 Impactor Data/Work Sheet. Differential and cumulative particle size distributions are plotted.

VII. REFERENCES

1. V.A. Marple, B.Y.H. Liu, "Characteristics of Laminar Jet Impactors," Environmental Science and Technology, 8, No. 7, pp. 648-654, July, 1974.

2. K.L. Rubow, V.A. Marple, and J.G. Olin, "A New Personal Cascade Impactor," (to be published)

3. M.A. McCauley, et. al., "Field Studies with a new Personal Cascade Impactor," (to be published)

APPENDIX A: EXAMPLE DATA REDUCTION CALCULATION

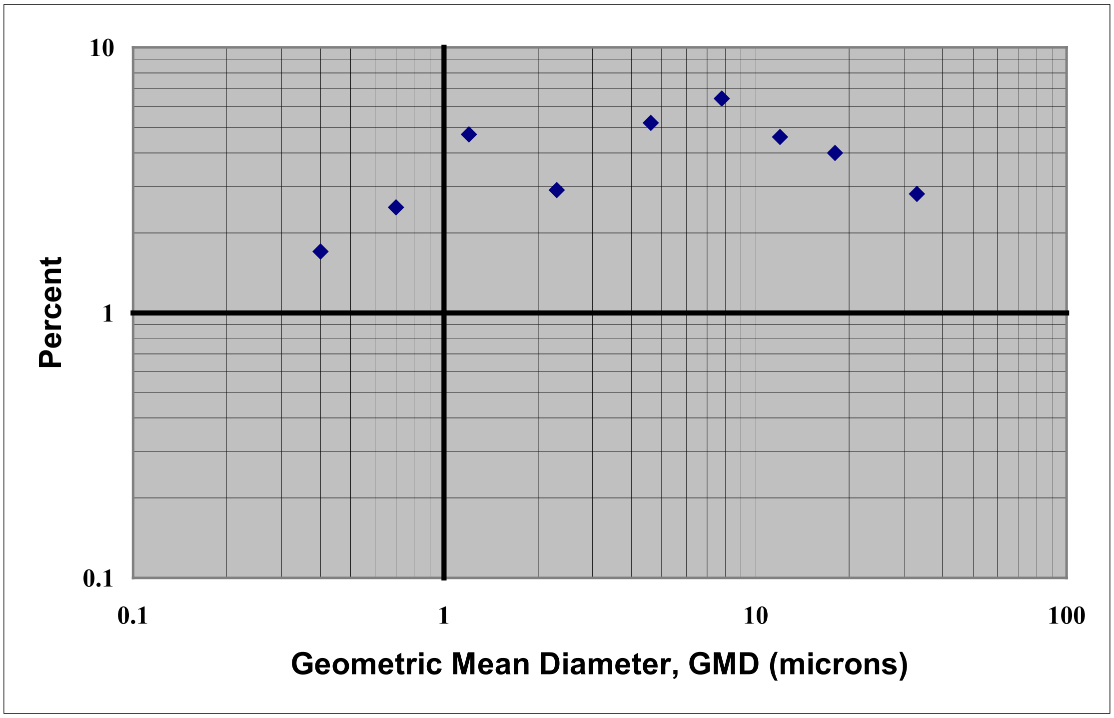

Figure 7: Differential Particle Size Distribution

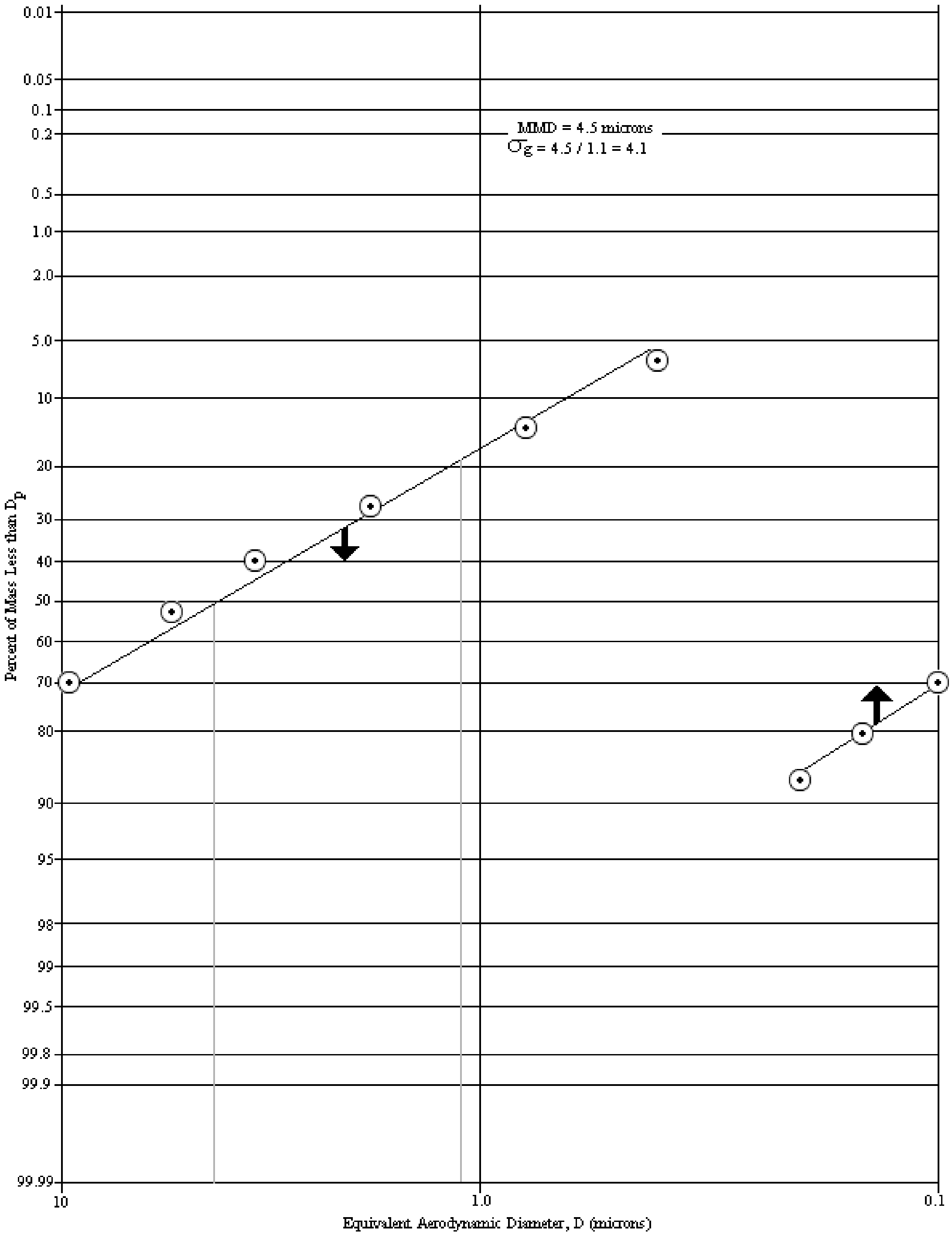

Figure 9: Cumulative Particle Size Distribution on Log-Normal Paper

APPENDIX B: CORRECTION FACTOR FOR SAMPLING EFFICIENCY AND INTERNAL LOSS

The Series 290 Marple Personal Cascade Impactors are the most carefully and extensively characterized impactors available. References 2 and 3 give complete data on impactor stage collection efficiencies, sampling efficiency, and internal losses. Other commercial impactors seldom have published internal loss data (in fact, its existence usually is ignored) and never have published sampling efficiency data. The purpose of this Appendix is to provide a correction factor - "effectiveness" - that corrects your data for sampling efficiency and internal losses.

At a given particle size, two parameters determine "effectiveness".

1. The "sampling efficiency," e: the percent of particles suspended in the ambient air that enter the inlet of the impactor.

2. The "internal loss;" f: the percent of particles which enter the inlet and are collected on extraneous internal surfaces, and not on the collection substrates or back-up filter.

The "effectiveness" E of the cascade impactor is:

$$E = e\,(1-f). \qquad \text{(B-1)}$$

The effectiveness of the Series 290 is higher than any other commercial impactor. For particles smaller than 10 microns it is usually assumed that E = l, and no corrections are necessary. For large particles, the 290 experiences the lower effectiveness common in any particulate sampler and open-faced filter.

