HIGH CONCENTRATION STANDARD AEROSOL GENERATOR

Final Comprehensive Report

Prepared for the
U.S. Army Armament Research and Development Command
Chemical/Ballistics Procurement Division
Aberdeen Proving Ground
Edgewood Area, Maryland 21010

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SoRI-EAS-85-724

Final Comprehensive Report

HIGH CONCENTRATION STANDARD AEROSOL GENERATOR

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July 31, 1985

Contract DAAK11-83-C-0038
A002 Final Comprehensive Report

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U.S. Army Armament Research and Development Command
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Project #5335

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I. Introduction

For aerosol research and testing it is important to have aerosols available with known and controllable properties. Particle size distribution is always an important parameter; frequently, a narrow size distribution is needed. For many investigations high concentration is the major consideration; sometimes this is coupled with the need for high flowrates. Under this contract Southern Research Institute (SoRI) has developed the High Concentration Standard Aerosol Generator (HCSAG) system with novel and frequently needed capabilities: high concentration, high flowrate, narrow size distribution, and particle size greater than 1 micron.

To create uniformly sized particles the generation mechanism must be very strictly controlled. To obtain a monodisperse aerosol by mechanical agitation such techniques as the vibrating orifice or oscillating reed are utilized. A liquid jet is segmented at regular intervals to produce droplets of the same volume. For each jet velocity and diameter the frequency of agitation must be tuned very accurately to prevent the formation of multiple sizes. The generation rate is limited to the order of $10^5$ per second.$^{1,2}$ To obtain a monodisperse aerosol by condensation techniques, the thermodynamic properties of the flowstream must be maintained within a narrow range while the aerosol is being cooled. This requirement is increasingly difficult to achieve as the desired particle rate (the product of concentration and flowrate) and particle size increase. Available generators of this type have low flowrates and are practically limited to small sizes.$^{3,4}$

An alternate approach for obtaining a narrow size distribution is to use a polydisperse aerosol generator followed by devices which separate the desired particle size from the larger and smaller sizes. This is the approach upon which the HCSAG is based. Classical impactors are used to separate the large particles from an aerosol stream and virtual impactors are used to remove the small particles.

This report describes the development of the HCSAG and serves as the instrument manual for the instrument. Section II (Operating Principle) gives the design criteria as well as describing the basic mechanisms upon which the HCSAG is based. Section III (Description of HCSAG) describes the actual components. Section IV (Performance Evaluation) presents aerosol data obtained during the course of developing the instrument. Section V (Operating Instructions) gives procedures for operating the HCSAG and Section VI (Maintenance) describes the procedures recommended to keep the components in good working condition. Section VII (Recommendations for Extending Performance) suggests procedures by which the system output could be modified to be more appropriate for given circumstances. These modifications include 1) increasing the concentration (if a lower flow or a wider size distribution is acceptable and 2) precautions and suggestions for use of different aerosol materials. Additional details of the system (including shop drawings, list lists of materials, and maintenance of commercially available components) are given in Appendices A and B and are referred to in the text of this report.
Since several components and operating parameters of this system represent extensions of the technology, significant effort has gone into reporting and analyzing data in a general form to promote understanding of the mechanisms involved.
II. Operating Principle

A. Design Criteria

The design criteria for the system required that aerosol produced by the HCSAG have a narrow size distribution in the range of 1 to 3 microns and that the concentration be high enough at a flowrate as high as 140 lpm to produce significant reduction in the transmittance of visible light over a 4 meter pathlength. The transmittance criterion corresponds to a concentration of at least $10^4$ particles per cm$^3$ for a particle diameter of 2 microns.

B. General Description of System

Figure II-1 gives a block diagram of the fundamental components of the system. Compressed air feeds about 425 slpm ($Q_{GEN}$) to a polydisperse aerosol generator (PAG) consisting of 6 Laskin nozzles. Aerosol from the PAG passes through two virtual impactors (VP1 and VP2) to the primary device (VP3) for removal of the small size fraction. The major purpose of VP1 and VP2 is to concentrate the primary aerosol stream by reducing the volume flowrate without discarding a proportionate fraction of the particles of interest. The flow split in both VP1 and VP2 is 10% so that 4 slpm exits through the token flow $Q_{2T}$ of VP2. A venturi is utilized to accurately adjust and monitor $Q_{2T}$.

VP3 is a novel virtual impactor in which a core of clean air, $Q_{CORE}$ is introduced at the center of the aerosol stream before entering the impactor jet. All of the token flow, $Q_{3T}$, is comprised of air from this clean core. Only particles with inertia large enough to penetrate into this token flow are thus retained. Retention of small particles in the primary aerosol stream, $Q_{3T}$, is far below that which can be achieved with traditional virtual impactors. Clean sheath air $Q_{SH}$ is also utilized to produce a sharper retention (or collection) efficiency than would otherwise occur; wall losses are probably reduced also. Figure II-3 presents results of empirical investigations of both types of virtual impactors. Masuda, et al identified limits on the proportions of $Q_{CORE}$, $Q_{2T}$, and $Q_{SH}$:

$$\frac{Q}{Q_{2T}} \geq 1.43$$
$$\frac{Q_{CORE}}{Q_{2T}} \geq 0.8 \frac{Q}{Q_{2T}}$$

where $Q$ is the total flowrate. This device, referred to as the Hochrainer virtual impactor after one of its developers and the current supplier, was tested in the original investigation at total flowrates from 5 to 30 lpm.

Referring back to Figure II-1, upon exiting VP3 the aerosol stream ($Q_{3T}$=3 lpm) enters the outlet impactor (OP) for removal of the large particles. OP is a classical impactor except that sheath air is added prior to the jet to maintain the desired size cut and reduce wall losses. The primary aerosol stream exits the system through a pressure let-down orifice (PLDO). This component is necessary because of the significant pressure head across the system which is necessary to establish the desired cutpoints around 1.5 $\mu$m.
Figure II-1. Block diagram of HCSAG.
Figure II-2. Illustration of annular aerosol flow and particle separation characteristics of Masuda, et al.\textsuperscript{5} impactor.
Figure 11-3. Efficiency of virtual impactors versus $\sqrt{\psi}$. See Figure 11-2. for explanation of $Q$'s.
After Conner$^6$ and Masuda, et al.$^5$

II-4
III. Detailed Description of HCSAG

In this section the HCSAG is described in further detail using drawings and photographs so that the user can identify the actual components, their function, and the valves and meters for adjustment and monitoring of operation. Appendix A (Shop Drawings of Noncommercial Components) and Appendix B (Maintenance Instructions of Commercially Available Components) give additional information. Figure III-1 is a schematic drawing of the HCSAG. Figures III-2 through III-11 are photographs showing various views of the system. Figure III-12 is an assembly drawing of the Hochrainer impactor.

A. Air and Liquid Supply

In Figure III-1 the user's air supply is connected to the main pressure regulator indicated in the upper left of the schematic. To keep system performance constant, the air supply should be capable of providing 25 scfm at 90 PSIG (and not more than 150 PSIG) with 10 PSI or less variation. This main air supply fitting is located just below the left corner of the front panel, shown in Figure III-2. From this regulator air passes through 2 additional oil traps and two 12 inch filter canisters in parallel. After these filters, the air supply branches to 6 paths, each with its own regulator, to the points where air is required by the system. The main inlet regulator is normally set at 60 PSIG using the gauge located on the upper left corner of the front panel, while the others are set at 45 PSIG (except for Poil). Most of this air supply subsystem, shown in Figure III-3, is located at the left end of the HCSAG.

The liquid supply subsystem is located toward the right rear corner (see Figure III-4). The path of the liquid in this subsystem is shown in Figure III-1 as "solid" tubing. As shown schematically in Figure III-1, three reservoirs (1, 2, and 3) in addition to the polydisperse aerosol generator (PAG) canister are utilized. The aerosol liquid (DuoSeal Vacuum Pump Oil at this time) is poured into the top (No. 1) reservoir at the fill tube. Opening the valve under reservoir No. 1 allows liquid to flow into reservoir No. 3 which feeds the PAG. Compressed air at pressure Poil is utilized to augment gravity flow in transferring liquid to the PAG. This pressure regulator is located at the bottom right of the front panel where it can be adjusted to keep the oil level constant as viewed through the site glass adjacent to it. Once that setting is established ΔPoil (measured at the gauge adjacent to the site glass) is an accurate parameter for reproducing a desired fluid level. Overflow from reservoir No. 3 flows to reservoir No. 2 until the levels in reservoirs No. 2 and 3 equalize. Then reservoir No. 2 is emptied by pumping liquid back to reservoir No. 1 via the hand operated peristaltic pump.

B. Polydisperse Aerosol Generator

Air to PAG is controlled at the top right of the front panel (see Figure III-2) by a ball valve. The pressure upstream of the 6x4 Laskin nozzles (PGJETS) and in the cannister (PGEN) are monitored at the front panel below the ball valve. The flowrate through the nozzles is given by

\[ Q_{GJETS} = 2.55 \left( P_{GJETS} + P_{BAR} \right)^n \]  

III-1
Figure III.1. High concentration standard aerosol generator. Solid arrows depict sample flow and dotted arrows are waste streams.
Figure III-3. Compressed Air Supply Subsystem. View of left end of HCSAG.
Figure III-4. Liquid Supply Subsystem. View of right end of HCSAG. Also shows coalescing filters for exhausting $Q_{1D}$ and $Q_{2D}$. 
Figure III-5. Polydisperse Aerosol Generator and First Virtual Impactor (above). View from rear of HCSAG.
Figure III-6. First and Second Virtual Impactors. View from rear of HCSAG.
Figure III-7. First and Second Virtual Impactors showing exhaust tubing to coalescing filters (left). View from left rear of HCSAG.
Figure III-8. Second Virtual Impactor (left), Venturi and Hochrainer Impactor. View from right rear of HCSAG. Coalesing filter for exhausting $O_{HD}$ is at bottom center.
Figure III-9. Exit from Second Virtual Impactor, Venturi, and Hochrainer Impactor. View from left end of HCSAG.
Figure III-10. Hochrainer Impactor (right) and Outlet Impactor (left). View from left end of HCSAG.
Figure III-11. Hochrainer Impactor (left), Outlet Impactor, and Pressure Let-Down Orifice (right). View of right rear of HCSAG.
Figure III-12. Hochrainer Impactor.
can also be monitored on the front panel for diagnostic purposes. It may be desirable to use this parameter to set and monitor the token flow of VP2 (the aerosol flowrate to VP3). If this is practical, the venturi would not be necessary and could be removed. Additional investigation of the behavior of \( \Delta P_{2T} \) would be needed to verify its usefulness as a flow monitor. Pressure fluctuations in this token flow due to turbulence are of concern.

D. Hochrainer Virtual Impactor

The token flow of VP2 passes through a venturi which provides an accurate determination of flowrate:

\[
Q_{2T} = 0.83\sqrt{\frac{\Delta P_V}{(P_3+P_{BAR})}} \tag{5}
\]

for \( Q_{2T} \) in alpm, \( \Delta P_V \) (pressure drop across the venturi) in inches of water, \( T \) in \({}^\circ\text{R}\), \( P_3 \) (pressure at the inlet to VP3) in PSIG and \( P_{BAR} \) in PSIA. \( \Delta P_V \) and \( P_3 \) are monitored by gauges on the front panel, near the center. The venturi is shown at the center of Figure II-11 with VP2 to the left and VP3 to the right. The aerosol stream is merged with two other flows \( Q_{CORE} \) and \( Q_{SH} \) in the Hochrainer impactor as described in Section IIB. An assembly drawing of this device is given in Figure III-12 with the major dimensions. Figures III-8 and III-9 are photographs of the actual device. \( Q_{CORE} \) and \( Q_{SH} \) are monitored by rotameters at the top center of the front panel. The readings from these meters must be corrected by

\[
Q_{CORE} \text{ or } Q_{SH} = Q_R \frac{1}{(P_3+P_{BAR})/14.7} \tag{6}
\]

for flowrate in slpm where \( Q_R \) is the reading of the rotameter. To convert this flow to actual volume flowrate at the jet of VP3:

\[
Q_{CORE} \text{ or } Q_{SH} = Q_R \frac{1}{(P_3+P_{BAR})} \tag{6a}
\]

where \( Q_{CORE} \) and \( Q_{SH} \) are in alpm. The flowrate through the jet of VP3 is given by

\[
Q_3 = 0.61\sqrt{\frac{\Delta P_3}{(P_3+P_{BAR})}} \tag{7}
\]

for \( Q_3 \) in alpm (upstream conditions), \( \Delta P_3 \) in inches of water, \( P_3 \) in PSIG, and \( P_{BAR} \) in PSIA. A meter giving \( \Delta P_3 \) is located on the front panel directly above the \( P_3 \) meter.