Figure B-1 gives E, e, and f versus particle size for the model 294 and 298 at a flow rate of 2 LPM. For other flow rates, the 2 LPM data is used with acceptable accuracy, although the effectiveness is probably higher at lower flow rates and lower at higher flow rates.

The corrected particle mass W_i for impactor stage i is found by dividing it by the effectiveness E:

$$W_{i(corrected)} = W_i / E. \qquad \text{(B-2)}$$

W_i, is found from column 5 of Figure 11, "Impactor Data/Work Sheet.

E is found from Figure 10 at the particle size D_p halfway between the cut-point of stage i and stage i-1, or

$$D_p = (D_{p(i)}. + D_{p(i-1)}) / 2.$$

Table IV demonstrates this correction procedure by applying it to the example in Appendix A.

Table IV: Example correction for effectiveness

Stage Number	Particulate Weight W (mg), From Appendix A	Particle Size Dp (microns), For Exaluating E	Effectiveness E, From Figure 10	Corrected Paticulate Weigth W (mg), From Eqn. B-2
1	1.00	21.3[1]	0.52	1.92
2	0.60	18.1	0.61	0.98
3	0.80	12.3	0.78	1.03
4	1.30	7.9	0.89	1.46
5	1.20	4.8	0.95	1.26
6	1.00	2.5	0.96	1.04
7	1.00	1.2	0.97	1.03
8	0.60	0.7	0.99	0.61
Filter	0.50	0.5[2]	1.00	0.50
TOTAL	8.00			

NOTES: (1) By convention, we use the cut-point of Stage 1.
(2) By convention, we use the cut-point of Stage 8 for the filter.

The corrected values of W_i are then used in the Impactor Data/Work Sheet in Appendix A to calculate the corrected particle size distributions.