A meter (\( \Delta P_{AC} \)) at the bottom of the front panel, under the \( \Delta P_V \) meter, is used to monitor the pressure drops across the laminar flow rings (No. 11 in Figure III-12). The holes in these rings can become covered with liquid due to wall losses. \( \Delta P_{AC} \) may be used to diagnose obstruction of flow by liquid. Under normal conditions \( \Delta P_{AC} \) oscillates between ±0.2"H.O. Cotton threads to serve as a wick were added to the base of these rings to reduce the buildup of liquid. The wick extends into the drain bottle for this region. Care should be exercised not to pull on this wick when emptying the drain bottle.
Because of the potential of liquid drops collecting on the entrance to the jet of VP3, the user is cautioned to avoid operating the system without \( \Omega_{\text{CORE}} \) and \( \Omega_{\text{SH}} \) flow. Most of the flow of VP3 is exhausted through a coalescing filter, a metering valve, and a rotameter. The valve and rotameter are located on the front panel just left of center. This valve is important for adjusting the flow split between the exhausted air, \( \Omega_{\text{HD}} \), and the token flow, \( \Omega_{\text{HT}} \). The rotameter gives \( \Omega_{\text{HD}} \) in slpm; it can be converted to alpm at the conditions of the inlet of VP3 by

\[
\Omega_{\text{HD}} = \Omega_{R} \frac{26.6}{(P_{3} + P_{\text{BAR}})} \sqrt{P_{\text{BAR}}}
\]

where \( \Omega_{R} \) is the rotameter value. The primary aerosol (without the small fraction) passes into the token flow of VP3. This flowrate \( \Omega_{\text{HT}} \) is determined by the difference \( (\Omega_{3} - \Omega_{\text{HD}}) \). The pressure differential, \( \Delta P_{\text{HT}} \), between the token flow and inlet to the jet of VP3 is also metered on the front panel for diagnostic use. This meter is located between the rotameter and control valve for \( \Omega_{\text{HD}} \). As with \( \Delta P_{2} \), this parameter is expected to be proportional to the token flow \( \Omega_{\text{HD}} \). However, additional investigation of its behavior, beyond the scope of this project, will be needed to verify its use as a monitor of \( \Omega_{\text{HT}} \).

E. Outlet Impactor

The token flow of VP3 is merged with a sheath of clean air in the outlet impactor (OP) shown in schematically in Figure III-1 and in the photographs of Figures III-10 and III-11. This sheath air flowrate \( \Omega_{I} \) is monitored by a rotameter at the top left of the front panel. The reading on this rotameter must be corrected by

\[
\Omega_{I} = \Omega_{R}\sqrt{(P_{I} + P_{\text{BAR}})} / 14.7
\]

for flowrate in slpm and by

\[
\Omega_{I} = \Omega_{R}\sqrt{14.7/(P_{I} + P_{\text{BAR}})}
\]

for flowrate in alpm where \( \Omega_{R} \) is the rotameter reading and \( P_{I} \) is the pressure at the inlet to OP in PSIG. The meter giving \( P_{I} \) is located below the \( \Omega_{I} \) rotameter. \( \Omega_{I} \) is set at a value for which OP will remove the large size fraction. In principle the exact value depends upon the trade-off between the desired width of the distribution versus the desired particle rate. However, the size distribution of particles from the Virtis SG-40 polydisperse aerosol generator with DuoSeal Vacuum Pump oil, drops off sharply at about 2\( \mu \)m so adjustment of \( \Omega_{I} \) has little effect on the output. Of course if \( \Omega_{I} \) is too high the desired particle sizes would be impacted. Varying \( \Omega_{I} \) affects \( P_{I} \) which affects the flow split in VP3. Thus \( \Omega_{\text{HD}} \) must be adjusted appropriately to maintain a constant token flowrate \( \Omega_{\text{HT}} \). The most important priority in adjusting \( \Omega_{I} \) is to provide the flowrate needed to maintain the pressure \( (P_{I}) \) necessary for suitable flow split of the virtual impactors throughout the HCSAG. This pressure is determined by the pressure drop occurring across the OP jet and the pressure let-down orifice PLDO at the HCSAG outlet (see Figure III-11). The desired flowrate, \( \Omega_{I} \), can be modified by changing the diameter of the PLDO. Two sizes (1/32" and 3/32") are supplied as accessories.

III-16
Wire screens are used as diffusers to evenly distribute the sheath air flow, $Q_I$, prior to merging with the aerosol stream, $Q_{HT}$. As with $\Delta P_{AC}$, the pressure differential ($\Delta P_{AC}$) between the token flow and the sheath flow is monitored to indicate obstructions of the sheath air flow due to liquid build up on these screens. This meter is located at bottom left of the front panel. The user is cautioned against operating the system without some sheath air to minimize the deposit of drops on the entrance cone of the VP3 jet.

The pressure drop across the jet of OP, $\Delta P_I$, is monitored on the front panel at the upper left between the $Q_I$ rotameter and the $P_3$ gauge. The flowrate through this jet is given by

$$Q_I + Q_{HT} = 2.9 \sqrt{\Delta P_I^T/(P_I+P_BAR)}$$

(10)

where $Q_I$ and $Q_{HT}$ are in alpm and $\Delta P_I$ is in inches of water.

F. Oil Drainage

As shown in Figures III-1 through III-11, a substantial part of the HCSAG hardware is designed to drain liquid collected on the walls away from the flowstreams. These losses are undesirable but unavoidable. Continuous operation of the HCSAG at conditions described in Section IV for 8 hours indicates that the current drainage system is adequate. Accumulation of liquid is very slow in all drain bottles except for the one which receives liquid collected from the inlet chamber of VP1. This bottle is located beside the PAG canister at the right end of the HCSAG, easily accessible for emptying.
Table IV-1. HCSAG Operating Parameters for Performance Test

<table>
<thead>
<tr>
<th>Dep. Run</th>
<th>P_{G1305}</th>
<th>P_{G101}</th>
<th>P_1</th>
<th>ΔP_1</th>
<th>P_2</th>
<th>ΔP_2</th>
<th>P_{2T}</th>
<th>ΔP_{2T}</th>
<th>Q_{ID}</th>
<th>ΔP_v</th>
<th>Q_{core}</th>
<th>Q_{SH}</th>
<th>P_1</th>
<th>ΔP_1</th>
<th>Q_{WD}</th>
<th>ΔP_{WT}</th>
<th>Q_{1}</th>
<th>ε</th>
<th>P_{1}</th>
<th>ΔP_1</th>
<th>ΔP_{AC}</th>
<th>ΔP_{AS}</th>
<th>ΔP_{oil}</th>
</tr>
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<td>17</td>
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<td>31</td>
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<td>.6</td>
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<td>7.6</td>
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<td>15.5</td>
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<td>.1-10</td>
<td>30-60</td>
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<td>4.0</td>
<td>0.3</td>
<td>-0.2</td>
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<td>.5</td>
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<td>140</td>
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<td>30-60</td>
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<td>.5</td>
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IV-2
Table IV-2. Stage Configuration of UW Mark V Impactor for Measurement of HCSAG Output Aerosol.
Table IV-3. Run Parameters and Results of Impactor Measurements of HCSAG Output Aerosol: Run No. 1.

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<th>VALUE</th>
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</tr>
<tr>
<td>TIME</td>
<td>1030</td>
</tr>
<tr>
<td>LOCATION</td>
<td>TEST LAB</td>
</tr>
<tr>
<td>SITE NUMBER</td>
<td>1</td>
</tr>
<tr>
<td>RUN NUMBER</td>
<td>1</td>
</tr>
<tr>
<td>RUN REMARKS</td>
<td>SEE OTHER DATA SHEETS</td>
</tr>
<tr>
<td>IMPACTOR TYPE</td>
<td>LVJ-179-7-9</td>
</tr>
<tr>
<td>WATER VAPOR</td>
<td>0.00%</td>
</tr>
<tr>
<td>CO2</td>
<td>1.00%</td>
</tr>
<tr>
<td>CO</td>
<td>0.00%</td>
</tr>
<tr>
<td>N2</td>
<td>99.00%</td>
</tr>
<tr>
<td>ORIFICE ID (OPTIONAL)</td>
<td>0.00%</td>
</tr>
<tr>
<td>SUBSTRATE MATERIAL</td>
<td>STAINLESS STEEL</td>
</tr>
<tr>
<td>GAS METER VOL</td>
<td>10,478 CUBIC FEET</td>
</tr>
<tr>
<td>IMPACTOR DELTA P</td>
<td>0.00 IN. HG</td>
</tr>
<tr>
<td>ORIFICE DELTA P</td>
<td>-10 INCHES H2O</td>
</tr>
<tr>
<td>STACK PRESSURE</td>
<td>.06 INCHES H2O</td>
</tr>
<tr>
<td>BAROMETRIC PRES</td>
<td>29.30 INCHES HG</td>
</tr>
<tr>
<td>STACK TEMP</td>
<td>74 DEGREES F</td>
</tr>
<tr>
<td>IMPACT TEMP</td>
<td>75 DEGREES F</td>
</tr>
<tr>
<td>SAMPLING TIME</td>
<td>20.00 MINUTES</td>
</tr>
<tr>
<td>AVERAGE GAS VELO</td>
<td>1.03 FEET/SEC</td>
</tr>
<tr>
<td>ORIFICE PRES</td>
<td>.00 INCHES HG</td>
</tr>
<tr>
<td>NOZERLE DIA</td>
<td>.500 INCHES</td>
</tr>
<tr>
<td>MAX PART DIA</td>
<td>.000 MICRO</td>
</tr>
<tr>
<td>STAGE CURR.</td>
<td>DP (IMP AERD)</td>
</tr>
<tr>
<td>1</td>
<td>1.010</td>
</tr>
<tr>
<td>2</td>
<td>1.033</td>
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<tr>
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**RESULTS**

| ACTUAL FLOW RATE | .567 CFM |
| FLOW RATE AT STANDARD CONDITIONS | .522 CFM |
| PERCENT ISOKINETIC | 534.77% |
| VISCOSITY | 181.9E-06 |
| CALCULATED IMPACTOR DELTA P | 1.20 IN. HG |
Table IV-4. Run Parameters and Results of Impactor Measurements of HCSAG Output Aerosol: Run No. 2.

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<th>RE.</th>
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**PARTICLE DIA. (MICRONS) (STDEV) (PERCENT) (MG/DAY N.C. METER)**

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**HISTOGRAM.data**

**RUN PARAMETERS**

- **Part No.**
- **Date of Test:** 12/14/64
- **Time of Test:** 8:55
- **Location of Test:** Lab
- **Remarks:**
- **Test Type:** Outlet
- **Remarks:** Keeping oil level slightly lower than other previous
- **Impactor Type:** USJ 1-377-9
- **Airflow Velocity:** 34-50
- **Grifice ID:** Optional
- **Substrate Material:** Bare Metal

**RESULTS**

- **Test Number:** 1
- **Run Number:** 2
- **Actual Flow Rate:** 3.34 CFM
- **Flow Rate at Standard Conditions:** 343 CFM
- **Percent Isothermal:** 345.832 %
- **Viscosity:** 181.4-0400/CH SEC
- **Calculated Impactor Delta P = 1.46 IN. HO**
Table IV-5. Run Parameters and Results of Impactor Measurements of HCSAG Output Aerosol: Run No. 3.

***************IMPACTOR VERSION 3.0***************

*********** INPUT DATA ***********

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<td>IMPACTOR TYPE</td>
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<tr>
<td>W V (DISK)</td>
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| WATER VAPOR | 0.0% |
| CO2         | 1.00% |
| CO          | 0.0% |
| H2O         | 99.00% |

| ORIFICE ID (Optional) | 0.0% |
| SUBSTRATE MATERIAL   | BARE METAL |

| GAS METER VOL. | 10.041 CUBIC FEET |
| IMPACTOR DELTA P | .00 IN. Hg |
| ORIFICE DELTA P | .10 INCHES H20 |
| STACK PRESSURE | .00 INCHES H20 |
| DEBREACHING P | 25.75 INCHES H20 |
| STACK TEMP    | 75 DEGREES F |
| HEATER TEMP   | 75 DEGREES F |
| IMPACTOR TEMP | 75 DEGREES F |
| SAMPLE TIME   | 20.00 MINUTES |

| MAX GAB VEL | 1.00 FEET/SEC |
| MAX GAB DELTA P | .00 INCHES H20 |
| NOZZLE DELTA P | .500 INCHES |
| MAX PART DELTA P | 20.00 MICRONS |

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TOTAL MASS CONCENTRATION = 1.256 x 82 MB/DAY NORMAL CUBIC METER

SPLINE FIT ON PHYSICAL DIAMETER BASIS

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MASS BURN IN STAGE 1   1.12 MG
MASS BURN IN STAGE 2   2.34 MG
MASS BURN IN STAGE 3   3.33 MG
MASS BURN IN STAGE 4   4.33 MG
MASS BURN IN STAGE 5   5.33 MG
MASS BURN IN STAGE 6   6.33 MG
MASS BURN IN STAGE 7   7.33 MG
MASS BURN IN FILTER   1.21 MG

MASS BURN IN BLANK SUBSTRATE   .00
MASS BURN IN BLANK FILTER   .00

RESULTS

TEST NUMBER: 1  RUN NUMBER: 3

ACTUAL FLOW RATE   .355 CFM
FLOW RATE AT STANDARD CONDITIONS   .349 CFM
PERCENT ISOKINETIC   34.59
VISCOSITY   181.42-66000/CM SEC
CALCULATED IMPACTOR DELTA P   2.147 IN. HO
Table IV-6. Run Parameters and Results of Impactor Measurements of HCSAG Output Aerosol: Run No. 4.

***************IMPACTOR VERSION 3.0***************

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| 1) GAS METER VOL | 10.903 CUBIC FEET |
| 2) IMPACTOR DELTA P | .00 IN. H2O |
| 3) ORIFICE DELTA P | -18. INCHES H2O |
| 4) STACK PRESSURE | .00 INCHES H2O |
| 5) BAROMETRIC PRES | 29.75 INCHES H2O |
| 6) STACK TEMP | 70 DEGREES F |
| 7) METER TEMP | 70 DEGREES F |
| 8) IMPACTOR TEMP | 70 DEGREES F |
| 9) EASEL TIME | 20.00 MINUTES |
| 10) AVG GAS VELOCITY | 1.95 FEET/SEC |
| 11) ORIFICE PRES | .00 INCHES H2O |
| 12) NEULDE DIA | .900 INCHES |
| 13) MAX PART DIA | 20.00 MICRON |

| MASS BAIN OF STAGE 1 | .01 HO |
| MASS BAIN OF STAGE 2 | .09 HO |
| MASS BAIN OF STAGE 3 | 1.10 HO |
| MASS BAIN OF STAGE 4 | 15.92 HO |
| MASS BAIN OF STAGE 5 | 11.11 HO |
| MASS BAIN OF STAGE 6 | 5.33 HO |
| MASS BAIN OF STAGE 7 | 1.15 HO |
| MASS BAIN OF FILTER | 1.15 HO |

| SO2 | 1.00% |
| 0.00% |

| TOTAL MASS CONCENTRATION | 1.05E+02 MG/DAY NORMAL CUBIC METER |

SPLINE FIT ON PHYSICAL DIAMETER BASIS

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**RESULTS**

**TEST NUMBER: 1 RUN NUMBER: 4**

**ACTUAL FLOW RATE: .354 CFM**

**FLOW RATE AT STANDARD CONDITIONS: .343 CFM**

**PERCENT ISOKINETIC: 343.777 %**

**VISCOITY: 161.40-9600/CM SEC**

**CALCULATED IMPACTOR DELTA P = 1.44 IN. H2O**
Table IV-7. Run Parameters and Results of Impactor Measurements of HCSAG Output Aerosol: Run No. 5.

----------------------------IMPACTOR VERSION 3.0-------------------------------

****** INPUT DATA ******

1) PART. DIAMETER          PHYSICAL
2) DATE OF TEST: 12/18/84
3) TIME OF TEST: 1500
4) LOCATION OF TEST: LAB
5) TEST NUMBER: 1 REMARKS:
6) TEST VENT: OUTLET
7) RUN NUMBER: 5-FILE NAME: IMPFTEST5.DT
8) RUN REMARKS: KEEPING OIL LEVEL IN LOWER 1/4 OF HOLE IN REFLECTOR
9) IMPACTOR TYPE: UNIT 1-317-P
10) DISK: 3-4-5-6-7-9
11) WATER VAPOR: 0.0%
   CO2: 1.06%
   CO: 0.0%
   O2: 19.06%
   H2: 90.06%
12) ORIFICE ID (OPTIONAL): 0.073A
13) SUBSTRATE MATERIAL: BARE METAL

1) GAS METER: 16.711 CUBIC FEET
2) ORIFICE DELTA P: 0.80 IN. HO
3) STACK PRESSURE: 0.80 INCHES H2O
4) ORIFICE PRESSURE: 29.75 INCHES H2O
5) STACK TEMP: 75 DEGREES F
6) METER TEMP: 75 DEGREES F
7) IMPACTOR TEMP: 75 DEGREES F
8) SAMPLE TIME: 20.00 MINUTES
9) AWG GAS VEL: 1.00 FEET/SEC
10) ORIFICE PRESSURE: 0.00 INCHES H2O
11) NOZZLE DIA: 0.500 INCHES
12) MAX PART DIA: 20.00 MICRONS

MASS GAIN OF STAGE 1: 0.01 MG
MASS GAIN OF STAGE 2: 0.12 MG
MASS GAIN OF STAGE 3: 1.02 MG
MASS GAIN OF STAGE 4: 2.18 MG
MASS GAIN OF STAGE 5: 3.72 MG
MASS GAIN OF STAGE 6: 3.19 MG
MASS GAIN OF STAGE 7: 1.51 MG
MASS GAIN OF FILTER: 0.40 MG

MASS GAIN OF BLANK SUBSTRATE: 0.00
MASS GAIN OF BLANK FILTER: 0.00

****** RESULTS ******

TEST NUMBER: 1 RUN NUMBER: 5
ACTUAL FLOW RATE: .544 CPM
FLOW RATE AT STANDARD CONDITIONS: .535 CPM
PERCENT ISOKINETIC: 340 / 456 %
VELOCITY TYPE: 181.66-8408/COM SEC
CALCULATED IMPACTOR DELTA P = 1.42 IN. HO

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TOTAL MASS CONCENTRATION = 1.33E+02 MG/DAY NORMAL CUBIC METER

SPLINE FIT ON PHYSICAL DIAMETER BASIS

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251.00 1800000 105.00 1.33E+02 6.00E+00
201.00 1800000 105.00 1.33E+02 6.00E+00
151.00 1800000 105.00 1.33E+02 6.00E+00
101.00 1800000 105.00 1.33E+02 6.00E+00
 51.00 1800000 105.00 1.33E+02 6.00E+00
Figure IV-2. Size distribution of HCSAG aerosol measured simultaneously with impactor (O) and Climent (—).
V. Operating Instructions

These instructions assume that the reader is familiar with the HCSAG and the nomenclature and figures of Section III. For illustrative purposes it is assumed that the conditions or operating parameters of Table IV-1 are to be achieved. It is assumed that a compressed air supply and shut-off valve has been connected to the main inlet to the HCSAG at the lower left corner near the front panel. Keep this shut-off valve closed until preparatory steps described below are achieved.

A. Precautions

The most important precaution is that no parts of the system downstream of pressure regulators and control valves be pressurized at more than 16 PSIG. This means that all pressure meters on the front panel should be kept below 16 PSIG except $P_{\text{GJETS}}$ and $P_{\text{MAIN}}$. If the outlets of the system are closed off for any reason then these two gauges cannot exceed 16 PSIG. Thus some care should be exercised to turn the main pressure regulator, $P_{\text{MAIN}}$, on slowly while watching the pressure gauges on the front panel.

B. Preparation

1. The drain bottles for the inlet chamber to VP1 and for the coalescing filters on $Q_{1D}$ and $Q_{2D}$ should be emptied. They are located at the right end of the system beside the PAG canister. (Emptying of the other bottles is discussed in the next section on Maintenance.)

2. The oil in the lower reservoir (No. 2) should be pumped up to the upper reservoir. Check the level in the upper reservoir to determine if liquid should be added. The system uses about one inch per hour. Oil is added by disconnecting the tygon tubing leading from the peristaltic pump to the top reservoir. The joint between the curved tube and the elbow fitting at the top of reservoir No. 1 (see Figure III-4) is convenient.

3. Check the level of liquid in reservoir No. 3. It should be at or near the top of the overflow tube. If it is not then open the control valve (several turns) at the bottom of the top reservoir (No. 1) to allow liquid to transfer.

4. Check the liquid level in the site glass on the front panel. Liquid should be visible but not higher than $2/3$ of the distance from the bottom of the site glass to the hole at the center of the reflector. If the level is too high then carry out the following steps:
   - close the aerosol generator valve,
   - turn the $P_{\text{oil}}$ regulator to zero (counter clockwise until the knob is loose),
   - open the connection normally used for putting liquid into the top reservoir,
- open the exhaust rotameter valve, if it is connected,
- turn the main regulator to zero,
- turn the air supply on,
- close the valve on the \( Q_{\text{add}} \) rotameter until liquid in the PAG starts flowing into reservoir No. 3. This can be seen by looking at the liquid line between these two components,
- if nothing happens check the regulator for the \( Q_{\text{add}} \) line and open it if it is not already open,
- when the level in the site glass drops below the appropriate height, turn off the \( Q_{\text{add}} \) valve and turn off the \( P_{\text{MAIN}} \) regulator,
- reconnect the liquid line at the top of reservoir No. 1.

5. It is very helpful to have an optical particle counter ready to sample from the HCSAG output to optimize final adjustments based on the output size distribution and concentration.

6. If the operating conditions from the last usage of the system were normal and no valves have been changed, then open the shut-off valve of the compressed air supply and proceed to "Initiating Operation" below. If the position of the controls are uncertain then perform the following steps:

- close all valves on the front panel except \( Q_{1D}, Q_{2D}, \) and \( Q_{\text{HD}} \) (which should be open) and turn all pressure regulators to zero (counter clockwise until loose),
- open the shut-off valve controlling the compressed air supply,
- turn the \( P_{\text{MAIN}} \) regulator to 50 PSIG and turn all other regulators to 45 PSIG, except for the \( P_{\text{oil}} \) and \( P_{\text{JETS}} \) regulators; \( P_{\text{oil}} \) should remain at zero while \( P_{\text{JETS}} \) should be adjusted to 35 PSIG,
- turn \( P_{\text{MAIN}} \) to 60 PSIG,
- adjust \( Q_{\text{core}}, Q_{\text{SH}}, \) and \( Q_{I} \) to about 20, 5, and 40 PSIG, respectively.

C. Initiating Operation

With \( P_{\text{MAIN}} \) at 60 PSIG and \( Q_{\text{core}}, Q_{\text{SH}}, \) and \( Q_{I} \) at about 20, 5, and 40 PSIG, respectively, open the ball valve on the front panel controlling the PAG (full open). The immediately adjust the \( P_{\text{oil}} \) regulator to about 10° \( H_{2}O \), returning to readjust it while adjustments of other valves are being performed. At this time \( P_{\text{JETS}}, P_{\text{GEN}}, P_{I}, \Delta P_{1}, P_{2}, \) and \( \Delta P_{2} \) should be near the values given in Table IV-1. If not, then review the steps to this point and check the system for abnormal signs.

Adjustments to achieve the appropriate values of the other parameters require an iterative approach. \( Q_{2D}, Q_{\text{core}}, Q_{\text{SH}}, Q_{\text{HD}}, \) and \( Q_{I} \) are relatively insensitive to the others so adjust those first. This should cause \( P_{3}, \Delta P_{3}, P_{I}, \) and \( \Delta P_{1} \) to be near the appropriate values. If not, readjust those valves. It is important to be familiar with the plumbing or have Figure III-1 at hand and to keep in mind that the appropriate values of \( Q_{2T} \) and \( Q_{HT} \) are attained when near balance pressures exist. Next, slightly adjust \( Q_{2D}, Q_{\text{core}}, \) and \( Q_{\text{SH}} \) to obtain the appropriate value of \( \Delta P_{V} \). Small deviations of \( Q_{2D} \) do not effect the output. Set points of \( \Delta P_{V}, Q_{\text{core}}, \) and \( Q_{\text{SH}} \)
are more important. Finally, adjust $Q_{HD}$ and $Q_I$ to obtain a positive $\Delta P_{HT}$ in the given range.

Next, review the meters for a value that deviates by more than 5% from the appropriate value, excluding $\Delta P_{HT}$. If a larger deviation is found repeat the adjustment procedure starting with $Q_{2D}$, $Q_{core}$, $Q_{SH}$, $Q_{HD}$, and $Q_I$.

Perform final adjustments of $Q_I$ and $Q_{HD}$ optimizing the output distribution measured with an optical particle counter, if available.

Adjust $P_{oil}$ to establish and keep the level in the site glass at the lower edge of the hole in the center of the reflector.

D. Continued Operation

Once the adjustments described above are performed, long-term operation can be expected. The drain bottles should be checked and the liquid level in the PAG adjusted as needed. The system has not gone through extensive testing needed to establish a $\Delta P_{oil}$ for an absolutely constant liquid level.

E. Halting Operation

When operation is completed the only step necessary for the HCSAG is to close the compressed air supply shut-off valve or turn the $P_{MAIN}$ regulator to zero. If all other valves are left in the same position then adjustments are not needed in the next period of operation except for $\Delta P_{oil}$. The operator will likely wish to adjust it to reestablish the appropriate liquid level in the PAG.
VI. Maintenance

A. Drain Bottles

Some of the drain bottles have an air relief tube on the side of the bottle as well as a tube for liquid to enter through the cap. One of the tubes must be disconnected from the system to twist the cap or the bottle. For three of the bottles the tube that is disconnected must be the air relief tube so that wicks will not be disturbed, potentially disrupting proper operation of the system.

One of the bottles that is connected to the union cross fitting just upstream of the venturi is shown in Figure III-9. A wick made of blotting paper extends along the lower wall of the token flow tube from VP2 to the union cross and down in the bottom leg to which the bottle is attached. Care should be exercised to refrain from rotating this cross or the bottle caps, thus tearing the wick. The top leg of the union cross can be disconnected to permit turning of the bottle while holding the cap steady. Only one full turn is necessary.

The second bottle of concern is the one which catches liquid drained from the entrance to VP3. A safe way to remove this bottle for emptying would be to detach the air relief tube at the side of the bottle. Then the bottle can be turned while holding the cap and wick steady. A suitable loose clamp must be used to resecure the air relief tube to the side of the bottle.

The third bottle of concern is that catching liquid drained from the union cross in the token flow, \( Q_{HT} \), of VP3. This cross has a wick extend back to VP3 like the one upstream of the venturi. The top leg of this cross can also be disconnected to permit turning of the bottle while holding the cap steady. Care must be exercised to refrain from rotating the union cross.

B. Orientation of Components

The orientation of components relative to the horizontal plane is also important for drainage. The VP1-VP2 unit should be tilted slightly rising toward the downstream direction. The venturi should be in the horizontal plane. The VP3 and OP components should essentially horizontal, rising slightly toward downstream rather than the opposite.

C. High Values of \( \Delta P_{AC} \) and \( \Delta P_{AS} \)

If \( \Delta P_{AC} \) or \( \Delta P_{AS} \) rise with use to high values then their respective flows are being obstructed, probably by liquid in laminar flow rings or screens. It is possible that this symptom can be eliminated by drainage given several days without operation. High flowrates of clean air in the reverse direction through these elements would augment the drainage process.
VII. Extending Performance

A. Other Liquids

If it is desired to use liquids other than the DuoSeal Vacuum Pump Oil in the HCSAG, several factors need to be checked to verify the feasibility. Appendix B gives physical and chemical properties of nonmetallic materials used in the system. Metal parts are made of aluminum, nickel plated brass, and stainless steel. If the user is uncertain after considering resistance of these materials to the liquid of interest, it is suggested that tests be performed exposing samples of the materials to the liquid. In addition to signs of corrosion, check for softening, swelling, or shrinking of plastic materials.