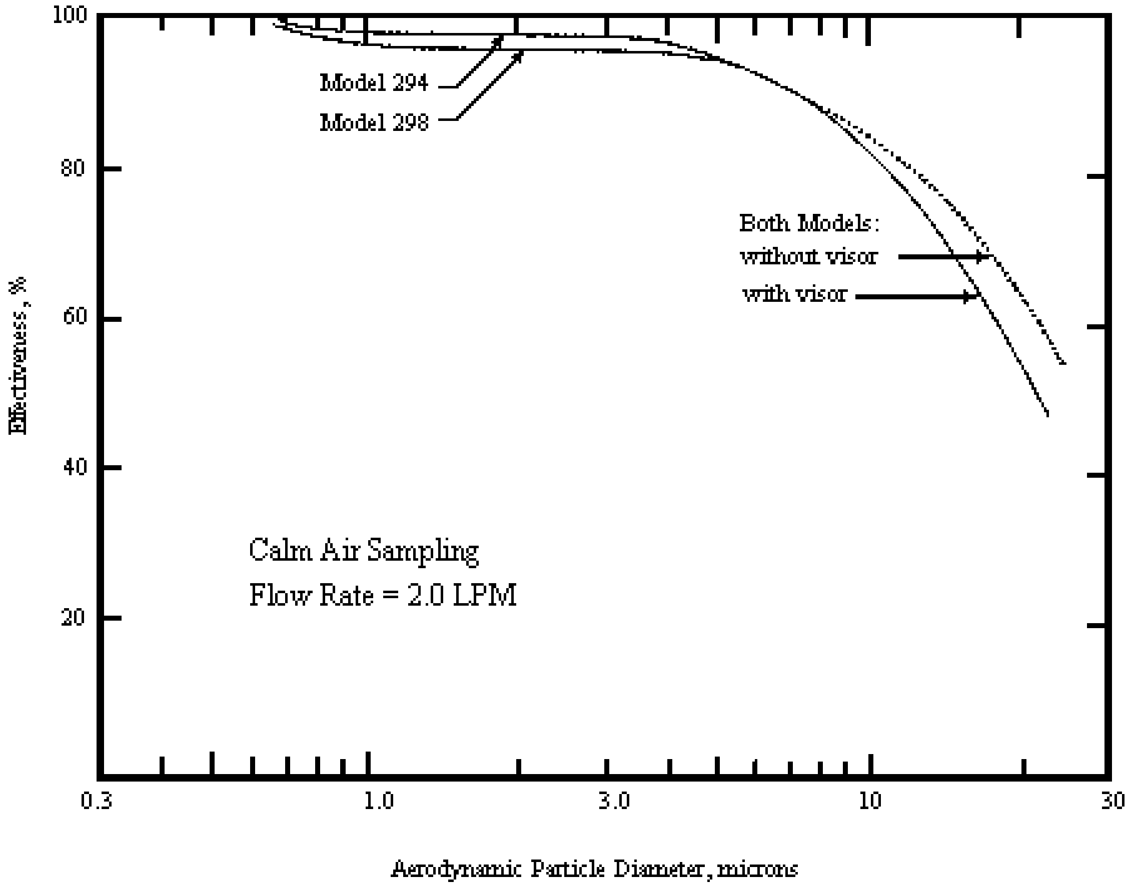

Figure 10: Effectiveness for Models 294 and 298

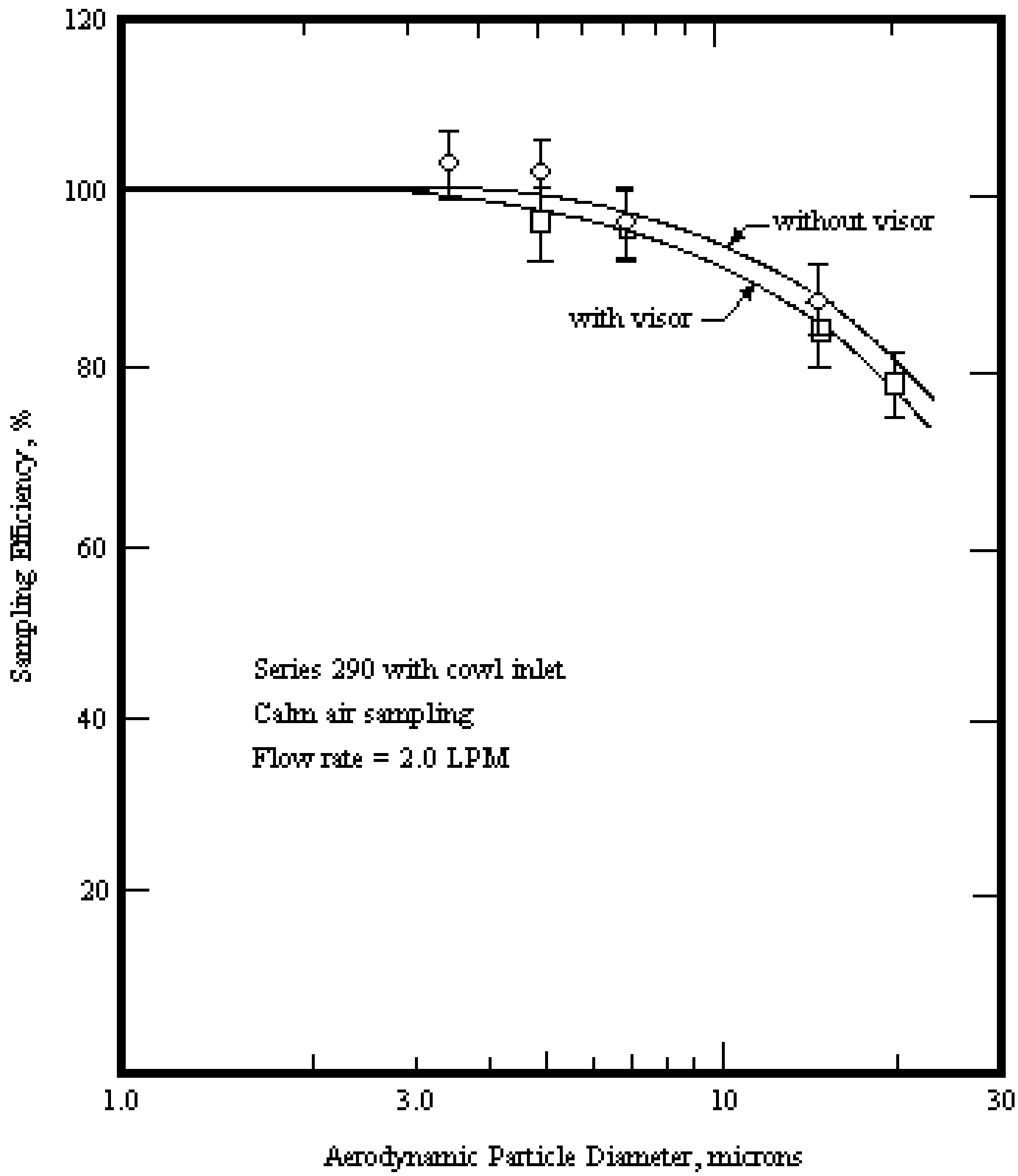

Figure 11: Inlet Sampling Efficiency

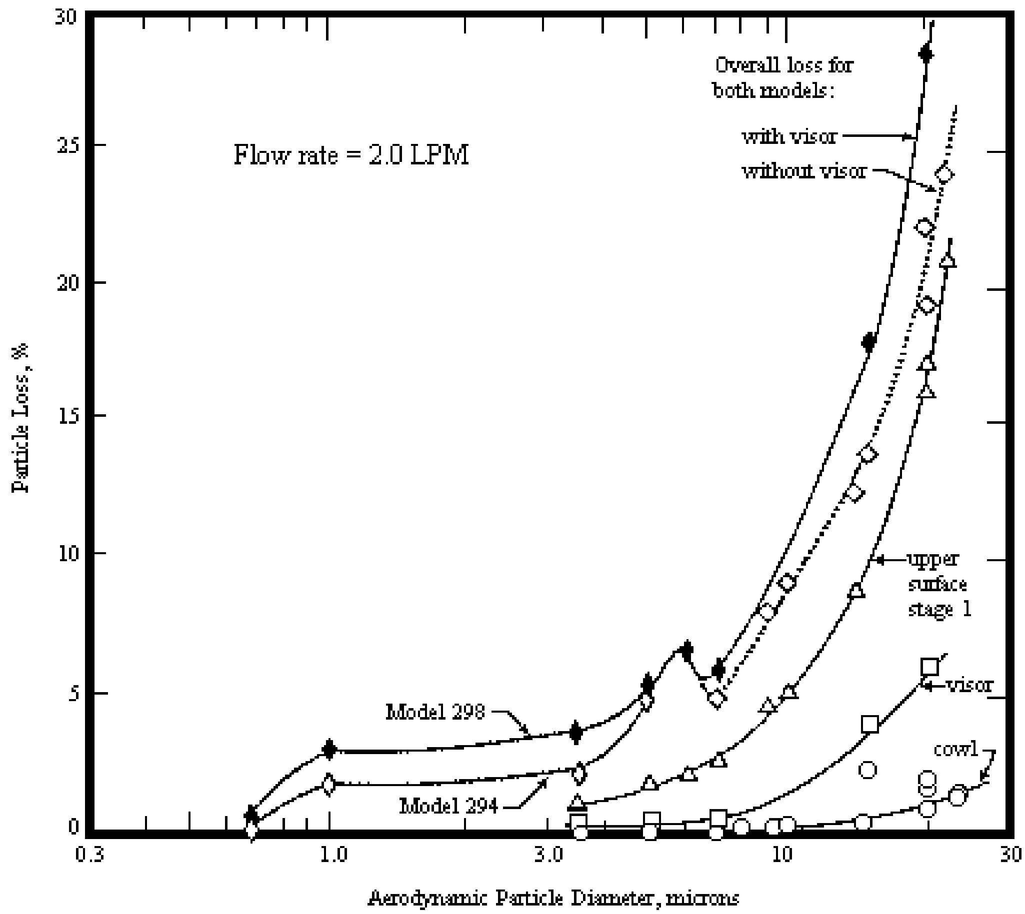

Figure 12: Particle Loss in the Model 294 and 298 Impactors

SERVICE LOCATIONS

For additional assistance, Thermo Fisher Scientific has service available from exclusive distributors worldwide. Contact one of the phone numbers below for product support and technical information or visit us on the web at www.thermo.com/aqi.

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