In addition to material problems, many liquids are extremely flammable or explosive when aerosolized. This can be checked by putting a small amount into a nebulizer and routing the aerosol stream through small tubing. If the aerosol exiting the tubing can be ignited, it will be hazardous to use in the HCSAG.

B. Increasing Concentration of Output Aerosol

Wall losses could probably be reduced in the system giving higher output concentrations by increasing the number of jets in VP1 and VP2. This redesign would decrease the pressures needed throughout the system eliminating that needed for the pressure letdown orifice PLDO and reducing the turbulence in the system.
VIII. References


4. Particle Technology Instruments. Thermo Systems Incorporated, St. Paul, MN. Form No. TSI 3000-R681 8M-2MBRI.


Sinking Frame
(Second Vertical Inlet) S1
<table>
<thead>
<tr>
<th>PART NO.</th>
<th>REV</th>
<th>DESCRIPTION</th>
<th>MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>703</td>
<td></td>
<td>Vertical Impactor Outlet</td>
<td>36-31</td>
</tr>
</tbody>
</table>
INLET CORE MODIFICATION

Existing 12-mm Tube

Impactor Inlet Core

Drill \( \frac{3}{8} \) \( \text{hole through} \)

- Bore \( \frac{1}{8} \) \( \text{deep} \)
- TIP -- 2 PLACES (90° PART)
Tune Stub Modifications

- Fabricate from 1/2" O.D. x 0.049 wall thickness stainless steel tubing
  - 8 pieces required

Fabricate from 1/2" O.D. (Wall thickness 0.049") S.S. tubing
  - 1 piece required

- From 1/2" O.D. (0.049 wall thickness) SS tubing Fabricate
  Above extension tube

- 1 piece required

A-21
Appendix B  Maintenance Instructions and Material Properties of Purchased Components

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cole-Parmer</td>
<td>Tygon plastic tubing, silicone tubing, PVC pipe.</td>
<td>B-2</td>
</tr>
<tr>
<td>Dwyer</td>
<td>Magnehelic Differential Pressure Gauge.</td>
<td>B-8</td>
</tr>
<tr>
<td>Dwyer</td>
<td>Rate-Master Variable Area Flowmeter</td>
<td>B-10</td>
</tr>
<tr>
<td>Fraunhofer-Institut</td>
<td>Virtual Impactor</td>
<td>B-14</td>
</tr>
<tr>
<td>Gelman</td>
<td>Acroflow II Filter Cartridge</td>
<td>B-27</td>
</tr>
<tr>
<td>Sargen-Welch</td>
<td>Duo Seal High Vacuum Pump Oil.</td>
<td>B-29</td>
</tr>
<tr>
<td>Sears</td>
<td>Fine Replacement Water Filter Cartridge</td>
<td>B-30</td>
</tr>
<tr>
<td>Virtis</td>
<td>SG-40 Smoke Generator</td>
<td>B-32</td>
</tr>
</tbody>
</table>

B-1
Tygon® (R-3603) plastic tubing
Soft, clear tubing slips over tubulatures easily. Grips tightly to glass or metal, bends to small-radius curves to speed set-ups. A long-life tubing that won't age or oxidize. Autoclavable at 250°F (121°C), 15 psi for 30 minutes. Transparent. Temp range: -50° to +165°F (-62° to +74°C).

b) Silicone tubing
For greater heat resistance and low compression set, this odorless, translucent tubing is recommended. Excellent biocompatibility. Meets FDA, USDA, USP class VI requirements. Do not use with concentrated solvents, oils, acids, or dilute NaOH. Autoclavable; remains flexible throughout a wide temperature range: -50°F to +320°F (-51° to +160°C).

c) Bev-a-line IV tubing
Safe up to 50% over TFE tubing. No plasticizers—safe for food, beverage, drug, lab, and medical use. Meets FDA, USDA, National Formulary, and USP standards for high-purity systems. Polyethylene liner with ethyl vinyl acetate outer shell, for all the advantages of polyethylene without stress-cracking. Heat-bondable: needs no connectors. Safe for alcohols. Temp range: -60° to +160°F (-51° to +71°C).

d) Gum rubber tubing
Tack-free latex tubing. Seamless for longer life. Ideal for liquids and gases. Amber-colored tubing can be sterilized repeatedly. Temp range: -22° to +302°F (-30° to +150°C).

e) Vinyl tubing
Tough, flexible polyvinyl tubing has excellent clarity. Odorless and nontoxic. Good water, chemical and abrasion resistance. Temp range: -40° to +180°F (-40° to +82°C).

f) C-Flex™ thermoplastic elastomer
High-performance, long-life tubing. This durable tubing formulation exhibits exceptional chemical and temperature resistance; surpasses USP class VI requirements, meets FDA standards. Excellent tensile and tear strength. Smooth surface; low gas permeability and good biocompatibility. Sterilizable by ethylene oxide, gamma radiation, or autoclave. Opaque white. Temp range: -50° to +230°F (-62° to +110°C).

TUBING

i) Polyurethane tubing
Clear, flexible, clean; ideal for high-purity work. Excellent chemical resistance. Temp range: -34° to +115°F (-20° to +46°C). Naigene.

j) Norprene® tubing
Ozone-resistant for longer life in electrical environments. Heat-sealable, nonaging, nonoxidizing—shows no sign of weakening or cracking after years of exposure to heat and ozone. Superior acid and alkali resistance. UL-listed for some applications. Food-grade Norprene tubing is available in quantities of 1000 feet or more; call for details. Opaque black. Temp range: -60° to +275°F (-51° to +135°C).

C-Flex—TM Concept, Inc. Norprene—TM Norton Co.
A GUIDE TO THE STRUCTURE & PROPERTIES OF RESINS

Biological properties of plastics
Most of the plastics used in our plasticware are biologically inert. Polyethylene, polypropylene, polyethylene terephthalate, polyethylene, and Teflon® FEP have been shown to have no effect on tissue cultures. Distilled water for preparing culture media can be controlled and stored safely in polyethylene containers.

Polylefins
These resins are break-resistant, nontoxic, noncontaminating. They are the only plastics lighter than water. They easily withstand exposure to nearly all chemicals at room temperature for up to 24 hours. Strong oxidizing agents eventually cause embrittlement. All polyolefins can be damaged by long exposure to ultraviolet light.

Polyethylene. The polymerization of ethylene results in an essentially straight-chain, high molecular weight hydrocarbon. Branching (side chain formation) occurs to an extent and can be controlled. Minimum branching results in "high-density" polyethylene (HDPE), also called "linear" polyethylene because of its closely packed molecular chains. More branching gives a less compact solid known as "low-density" or "conventional" polyethylene (LDPE). In general, HDPE has greater chemical resistance than LDPE, and is more rigid. Polyethylene is chemically unreactive; strong oxidizing agents eventually cause some oxidation; some solvents cause softening or swelling, but no solvent is known for polyethylene at room temperature.

Polypropylene (PP). Similar to polyethylene, but each unit of the chain has a methyl group attached. It is translucent, autoclavable, and has no known solvent at room temperature. It is slightly more susceptible to strong oxidizing agents than conventional polyethylene because of its many branches (methyl groups).

Polyethylene terephthalate (PETF or "TPX"). It is similar to polybutylene, but has an isobutyl group attached to each unit of the chain instead of a methyl group. Its chemical resistance is closer to that of PP. It is more easily softened by some hydrocarbons and chlorinated solvents, and strong oxidizing agents will attack it over a period of time. Its excellent transparency, rigidity, and chemical resistance, plus its resistance to impact and to high temperatures, make PETF a superior material for labware. PETF withstands repeated autoclaving, even at 150°C. It can be used intermittently to 175°C.

Polycarbonate (PC). Toughest of all thermoplastics, polycarbonate is window-clear, amazingly strong and rigid, autoclavable, and non-toxic. Polycarbonate is a special type of polyester in which dioxylic phenols are joined through carbonate linkages. These linkages are subject to chemical reaction with bases and concentrated acids, hydrolytic attack at elevated temperatures (e.g., during autoclaving), and make PC soluble in various organic solvents. The transparency and unusual strength make PC ideal for high-speed centrifuge ware.

Polysulfone (PSF)
Clear, strong, nontoxic and virtually unbreakable. Unlike polycarbonate, polysulfone will not hydrolyze during autoclaving and has a natural straw-colored cast. PSF is resistant to acids, bases, aqueous solutions, aliphatic hydrocarbons and alcohols. PSF is composed of phenylene units linked by three different chemical groups—aliphatic, ether and sulfone. Each of the three linkages imparts specific properties to the polymer: chemical resistance, temperature resistance and impact strength.

Polystyrene (PS)
Rigid, with excellent dimensional stability. Polystyrene has good chemical resistance to aqueous solutions. This extremely clear material is commonly used for disposable laboratory products.

Polyvinyl chloride (PVC)
Similar in structure to polyethylene, but each unit contains a chlorine atom. The chlorine atom renders it vulnerable to some solvents, but also makes it more resistant in many applications. PVC has extremely good resistance to oils and very low permeability to most gases. It is also transparent and has a slight bluish tint. Narrow-mouth bottles made of PVC are relatively thin-walled and can be flexed slightly. When blended with phthalate ester plasticizers, PVC becomes soft and pliable, ideal for laboratory tubing.

Fluorocarbons
Remarkable chemical resistance is typical of Teflon® tetrafluoroethylene (TFE) and fluorinated ethylene propylene (FEP).

Teflon® TFE is opaque white. Has the lowest friction coefficient of any solid. It makes superb stopcock and separatory funnel plugs because of its low friction and tight seal.

Teflon® FEP is flexible, translucent, has a slight bluish cast and a heavy feel because of its higher density. It resists all known chemicals except molten alkali metals, elemental fluorine and fluon premature. It withstands temperatures from -270°C to +205°C, and may be sterilized repeatedly by all known chemical and thermal methods. It can even be boiled in nitric acid.

Teflon® FEP is a plastic with higher mechanical strength at elevated temperatures than TFE or FEP. Maximum continuous service temperature is +500°F (+260°C).

Teflon® ETFE is translucent white and slightly flexible. Similar to Teflon TFE and FEP, with higher mechanical strength and impact resistance.

Haier® E-CTFE is an alternating copolymer of ethylene and chlorotrifluoroethylene. Withstands continuous exposure to extreme temps; maintains excellent mechanical properties across this entire range; excellent chemical resistance; radiation resistant.

Plasticware, 1985
Chemical resistance and physical properties of resins

Interpreting these charts

The Chemical Resistance Chart on the facing page and the Chemical Resistance Summary Chart below are general guides only. Because so many factors can affect the chemical resistance of a given product, you should test under your own conditions. If any doubt exists about specific applications of our products, please contact our Technical Service Department at our toll-free number: 1-800-325-9490.

Effects of chemicals on plastics

Chemicals can affect the strength, flexibility, surface appearance, color, dimensions, or weight of plastics. The two basic modes of interaction which cause these changes are (1) chemical attack on the polymer chain, including oxidation; reaction of functional groups in or on the chain; or depolymerization, with resultant reduction in physical properties; and (2) physical change; absorption of solvents, resulting in softening and swelling, or permeation of solvent through the plastic; dissolving in a solvent; cracking from interaction of a "stress-cracking agent" with molded-in stresses.

The reactive combination of compounds of two or more classes may cause a synergistic or undesirable chemical effect. Other factors affecting chemical resistance include temperature, pressure and internal or external stresses (for example, centrifugation), length of exposure and concentration of the chemical. As temperature increases, resistance to attack decreases.

Caution!

Do not store strong oxidizing agents in plastic labware except that made of Teflon® FEP. Prolonged exposure causes embrittlement and failure. While prolonged storage may not be intended at time of filling, a forgotten container will fail in time and result in leakage of contents. Do not place plastic labware in a direct flame or on a hot plate.

Resin codes

LDPE: Low-density (conventional) polyethylene
HDPE: High-density (linear) polyethylene
PP: Polypropylene
PA: Polyalloxan
PMP: Polymethylpentane ("TPX")
FEP: Teflon® FEP (fluorinated ethylene propylene)

Chemical resistance classification

E—30 days of constant exposure with no damage. Plastic may even tolerate chemical for years.
G—Little or no damage after 30 days of constant exposure to the reagent.
F—Some effect after 7 days of constant exposure to the reagent. Solvents may cause softening, swelling and permeation losses with LDPE, HDPE, PP, PA and PMP. Effects of solvents on these five resins are normally reversible.
N—Not recommended for continuous use. Immediate damage may occur, severe crazing, cracking, permeation losses.

Physical properties

<table>
<thead>
<tr>
<th>Resin</th>
<th>Max use temp °F/°C</th>
<th>Trans Parity</th>
<th>Sterilization</th>
<th>Specific gravity</th>
<th>Flexibility</th>
<th>Brittleness temp °F/°C</th>
<th>Permeability (approx)</th>
<th>Water absorption (%)</th>
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</thead>
<tbody>
<tr>
<td>LDPE</td>
<td>170/80</td>
<td>Translucent</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>-148/-100</td>
<td>20 60 280</td>
</tr>
<tr>
<td>HDPE</td>
<td>248/120</td>
<td>Translucent</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>-148/-100</td>
<td>3 40 50</td>
</tr>
<tr>
<td>PP</td>
<td>275/135</td>
<td>Translucent</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>-130/-100</td>
<td>4 25 50</td>
</tr>
<tr>
<td>PMP</td>
<td>347/175</td>
<td>Translucent</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>-130/-100</td>
<td>6 27 30</td>
</tr>
<tr>
<td>FEP</td>
<td>401/205</td>
<td>Translucent</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>-120/-100</td>
<td>20 60 135</td>
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<tr>
<td>ETFE</td>
<td>302/150</td>
<td>Translucent</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>-148/-100</td>
<td>3 20 85</td>
</tr>
<tr>
<td>PC</td>
<td>275/135</td>
<td>Clear</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>-211/-125</td>
<td>3 20 85</td>
</tr>
<tr>
<td>PVC</td>
<td>158/70</td>
<td>Clear</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>-20/-30</td>
<td>0.5 1-6 10-35</td>
</tr>
<tr>
<td>PA</td>
<td>296/130</td>
<td>Clear</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>-40/-10</td>
<td>3 30 100</td>
</tr>
<tr>
<td>PSF</td>
<td>329/165</td>
<td>Clear</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>-148/-100</td>
<td>3 15 80</td>
</tr>
</tbody>
</table>

1For oxidizing acids, see "Oxidizing agents, strong."

Phone us for a FREE poster of these compatibility charts.

Teflon, Teflon—Reg TM E.I. du Pont de Nemours and Company
*Reprinted with permission of Naige Company

*Recommendations for sterilization: see page 5.
*Stabilizing reduces mechanical strength. Do not use PC vessels for vacuum applications if they have been autoclaved.
### Chemical Resistance of Plastic Resins

See page 4 for keys to resin codes and chemical resistance classification. A colorful wall poster, incorporating the information in this chart, is yours free, compliments of Naige Company and Cole-Parmer. Just phone us.

First letter = resistance at 20°C; second letter = resistance at 50°C. Intended as a guide; test before using.

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THE USE & CARE OF PLASTICWARE*

General cleaning

For most general applications, plastics may be washed in a mild detergent, followed by a rinse with tap water and a dry air blast. Most plastics, particularly LDPE, HDPE, PP, PMP and PA, have non-wetting surfaces which resist attack and are easy to clean. Do not use abrasive cleaners or scouring pads on any plastic labware. Do not use strong alkali cleaning agents with polycarbonate.

Dishwashers. Labware washing machines can be used with all resins except low-density polyethylene, acrylic and polystyrene due to temperature limitations. The exceptional strength of polycarbonate will be weakened by repeated washings in dishwashers. Polycarbonate labware exposed to high stresses (centrifugation or vacuum), should always be washed by hand using mild, non-alkaline detergents. To avoid excessive abrasion of plastics in dishwashers, metal spindles should be covered with soft material such as plastic tubing. The labware should be weighted down and held in place with accessory racks.

Ultrasonic cleaners may be used as long as the labware does not rest directly on the bottom of the tank; use a cleaning basket.

Special problems

Grease and oils. For many applications, washing with a mild detergent will remove grease and oil.

Organic solvents (such as acetone, alcohols or methylene chloride) may be used with caution when more rigorous cleaning is needed. Extended exposure to these solvents may cause some swelling of polyolefins. Be sure to rinse off all solvents before using labware. Use only alcohols on polycarbonate, polysulfone, polyurethane or PVC; other organic solvents will attack these plastics. Do not use any organic solvent with acrylic.

Baking labware in dilute sodium bicarbonate (NaHCO₃) is also an effective method for removing grease and oil. Do not use with polycarbonate, low-density polyethylene, acrylic or polystyrene.

Organic matter. Chromic acid solution will remove organic matter, but since this solution is a strong oxidizing agent, it may eventually embrittle plastics. To minimize embrittlement, soak plastic for no more than 4 hours. The following formula is an effective cleaning agent: dissolve 120 grams of sodium dichromate (Na₂Cr₂O₇·2H₂O) in 1000 ml tap water. Carefully add 1600 ml concentrated sulfuric acid to this solution. Note: because this solution generates considerable heat, we recommend external cooling. Do not mix in a plastic container.

This solution is designed to produce an excess of dichromate in form of a precipitate, which usually has actuality the useful life of chromic acid and dissolves as needed. This chromic acid solution should be used repeatedly until it begins to develop a greenish color, indicating a loss of potency. Because of the excess dichromate built into this formula, this solution lasts considerably longer than commercially available solutions. Sodium hypochlorite solutions (bleaches) are also effective in removing organic matter. Use at room temperature for this application.

Sterilizing plastics

Autoclaving. All items should be carefully cleaned before autoclaving. This will prevent baking contaminants onto the surface of the plastic. After cleaning, all items should be rinsed thoroughly in distilled water before autoclaving. Certain chemicals will have no appreciable effects on plastics at room temperature may cause deterioration at autoclaving temperatures and therefore should be removed.

Because of differences in heat transfer characteristics between plastics and inorganic materials, the contents of plastic containers may experience greater than to reach sterilization temperatures typically 121°C. Therefore, longer autoclaving cycles may be necessary for liquids in large-volume plastic containers. Adequate cycles can be determined only by experience with specific liquids and containers.

Polypropylene, polyethylene, polyethylene, polystyrene, polyethylene, Tetra* ETFE, and Teflon® FEP may be autoclaved repeatedly at 121°C. at 15 ps. Cycles should be at least 15 minutes at 121°C to assure sterility.

Polycarbonate is autoclavable. However, cycles should be limited to 20 minutes at 121°C. Polycarbonate shows some loss of mechanical strength after repeatedly autoclaving and therefore may not function well under high-stress applications (such as centrifugation or vacuum). Avoid using strong alkaline detergents on polycarbonate. All polycarbonate items should be rinsed thoroughly with distilled water before autoclaving.

Polyethylene is autoclavable. Somewhat weakened by autoclaving, although less than polycarbonate. If autoclaved repeatedly, it will eventually fail under high-stress applications, such as high-speed centrifugation.

Polystyrene, polyvinyl chloride, styrene acrylonitrile, acrylic, low-density polyethylene, and high-density polyethylene are not autoclavable under any conditions. These plastics will melt when autoclaved.

Always loosen or remove closures before autoclaving. If this is not done, pressure differentials will cause containers to collapse during autoclaving.

Gas sterilization. All of the resins mentioned here may be gas sterilized (ethylene oxide, formaldehyde). We recommend allowing an appropriate aeration time suited to the particular application before using the item. Gas sterilization can cause pressure differentials at elevated temperatures, so closure threads should be totally disengaged.

Chemical sterilization. In general, all of the plastics mentioned can be subjected to commonly used disinfectants (quaternary ammonium compounds, isothiocyanates, formal, benzalkonium chloride, etc.). There may be some surface attack (crazing) when using a more chemically aggressive disinfectant on the least resistant plastics (styrene, styrene acrylonitrile, PVC, polycarbonate, acrylic) with prolonged use. Isotonic salts can be reduced with sodium thiosulfate.

Dry heat. Only Teflon FEP, polyethylene, and polyethylene may be hot-air sterilized (160°C). Other all plastics above may show signs of accelerated oxidative degradation. If polyethylene or polyethylene containers are hot-air sterilized, be sure to remove polyethylene closures.

Hazardous matter

Before labware contaminated with toxic materials is removed from the work area, it should be sterilized appropriately. Autoclaving is the preferred method for sterilization; however, any method of chemical or heat sterilization compatible with the plastic may be used. Liquid waste containing biohazardous materials must always be decontaminated before disposal.

Labware that is contaminated with both hazardous and radioactive material must first be sterilized. Methods for removing radioactive material depend on the isotope used, its quantity, half-life, material and stability. For routine decontamination of plastic labware, first soak in decontaminant/cleaner for 24 hours at room temperature. Follow with several rinsings in distilled water. To accelerate decontamination, increase the cleaner concentration and solution temperature. Agitation and scrubbing will also speed this process. Do not use polycarbonate. Always dispose of radioactive wastes and effluents properly.

For additional information on handling contaminated labware, contact your Biosafety/Radiation Safety office, or refer to NIH publications Biohazardous Safety Guide, Laboratory Safety Monograph, and Radiation Safety Guide.

Trace metals

For most trace metal analyses, plastic is generally "cleaner" or less contaminated than glass or other materials. However, plastic does contain trace levels of certain metals. To minimize potential low-level contamination, these metals can be removed or leached from plastic by soaking in 1N HCl and rinsing in distilled water. For more precise work, use HCl, followed by soaking in 1N HNO₃ and rinsing in distilled water. Soaking times may vary according to individual needs, but plastic should be soaked no longer than 8 hours.

Caution: concentrated nitric acid is a strong oxidizing agent and will embrittle many plastics.

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Teflon, Tetra* REG. TM E.1 du Pont de Nemours & Company

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Magnelnic® Differential Pressure Gage

SPECIFICATIONS

Dimensions: 4 3/4" dia x 2 3/16" deep
Weight: 1 lb 2 oz
Finish: Baked dark gray enamel
Connections: 1/8" NPT high and low pressure taps, duplicated, one pair side and one pair back
Accuracy: Plus or minus 2% of full scale, at 70°F
(Mont 2000 0-3, 2000-0-0.5)
Pressure Rating: 15 PSI
Ambient Temperature Range: 20°F to 140°F
Standard gage accessories include two 1/8" NPT plugs for duplicate pressure taps, two 1/8" pipe to rubber tubing adapters, back mounting stud with two washers and jam nut and three finish mounting adapters with screws

Caution: Use with or without composite gages only
For repeated over-ranging or high cycle race, contact factory

EXPLODED VIEW
Series 2000

1. Case
2. Cover with zero adjust easy
3. O-ring seat
4. Bezel
5. Diaphragm assy plate
6. Retaining ring
7. Range Spring assembly
a. Clamp nut screw
b. Range spring
6. Mounting screws (2 reqd)
8. Clamp plate
9. Spreader (2 reqd)
10. Clamp plate
11. Range Spring with magnet
150. Washers Assembly—consists of
a. Front pivot
b. Locking nut
c. WASHERd
200. Mounting screws (4 reqd)
201. Lock assembly (not shown)
2. Pivot (1 reqd) (not shown)
3. Rear pivot (not shown)
230. Zero adjust assembly—consists of
a. Food screw with washers (2 reqd)
b. Adjust sleeve
c. Flange
d. Finger
260. Scale Assembly—consists of
a. Mounting screws (2 reqd)
b. Bumper inner stop (2 reqd)
c. Scale
330. Diaphragm Assembly—consists of
a. Diaphragm pressurized to 500 PSI
b. Linkage assembly, complete
c. Foot plate
d. Rear plate
360. Mounting Hardware Kit
a. Adapter—pipe plug in 1/4" NPT to rubber tubing
2. (2 reqd)
b. Pipe plug in 1/4" NPT
3. Mounting screws (2 reqd)
4. Long screws (2 reqd)
5. Short screws (3 reqd)
f. Stud screws
6. Stud washer
7. Stud head
8. Stud (hexagonal)

Ordering Instructions:
When corresponding with the factory regarding Magnelnic® gage problems, refer to the call-out numbers in this view. Be sure to include model number, pressure range, and any special options. Field repair is not recommended; contact the factory for repair service information.
**MAGNEHIC INSTALLATION**

1. Select a location free from excessive vibration and where the ambient temperature will not exceed 140°F. Also, avoid direct sunlight which accelerates deterioration of the plastic cover. Sensing lines may be run any necessary distance. Long tubing lengths will not affect accuracy but will increase response time slightly. Do not restrict lines. If pulsating pressures or vibrations cause excessive pointer oscillation, consult the factory for ways to provide additional damping.

2. Most gages may be installed in any position, i.e., vertical or horizontal, without affecting its accuracy as long as it is properly recessed in the position in which it is being used. The exceptions are models 2000 00 (± 2.5 %) which can be used only in a vertical position and 2000 0 (± 5.0 %) which must be specially calibrated for positions other than vertical. The same applies to metric equivalents to these two ranges. All standard gages are originally calibrated with diaphragm vertical.

3. **Surface Mounting**
   - Locate mounting holes, 1 3/8" apart on a 4 1/8" dia. circle. Use No. 6-32 machine screws of appropriate length.

4. **Single Stud Surface Mounting**
   - Locate mounting hole. Use double ended 1/8" thread plug, Part No. 306L, securely inverted to center low pressure opening. Mount through a hole drilled with a washer and jam nuts as in sketch. As an alternate, mount the gage with the stud using a 1/8" pipe thread flange or other 1/8" pipe thread opening.

5. **Flush Mounting**
   - Provide a 4 1/2" dia. opening in panel. Insert gage and secure in place with No. 6-32 machine screws of appropriate length. Before the gage is secured in place, mount gage on 1/4"-28 pipe, order optional A-108 pipe mounting kit.

6. **To zero the gage after installation**
   - Set the indicating pointer exactly on the zero mark, using the external zero adjust screw on the cover at the bottom. Note that the zero check or adjustment can only be made with the high and low pressure taps both open to atmosphere.

**Operation**

- **Positive Pressure**: Connect tubing from source of pressure to either of the two high pressure ports through the port not used. Vent one or both high pressure ports to atmosphere.

- **Negative Pressure**: Connect tubing from source of vacuum or negative pressure to either of the two low pressure ports. Plugs the port not used. Vent one or both high pressure ports to atmosphere.

- **Differential Pressure**: Connect tubing from the greater of two pressure sources to either high pressure port and the lower to either low pressure port. Plugs both unused ports. When one side of a gage is located in a dirty, dusty atmosphere, we suggest an A-3 H Filter/Plug be installed in the open port to keep inside of gage clean.

**Maintenance**

- **No lubrication or periodic servicing is required. Keep case exterior and cover clean. Occasionally disconnect pressure lines to vent both sides of gage to atmosphere and re-zero. Optional vent valve, (bulletin S-101), should be used in permanent installations**.

**Calibration Check**

- Select a second gage of manometer of known accuracy and in an appropriate range. Using short lengths of rubber or vinyl tubing, connect the high pressure side of the Magnetric gage and the test gage to two legs of a tee. Very slowly apply pressure through the third leg. Allow a few seconds for pressure to equalize, fluid to drain, etc., and compare readings. If accuracy unacceptable, gage may be returned to factory for recalibration. To calibrate in the field, use the following procedure:

**Calibration**

- **1. Zero gage, P/N L, held firmly, loosen bezel.** P/N 4 by turning counterclockwise. To avoid damage, a canvas strap wrench or similar tool should be used.

- **2. Lift out plastic cover and O-ring.**

- **3. Remove scale screws and scale assembly.** Be careful not to damage pointer.

**4. The calibration is changed by moving the clamp, P/N 70. B. loosen the clamp screw(s) and move slightly toward the heads if gage is reading high, and away if reading low. Tighten clamp screw and install scale assembly**.

**5. Place cover and O-ring in position.** Make sure the hex shaft on inside of cover is properly engaged in zero adjust screw, P/N 230 B.

**6. Secure cover in place by screwing bezel down snug.** Note that the area under the cover is pressurized in operation and therefore gage will leak if not properly tightened.

**Trouble Shooting Tips**

- **Gage won't indicate or is sluggish**
  - Duplicate pressure port not plugged.
  - Diaphragm ruptured due to over-pressure.
  - Fittings or sensing lines blocked, pinched, or leaking.
  - Cover loose or "O" ring damaged, missing.
  - Pressure sensors, (static tips, Pilot tube, etc.) improperly located.
  - Ambient temperature too low. For operation below 20°F, order gage with low temperature, (LT) option.
  - Pointer sunk gage can't be zeroed.
  - Scale touching pointer.
  - Spring/magnet assembly shifted and touching helix.
  - Metallic particles clinging to magnet and interfering with helix movement.
  - Cover zero adjust shaft broken or not properly engaged in P/N 230 B ad justing screw.

We generally recommend that gage needing repair be returned to the factory. Parts used in various sub-assemblies vary from one range of gage to another and use of incorrect components may cause improper operation or failure. Gages received at the factory are carefully calibrated and tested to assure “like new” operation. After receipt and inspection, we will be happy to quote repair costs before proceeding.

Consult factory for assistance on unusual applications or conditions.

Use with air or compatible gases only.
Series RM Rate-Master® Flowmeters

Molded of tough polycarbonate plastic. Used to indicate or manually control air or gas flow from .1-1800 SCFH... water flows to 8 GPM

The Dwyer Rate-Master line of direct reading precision flowmeters incorporates many unique user features at moderate cost. These low cost flowmeters are ideal for general use.

Easy to read design – The direct reading scales eliminate troublesome conversions. The scales are brushed aluminum, coated with epoxy and the graduations are on both sides of the indicating tube. Special integral flow guides stabilize the float throughout the range to keep it from hunting or wandering in the bore. The float is highly visible against a white background.

Construction assures accuracy—All Rate-Master flowmeter bodies are injection molded of tough, clear, shatter-proof polycarbonate plastic around a precision tapered pin. Critical internal diameter of the variable orifice tube is held within ± 0.0004". The result is accurate and repeatable readings. The single piece plastic body is mounted to a stainless steel backbone into which pipe thread inserts are welded to absorb piping torque. Precision metering valves of brass or stainless steel (specify BV or SSV on order) are available as an optional extra and permit precise flow adjustments. For vacuum applications, Model RMA units are available with top mounted valves (specify TMV). The small Series RMA models are accurate within ± 4% of full scale reading; Series RMB within ± 3%; large Series RMC within ± 2%.

Installation is simple – The Rate-Master can be neatly through-panel mounted to keep flow tube centers in the same plane as the panel surface or surface mounted on the panel by means of tapped holes in the backbone. When through-panel mounted, the bezel automatically positions the instrument at the correct depth in the panel cutout. Surface mounted units can also be held in place by the piping. All mounting hardware plus installation and operating instructions are included.

Cleaning is easy – To release the plastic flowmeter body from the stainless steel backbone, just remove four screws. Pipe thread flow connections remain undisturbed. Remove the slide cover and the plug ball stop, clean the flow tube with soap and water and reassemble. It's that simple.

Specials – See page 5 for typical examples of special ranges, scales, mounting arrangements, etc., available on special order, or in OEM quantities.

Easy-to-interchange bodies – Within a given Series, Rate-Master flowmeter bodies can be instantly interchanged. Simply unplug the body from backbone and replace it with another. "O" rings provide a tight seal on inlet and outlet. Piping remains undisturbed. Interchangeability is useful where different scale ranges are sometimes required at the same location in the laboratory or plant.

Adjustable pointer flags – Red-lined pointer flags provide quick visual reference to a required flow level. Of clear plastic, they snap into place inside bezel and slide to desired level.

Top Mounted Metering Valves – Same precision construction for vacuum applications.
SPECIFICATIONS

M40 Body: Polycarbonate
Wetted Metal Parts: Stainless Steel (except for optional brass valves)
Floats: St. Steel, Blk. Glass, Alum., K Monel
Float Stops: Polycarbonate
Pipe Connections: Model RMA: 1/4"; Model RMB, 1/8"; Model RMC, 1/4" NPT
"O" Rings: Neoprene and Buna N
Fittings: Stainless Steel brazed to Stainless Steel backbone plate
Rivets: Stainless Steel, set into slots
Scale: Brushed Aluminum - Clear Epoxy Coated
Pressure Rating: RMA 100 PSI; RMB 70 PSI; RMC 35 PSI max.
Temperature Rating: To 130° F maximum

Accuracy: Model RMA, 1%; Model RMB, 3%; Model RMC, 2% of full scale

OPTIONS AND ACCESSORIES

Metering Valve: Brass
Top Mounted Valve: Stainless Steel - available only on RMA for vacuum applications
Pointer Flag: Polycarbonate

Series RM RATE-MASTER® Models and Ranges

<table>
<thead>
<tr>
<th>Model RMA - 2&quot; Scale</th>
<th>Model RMB - 5&quot; Scale</th>
<th>Model RMC - 10&quot; Scale</th>
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<tbody>
<tr>
<td>Range SCFM Air</td>
<td>Order- ing No.</td>
<td>Range SCFM Air</td>
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<tr>
<td>05-5 1 2-50 49</td>
<td>5-50 101</td>
<td>1-1 2 1-10 50</td>
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<td>22-200 12</td>
<td>5-50 151*</td>
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<td>10-100 25</td>
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<td>CC Air/min.</td>
<td>Gall. Water per hour</td>
<td>Gall. Water per hour</td>
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<td>2-2 142</td>
<td>3-3 143</td>
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<td>5-5 26</td>
<td>6-6 144</td>
<td>1-8 145</td>
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DIMENSIONS - IN INCHES

<table>
<thead>
<tr>
<th>Model RMA</th>
<th>Model RMB</th>
<th>Model RMC</th>
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<tr>
<td>A 4 1/4</td>
<td>8 1/16</td>
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<td>L 1 1/4</td>
<td>2 3/4</td>
<td>1 1/2</td>
</tr>
</tbody>
</table>

How To Order

1. Select model desired by letter designation. RMA, RMB, or RMC.
2. Specify range desired by adding the order number after a dash following the letter designation. Example RMA-6.
3. If additional features are required, and available, add the option designation to the basic model code - e.g.: BV for Brass Valve, SSV for Stainless Steel Valve, and TMV for Top Mounted Valve. For example, RMA-6-SSV is the 2" scale flowmeter range No. 6 with a stainless steel valve.
4. Add accessories as desired.
CONVERSION CURVES FOR GASES

If more convenient, approximate correction factors may be determined using the following formulas:

A. Pressure: \( Q_p = Q_x \sqrt{\frac{P_p}{P_1}} \)

where
- \( Q_x \) = Observed flowmeter reading
- \( Q_p \) = Actual flow corrected for pressure
- \( P_p \) = Standard atmospheric pressure, 14.7 PSI
- \( P_1 \) = Actual pressure, 14.7 PSI + pressure in PSI inside flowmeter. Measured at outlet on all but TMV units. Inlet pressure on TMV models.

B. Specific Gravity: \( Q_s = Q_x \sqrt{\frac{I}{S.G.}} \)

where
- \( Q_s \) = Observed flowmeter reading
- \( Q_x \) = Actual flow corrected for specific gravity
- \( I \) = Specific gravity of air
- \( S.G. \) = Specific gravity of gas being used in flowmeter originally calibrated for air.

NOTE: The corrections shown in the curves and in the formulas are for variations in specific gravity and internal pressure only. Further correction may be necessary for variations in viscosity and changes in type of flow from laminar to turbulent or vice versa. This is particularly true in the case of extremely low flows of the lighter gases. Nevertheless, these charts and correction factors can be quite useful when dealing with small changes in pressure* and specific gravity.

*Measured at discharge on all but TMV units. Inlet pressure on TMV models.
How flowmeters work:

Variable area flowmeters are basically vertical internally-tapered tubes mounted with the large end at the top. A float or rotor with an outer diameter slightly less than the minimum diameter of the tube is placed inside the tube. The clearance space between the float and the tube forms an annular passage or orifice. As the tube is tapered, the area of this orifice is larger when the float is near the top than it is when the float is near the bottom. By connecting the tube into a fluid flow line a flow direction is from bottom to top, the float will move upward and be supported at a point where the orifice is just large enough to pass the fluid flowing through the system.

Several Forces are involved - The precise position of the float within the tube is determined by several forces acting on it. These forces are: 1. The weight of the float; 2. The velocity pressure of the flowing fluid multiplied by the area of the float; 3. Buoyancy of the float weight of fluid volume displaced by the float; 4. Viscous aerodynamic or hydrodynamic drag of the fluid on the float. The float's weight acts downward - while velocity pressure, buoyancy and drag all act upward on it.

Read-out and scales - By making the tube transparent so that float position can be seen and by providing a scale along side, we may "read" the float position in terms of numbers on the scale. These scale numbers can be of two types: 1. Of an arbitrary nature (by themselves they mean nothing, but become meaningful when compared with a calibration curve); or 2. They can be precalibrated for direct reading; to show the actual volume flow (in cfm, cc per minute, etc.) of the fluid for which the flowmeter is calibrated.

Limiting factors - Although the basic relationship outlined above is linear, certain fluid properties tend to modify this relationship. These changes are accentuated where the variable orifice formed between float and tube becomes either very large or very small. For example...

Sonic velocity - Where the orifice is particularly large and is combined with a heavy float, velocities of a gas or other fluid through the orifice area can approach sonic velocity. In this velocity range, reflected shock waves cause the float to become unstable, and it will typically hunt from side to side and from top to bottom within the bore. At best, this condition makes it impossible to take a reading, and at worst may even destroy the flowmeter. The addition of flow guides (built into certain Dwyer Rate-Master flowmeters) can often improve the stability and performance of the system by channeling the flow into multiple streams that equalize dynamic effects and preventing oscillation of the float. This has the net effect of moving the limit of satisfactory operation upward, and thereby expanding the range and accuracy we can achieve with any given flowmeter tube.

Laminar flow - In flowmeters where the orifice area is extremely small, the conditions result in smooth flow, or laminar flow. Other factors which contribute to the transition to laminar flow are low velocity (often associated with a lightweight float), low density or specific gravity and high viscosity of the flowing fluid. When laminar flow conditions prevail, a greatly expanded scale is usually required. Meters operating in the laminar flow area are very difficult to manufacture and cabibrate to the degree of accuracy usually expected of variable area flowmeters.

Turbulent flow - Most variable area flowmeters operate in the turbulent flow range which occurs below sonic velocities and above the laminar flow range. In turbulent flow, the flowing fluid particles move in random paths within the stream - rather than in violent shock waves as in sonic flow or very smooth parallel paths as in laminar flow. In turbulent flow, variables follow the relationships shown in the curves on Page 4. These curves are quite accurate for small changes in pressure and specific gravity. For large changes or where a change in viscosity is involved, it is much better to have the flowmeter recalibrated for the specific conditions under which it will be used.

Reynolds Numbers - Reynolds Numbers are useful in the study of fluid behavior and are quite helpful in separating laminar and turbulent flow. The Reynolds Number of a fluid flow system is described as a dimensionless index. It is equivalent to the diameter of the orifice in feet times the average velocity of the fluid in feet per second times the density of the fluid in pounds per cubic foot divided by the absolute viscosity in pounds per second foot. A system operating with a Reynolds Number of less than 2000 is said to be subject to laminar flow, whereas Reynolds Numbers above 3000 are clearly in the turbulent flow area.

How sight flow indicators work:

A sight flow indicator basically consists of a small housing equipped with a glass window which is inserted in a run of pipe to observe the flow of the fluid in the pipe. To enhance the visibility of the flow, a spinner is often incorporated in the indicator. The axis of the spinner is offset from the center of the flow stream so that fluid impinging on the spinner vanes causes it to turn. The spinner also aids in the detection of low flows as well as providing visibility of flow from a distance. In addition, the speed of rotation gives a relative indication of flow velocity. Midwest Sight Flow Indicators are also available with hinged flappers instead of spinners to indicate bi-directional flow.

Sight flow indicators can be provided with a single window on the front of the indicator or double windows, one on the front and one on the back of the indicator. Double window units are best when observing the clarity or color of a liquid. Midwest single window units are always equipped with spinners to provide for observation of clear fluid flows at the lowest cost.

Vertical tube-type sight flow indicators consist of a clear glass tube, equal to or greater than the diameter of the pipe into which it is inserted, and are utilized to observe high flow rates in vertical pipe runs. No spinners or other type of detection devices are incorporated in these units. As a result, they offer no significant resistance to flow and therefore provide the lowest pressure drop of any type sight flow indicator.

Midwest Sight Flow Indicators are available with special materials to meet various applications. Optional materials are available for the sealing gaskets, spinners, and housings or flanges.
Virtual impactor

Dear Dr. Farthing,

thank you very much for your telephone call on 18 January 1983.

We offer you a virtual impactor according to figure 1 of the article by Masuda, Hochrainer and Stöber in the Journal of Aerosol Science 10 (1979), 275-287. The material of the impactor shall be brass.

The price is DM 6804,- and includes material, manufacturing and shipment by air mail. The delivery time will be 3 month after receipt of your order.

With kind regards,

[Signature]

(Dr. D. Hochrainer)

Enclosure: Reprint from J. Aerosol Science
AN IMPROVED VIRTUAL IMPACTOR FOR PARTICLE CLASSIFICATION AND GENERATION OF TEST AEROSOLS WITH NARROW SIZE DISTRIBUTIONS

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(Received 13 November 1978)

Abstract - The virtual impactor performance has been improved with regard to its separation characteristics by a new design embedding the aerosol flow between a core and an enveloping sheath of clean air flow. With this feature, the new impactor has successfully overcome the intrinsic disadvantage of conventional designs which always have finite separation efficiencies, even if zero inertia particles are sampled. Furthermore, various and high degrees of precision in size separation were established by adjusting the clean air flow rates. Test aerosols with narrow size distributions were obtained by passing paraffin aerosols, coal dust, slate powder and asbestos fibers through a series of two units of the new virtual impactor.

1. INTRODUCTION

The generation and the measurement of aerosols are basic experimental topics in aerosol science and technology. They play an important role in the experimental assessment of the health hazards associated with inhalable atmospheric particles. In such studies as well as for the investigation of size-related dust deposition in pipes or for the examination of the efficiency of industrial dust collectors and dust separators, it is desirable to have test aerosols of narrow size distribution. Furthermore, it is sometimes required that the test aerosol consists of the same material as the actual aerosol to be sampled, for example, coal dust.

In order to obtain test aerosols with such desirable characteristics, a special feeder discharging continuously small amounts of fine particles has been developed (Masuda et al., 1976) and several methods of powder dispersion have been studied (Masuda et al., 1977). In general, the size distribution of an aerosol produced by dispersing fine particles covers a rather wide size range and is not immediately suitable as a test aerosol. Instead, it is necessary to separate the desired small size range from the aerosol to obtain a test aerosol with narrow size distribution.

An instrument suitable for this purpose is the virtual impactor as developed by Conner (1966) which leaves the coarse fraction of particles suspended in an air flow. The separation efficiency of the virtual impactor has been calculated numerically and tested with large-scale equipment (Yoshida et al., 1978). It became apparent that the quality of the size separation of this instrument is not as good as for conventional solid-plate impactors. In particular, the separation efficiency for zero-inertia particles is determined by the ratio of the straight undeflected flow rate to the total flow rate and cannot vanish as required. Therefore, the virtual impactor needs improvement with regard to the size separation achievable in this type of instrument.

In applications of impactors in ambient air sampling (Dzubay and Stevens, 1975), two-stage dichotomous virtual impactors have been utilized. Such impactors have better separation characteristics (Loo et al., 1976) because the separation efficiency is determined by the product of the separation efficiencies of each stage. For similar applications, a spectral impactor utilizing a clean air flow for winnowing of the aerosol, has been developed to get
size-separated deposits in a single-stage impactor (Zebel and Hochrainer, 1972). This method appeared to be suitable to improve the virtual impactor.

In this study, the virtual impactor has been modified by embedding the aerosol flow between a core and an enveloping sheath of clean air flow. It has been shown that the quality of the size separation is adjustable by changing the ratios of the flow rates. Furthermore, narrow size fractions of paraffin aerosol, coal dust, slate powder and asbestos aerosols have been obtained in experiments employing two units of the new virtual impactor in series.

2. DESIGN OF THE IMPROVED VIRTUAL IMPACTOR

Figure 1 shows the new virtual impactor. Aerosol is drawn in through entrance (2) while clean air passes through entrances (1) and (3) so as to attain an annular flow of aerosol. The merging flow is then accelerated by the narrowing cross-section of the duct, thus, giving adequate momentum to the aerosol particles. Finally, the particles are separated according to their aerodynamic diameters at the gap between the jet (4) and the nozzle (5). The finer aerosol leaves the impactor through the suction tube (6), while the coarser aerosol exits through the connection tube (7). The nozzle gap can be varied by an adjustment screw (8). The core flow of clean air is streamlined by means of a honeycomb (9) made from straws (3 mm in diameter). Two rings (10) each with 60 holes of 0.8 mm dia. force the outer clean air into laminar flow and effect a uniform flow velocity independent of the angular coordinate. These rings are fixed on the inner cylinder and O-rings are used to prevent air leakage through unexpected gaps between the laminator rings and the impactor walls. Unchecked air leakage may distort the annulus of the aerosol flow, resulting in less precise separation. The aerosol flow is also laminarized by two rings (11) each with 36 holes of 1.6 mm dia. Port (12) is a pressure tap.

Fig. 1. Improved virtual impactor.
3. THEORETICAL ASPECTS OF THE SIZE SEPARATION EFFICIENCY

When a monodisperse aerosol is sampled with the impactor, the accelerated particles within a concentric circle of critical radius $R$, are separated from the main flow and pass into the straight undeflected flow through the nozzle (5). Then, the separation efficiency $\eta$ is defined by

$$\eta = \frac{\int_0^{R_e} 2\pi u n r \, dr}{\int_0^R 2\pi u n r \, dr}$$

where $n$ is the number concentration of aerosol particles, $u$ is the air velocity and $R$ is the jet radius. The distribution of the particles in the annular aerosol flow is assumed to be uniform, i.e.

$$n(r) = \begin{cases} 0 & : 0 \leq r < R_1 \\ \text{constant} & : R_1 \leq r < R_s \\ 0 & : R_s \leq r \leq R \end{cases}$$

As indicated in Fig. 2, $R_1$ and $R_s$ are the inner and the outer radius of the annular aerosol flow in the jet (4), respectively.

From equations (1) and (2), it is clear that

$$\eta = 0 \quad \text{for} \quad 0 \leq R_1 < R_s$$

and

$$\eta = 1 \quad \text{for} \quad R_1 < R_s \leq R.$$
If the critical radius \( R_c \) is between \( R_a \) and \( R_p \), then the separation efficiency becomes:

\[
\eta = \frac{\int_{0}^{R_c} ur \, dr - \int_{R_a}^{R_c} ur \, dr}{\int_{0}^{R_c} ur \, dr - \int_{R_a}^{R_p} ur \, dr},
\]

(5)

which can be rewritten with the flow rates as

\[
\eta = \eta_0 \frac{Q_1}{Q_p} - \frac{Q_3}{Q_p} = \eta_0 z - \beta: \quad R_a \leq R_c \leq R_p,
\]

(6)

where \( Q_i \) is the total flow rate, \( Q_p \) is the aerosol sample flow rate and \( Q_1 \) is the clean air core flow rate in the center. The factors \( z \) and \( \beta \) in equation (6) are defined as flow rate ratios

\[
z = \frac{Q_i}{Q_p}, \quad \beta = \frac{Q_1}{Q_p},
\]

(7)

and

\[
\eta_0 = \sqrt{\frac{\int_{0}^{R_c} ur \, dr}{\int_{0}^{R_a} ur \, dr}} = \frac{Q_1}{Q_i},
\]

(8)

is the separation efficiency of a conventional virtual impactor which does not have any clean air flow. \( Q_s \) is the flow rate within the critical trajectories. When the velocity distribution is uniform, equation (8) reads

\[
\eta_0 = \left(\frac{R_c}{R}\right)^2.
\]

(9)

This indicates that the separation efficiency \( \eta \) of the new virtual impactor can be considered as being composed of a separation efficiency \( \eta_0 \) of a conventional virtual impactor and the flow rate ratios \( z \) and \( \beta \).

The slope of the separation characteristic may be expected to depend upon the flow rate ratio \( z \), while the value of \( \beta \) determines the critical Stokes number (see equation (16)) \( \psi = \psi_0 \) where \( \eta = 0 \).

In order to obtain the critical Stokes number \( \psi_0 \), equation (6) will require

\[
\beta = z \eta_0 \quad \text{for} \quad \psi = \psi_0
\]

(10)

or by definitions,

\[
Q_1 = Q_s
\]

(11)

which is satisfied by \( R_a = R_p \). Then, if \( Q_3 \) is the undeflected flow rate through the nozzle (5), the condition for \( \eta = 0 \) is necessarily

\[
Q_3 \leq Q_s
\]

(12)

because no higher flow rate than \( Q_s \) can pass through the nozzle if the flow shall not contain aerosol particles.

For \( \psi < \psi_0 \), equation (6) will turn negative and does not yield physically meaningful data. However, for \( \psi_0 \to 0 \), the conventional virtual impactor has a finite efficiency

\[
\eta_0 = \frac{Q_1}{Q_i}
\]

(13)

and it follows from equation (10) that

\[
\beta \geq z \frac{Q_3}{Q_i}.
\]

(14)
4. EXPERIMENTAL ARRANGEMENTS AND PROCEDURES

The experimental arrangement for testing the performance of the new virtual impactor is shown in Fig. 3. The performance tests were carried out with latex aerosols (Dow Chemical Co.). The air flow rates were measured by rotameters which had been calibrated with a gas meter. The two separate aerosols leaving the instrument were collected on the membrane filter F1 and F2 (Sartorious-Membranfilter GmbH). After sampling, the filters were exposed to acetone vapor for about 2 hr in order to make the filter foil transparent. Subsequently, the particles collected on the filters were counted under a microscope and the separation efficiency was calculated by

$$\eta = \frac{N_1}{N_1 + N_2},$$  \hspace{1cm} (15)

where $N_1$ is the number of coarse particles collected on the filter $F_1$ and $N_2$ is the number of fine particles collected on the filter $F_2$. At a total flow rate of 20 L/min the wall losses, which may depend on flow rate, particle size and particle material (Loo et al., 1976; McFarland et al., 1978) were only 0.6 and 0.2% for 0.822 and 1.10 μm latex particles, respectively.

In all the experiments, the ratio of the straight undeflected flow rate $Q_3$ to the total flow rate $Q_1$ was held constant at 0.1. However, the total flow rate was varied between 5 and 30 L/min. The separation efficiencies obtained were expressed in terms of the square root of the Stokes number $\psi$, a dimensionless inertia parameter giving

$$\sqrt{\psi} = \frac{D_0 u_0 C}{18 \mu D_p D_{pe}}$$  \hspace{1cm} (16)

where $D$ is the jet diameter $2R$, $D_p$ is the aerodynamic particle diameter, $u_0$ is the mean air velocity, $\mu$ is the air viscosity and $\rho_p$ is the particle density. The Cunningham's slip correction factor $C$ is given (e.g. Fuchs, 1964) by

$$C = 1 + \frac{\lambda}{D_p} \left( 1.23 + 0.41 \exp \left( -0.44 \frac{D_p}{\lambda} \right) \right),$$  \hspace{1cm} (17)

where $\lambda$ is the mean free path length of the air molecules.

Another set of experiments involved two of the new virtual impactors in series.
arrangement aimed at the generation of quasi-monodisperse aerosols. Paraffin particles, coal dust (Tremontia II, fine*: \( \rho_p = 1.32 \text{ g/cm}^3 \), measured by the pycnometer method), slate powder (IKO-Schiefer**: \( \rho_p = 2.78 \text{ g/cm}^3 \), measured by the pycnometer method) and asbestos fibers (U.I.C.C. standard-Amosite) were used as test materials. The coal dust and the slate powder were brought into aqueous suspension by small amounts of soap and atomized with compressed air. However, the asbestos aerosol was generated from a fluidized bed by mechanical vibrations (Spurny et al., 1975). Other experimental conditions are listed in Table 1.

<table>
<thead>
<tr>
<th>Experimental conditions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Latex particles:</td>
<td>( D_p = 0.52, 0.72, 0.82, 1.10, 2.02 \mu \text{m} )</td>
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<tr>
<td>( \rho_p = 1.05 \text{ g/cm}^3 )</td>
<td></td>
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<tr>
<td>Mean air velocity:</td>
<td>( U_0 = 30-150 \text{ m/sec} )</td>
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<tr>
<td>Stokes number:</td>
<td>( \psi = 0.03-1.5 (-) )</td>
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<tr>
<td>Flow Reynolds number in</td>
<td>( Re = 4000-20000 (-) )</td>
</tr>
<tr>
<td>impactor jet:</td>
<td></td>
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<tr>
<td>Jet diameter:</td>
<td>( D = 0.2 \text{ cm} )</td>
</tr>
<tr>
<td>Gap between jet and lower nozzle:</td>
<td>( 0.05 \text{ cm} )</td>
</tr>
</tbody>
</table>

5. RESULTS AND DISCUSSION

Figure 4 shows the experimental results obtained with the new impactor when no clean air was used. In the low inertia region \( (\sqrt{\psi} < 0.4) \), the data are almost on the theoretical curve calculated by assuming potential flow (Yoshida et al., 1978). However, with increasing inertia, the experimental separation efficiency increases faster than predicted by the theory. This tendency is similar to that obtained by other investigators (Conner, 1966; Yoshida et al., 1978). Such discrepancy between data and theory may be explained by the fact that the particle trajectories will deviate from the streamlines in the curved section of the narrowing

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* The generous assistance of the Steinkohlenbergbauverein, Essen, in obtaining the samples and the information on the denumir is gratefully acknowledged.
Improved virtual impactor

duct for the merged flow, especially in the vicinity of the cylindrical section of the jet (4). Here, the radial flow components toward the center must decelerate so that the particle inertia will bring the trajectories closer to the center axis. In order to estimate the deviation, it may be assumed that the centrifugal force \( m_p \omega^2 \rho_0 \) (\( m_p \): particle mass, \( \rho_0 \): radius of curvature of the curved section of the jet) will act upon a particle within a range of one jet diameter above the cylindrical section of the jet. The solution of the equation of motion is represented by

\[
\delta = \frac{\delta}{D} = \frac{\psi}{\bar{r}_0} \left( \bar{r} + \psi e^{-\bar{r} - \psi} \right),
\]

where \( \delta \) is the deviation of the particle trajectory at the jet inlet, \( \bar{r}_0 = r_0/D \) and \( \bar{r} = t u_0/D \). \( r_0 \) and \( \bar{r} \) are dimensionless radius of curvature and time, respectively. For the instrument under consideration, values of \( \bar{r}_0 = 10 \) and \( \bar{r} = 1 \) may be used. The outer radius of the aerosol flow \( R' \) is then given by

\[
R' = \frac{R}{R} = 1 - 2\delta
\]

and the separation efficiency must be modified to

\[
\eta_0 = \left( \frac{R}{R'} \right)^2 = \left( \frac{\eta_0}{1 - 2\delta} \right)^2.
\]

The results of these calculations are shown in Fig. 4. The prediction is considerably improved, showing that the main cause of the discrepancy may be the deviation of the particle trajectories from the streamlines in the curved section of the jet (4).

In case of clean air flow, it can be shown that also a ratio \( R'_w/R_w \) for the annual aerosol flow is given by equation (19), when the following substitutions are made for \( \psi, \bar{r} \) and \( \bar{r}_0 \) in equation (18):

\[
\psi_w = \psi \frac{D}{D_w}, \quad \bar{r}_w = \bar{r} \frac{D_w}{D}, \quad \bar{r}_0 = \frac{D}{D_w} \left( \bar{r}_0 \left( \frac{D}{D_w} \right)^2 \right).
\]

Therefore, a general relationship

\[
R'_w = \frac{R'_w}{R_w} = \frac{R'}{R} = 1 - 2\delta
\]

can be obtained and it is easy to show that equation (6) is also valid when \( \eta_0 \) is replaced by \( \eta_0 \).

Although a uniform distribution of the inlet velocity is a reasonable assumption in view of the high acceleration, the effect of the distribution may also be estimated by assuming a velocity distribution:

\[
\frac{u}{u_0} = \frac{32}{30} \left[ 1 - \left( \frac{r}{R} \right)^{10} \right].
\]

The small frame in Fig. 4 gives the modified velocity distribution. The separation efficiency can be obtained by use of equation (8), (23) and the same critical radius \( R_c \) as in the potential flow calculations. The prediction is qualitatively improved as shown in Fig. 4, indicating that the actual velocity distribution may be another cause contributing to the discrepancy between the data and the unmodified theory.

In spite of the theoretical bias, almost all the data are represented by a single experimental curve for \( \eta_0 \). Therefore, it is possible to interpret the separation characteristics of the new impactor with clean air flows based on the experimental curve for \( \eta_0 \). Figure 5 shows how the separation characteristics change experimentally with the flow rate ratio \( \alpha \). The curves in the figure are obtained by use of equation (6) and the experimental curve in Fig. 4. The prediction is satisfactory and the quality of the separation, i.e. the slope of the curves, is adjusted by the
flow rate ratio \( \alpha \). With increasing flow rate ratio \( \alpha \), the slope of the separation characteristic becomes steeper, an effect predicted by equation (6). When \( \alpha = 2 \), the quality of separation is almost the same or better than in case of a conventional solid-plate impactor. Therefore, \( \alpha = 2 \) may be sufficient and suitable for actual industrial applications of the impactor as a powder separator. Besides this fact, the new impactor can be used continuously to get large volumes of size-separated airborne products.

Figure 6 shows the results obtained for several values of \( \beta \) at \( \alpha = 5 \). Agreement between data and the predicted curves is satisfactory for \( \beta = 3 \) and 3.5. In the other cases, at least the cut-off size, as defined by the separation efficiency \( \eta = 0.5 \) coincides with the prediction, showing that the cut-off size is adjustable by selecting a proper flow rate ratio \( \beta \). However, the experimental data deviate from the prediction when the flow rate ratio \( \beta \) is small. To elucidate the cause of these deviations, a cover glass was placed on top of the lower nozzle at a distance of 1 mm from the jet so that particles were collected by impaction. Subsequently, the shape of the particle deposits on the glass was inspected under a microscope. The results are presented in Fig. 7. The shapes for \( \beta = 3 \) and 3.5 are not shown because they were almost perfect circles. The shape for \( \beta = 2.5 \) is still reasonably circular, but the shapes for \( \beta = 2 \) and 1.5 are considerably distorted. With these data and the experimental curve in Fig. 4, the
Fig. 7. Distortion of annular aerosol flow by different flow ratios $\beta (a = 5)$.

separation efficiencies were calculated by numerical integration assuming that the critical radius $R_c$ equals $R\sqrt{\gamma_0}$ (see equation (9)). The dotted lines in Fig. 6 give the results. The large deviations in the high inertia range for $\beta = 1.5$ are not explained, but the other data are almost on the new lines. It may be concluded, therefore, that the main cause of these deviations is a distortion of the annular flow of the aerosol.

The range of applicability of the new impactor depends on the flow rate ratio $Q_2/Q_1$, where $Q_1$ is the enveloping sheath flow of clean air. If this flow rate ratio is selected to satisfy the condition

$$Q_2/Q_1 \leq 0.2,$$  \hspace{1cm} (24)

then good agreement between data and prediction is expected up to total flow rates of 30 l/min, because the deposit patterns were almost circles. If the flow rate ratio $\alpha$ exceeds the value of 1.43, then equation (24) requires a minimum flow rate ratio $\beta$. This can be shown from the balance of flows:

$$Q_1 + Q_2 + Q_\alpha = Q_t,$$  \hspace{1cm} (25)

or

$$\frac{Q_1}{Q_t} + \frac{Q_2}{Q_t} + \frac{1}{\alpha} = 1.$$  \hspace{1cm} (26)

With equation (24) and

$$\frac{Q_1}{Q_t} = \frac{\beta}{\alpha}$$  \hspace{1cm} (27)

the inequality

$$\frac{\beta}{\alpha} + 0.2 + \frac{1}{\alpha} \geq 1$$  \hspace{1cm} (28)

is established which leads to

$$\beta \geq 0.8\alpha - 1.$$  \hspace{1cm} (29)

This is a valid restriction only if $\alpha \geq 1.43$. For $\alpha < 1.43$, minimum flow rate ratio $\beta$ is determined by equation (14).

It may be noted that any restriction of the operation condition can be overcome because the cut-off size is adjustable by changing the jet diameter and/or the total flow rate. Therefore, there are no essential difficulties for actual applications.

Figure 8 shows the results obtained by using two units of impactors in series. In this arrangement, the aerosols are divided into three fractions. The experimental conditions were $\alpha = 10$, $\beta = 7$ for the first and $\alpha = 10$, $\beta = 8$ for the second impactor, while the total flow rate for each impactor was maintained at 10 l/min. The jet diameters were determined by

*The actual flow rate was slightly different in each experiment and was corrected by pressure data.
microscope as 2.0 mm for the first and 2.1 mm for the second impactor. Cunningham's slip correction factor was about 1.08 for particle diameters of 2-3 μm. Then the separation characteristic of the first impactor is almost linear between 2.0 μm (η = 0) and 2.3 μm (η = 1) in terms of the aerodynamic diameter. Also the second impactor has linear characteristic between 2.4 and 2.8 μm.

Figure 8a presents pictures of the three fractions of paraffin particles as separated by the impactors in series. The differences between the deposits shown in the photomicrographs are distinguishable. The finest fraction contains very small particles and the coarse fraction has very large particles. The intermediate fraction, however, has no particles of extreme size.

Figure 8b and c are photomicrographs of coal dust and slate powder, respectively. The separations are sufficient in these experiments, but there are a few particles that are smaller than expected. When the experiments were carried out with less well-dispersed suspensions in the atomizer, the number of the unexpectedly small particles increased, showing that the aggregates leaving the atomizer were dispersed in the jet due to impaction or high speed shear flow. Therefore, the particles in the atomizer suspension must be fully dispersed if they are to yield a good test aerosol.

Figure 8d shows the separated asbestos. The three photomicrographs are quite different in character. The finest fraction has very thin fibers and small isometric particles, and the separation depends more on the diameter than on the length of fibers. This fact agrees with previous results indicating that the aerodynamic diameter of fibers is only slightly influenced by the length but predominantly proportional to the diameter (Stöber et al., 1970).

In view of these experimental results, it may be concluded that the continuous separation of particles and the generation of test aerosols of narrow size distribution in the micrometer range is facilitated by use of the new and improved virtual impactors. No difficulties are anticipated in the application of the method to larger size particles as long as the gravity has a negligible effect.

A final note concerns the possibility of employing this impactor as a sampler for respirable dust. The slope of the separation characteristic in case of $Q_3/Q_0 = 0.1$ is steeper than the ACGIH-sampling curve (Aerosol Technical Committee, 1970). It may be possible, however, to reduce the slope by using larger values of $Q_3/Q_0$ or larger gaps between the jet and lower nozzle than those employed in this experiment. Apparently three points along a separation curve can be chosen in order to fit it to a standard sampling curve of respirable dust. The first fitting point would be at $\eta = 0.5$ by selecting $\sqrt{\psi}$, the second point at, for example, $\eta = 0.75$ and the third point at $\eta = 0.25$ could be fitted by adjusting $\alpha$ and $\beta$ in equation (6). This possibility will be studied in future work.

6. CONCLUSIONS

The present study has confirmed both theoretically and experimentally that a precise separation of fine particles is attainable by use of a virtual impactor improved by employing clean air flows confining the aerosol to an annular flow. The quality of the separation, which is adjustable by changing the clean air flow rate ratios, has been successfully predicted on a semi-empirical base. An increase in the ratio of clean air flow rate to aerosol flow rate improves the separation quality. The cut-off size is also adjustable within a certain range of particle inertia. However, the separation falls below the prediction, if the ratio of outer clean air flow rate to total flow rate exceeds 0.2. The reason for this behavior could be explained by apparent distortions of the annular aerosol flow.

A set of two improved virtual impactors was successfully applied in an attempt to prepare test aerosols of narrow size distribution from actual coal dust and slate powder. There were no difficulties as long as the feed dust was fully dispersed.

Acknowledgement - The authors express their appreciation to Drs K. Spurny and G. Zehel (Silikose-Forschungsinstitut der Bergbau-Berufsgenossenschaft) for their kind interest and valuable discussions. One of the characteristics were slightly different in each experiment because of different atmospheric pressure.
Fig. 8. Separation of particles by use of two improved impactors in series ($Q_{11} = Q_{12} = 10$ l/min, $z_1 = z_2 = 10$, $\beta_1 = 7$, $\beta_2 = 8$).
Improved virtual impactor

authors (H.M.) gratefully acknowledges the support of the Alexander-von-Humboldt-Stiftung by a stipend facilitating this work. He also thanks Prof. K. Linoya (Kyoto Univ.), Drs H. Oldiges, D. Seetha, W. Hollkader and other members of the Institut für Aerobiologie for their helpful suggestions and encouragement. The impactors were built with great skill and diligence by the workshop of the institute.

REFERENCES


Acroflow® II Cartridges
Designed for your final filtration applications

FEATURES AND BENEFITS
• does not contain glass or asbestos fibers
• high filtration capacity
• rapid resistivity recovery

Acroflow® II is a membrane pleated cartridge composed of a nylon reinforced acrylic copolymer. As an added advantage, the 0.2 and 0.45 µm sizes feature serial filtration. The filter media serves as a surface filter for particles larger than pore size and as a depth filter for smaller particles. Acroflow cartridges offer a wide chemical compatibility range and are available in 10", 20", and 30" lengths.

APPLICATIONS
Pharmaceuticals: Biologicals • Clarification • Compressed air
• Packaging container wash and rinse • Rinse water for lines
• Rinse water for mixing tanks
Electronics Manufacturing: Deionized water • Laser coolant
• Water • Non-toxic gas filtration
Cosmetics: Deionized water for bacterial control • Shampoo
• Clarification • Solids removal from viscous cosmetics
Food and Beverage: Wine • Compressed air • Water for soft drinks • Alcohols
Biochemicals and Reagents: Reagent filtration • Cell counter diluents • Hemodialysis concentrates • Makeup water

SPECIFICATIONS
Materials of Construction
End Caps: Phenylene Oxide
Outer Support Tube: Polypropylene
Upstream Filter Support: Polyester
Downstream Filter Support: Polypropylene
Core: Acetal Copolymer
Sealing Material: Polyurethane
O-Rings: Ethylene Propylene Copolymer
Gaskets: Buna-N
Filter Media: Acrylic Copolymer

Typical Effective Filtration Area: 24.9 cm (9.8 in.)—0.37 m²
(4.0 ft²), 49.8 cm (19.6 in.)—0.74 m² (8.0 ft²), 74.7 cm
(29.4 in.)—1.11 m² (12.0 ft²)

Dimensions: Length—See Ordering Information
Diameter—6.6 cm (2.6 in.)

Sterilization
Hot Water Sanitization: 15 minutes at 82°C (180°F)
ETO: 40% R.H., 12% ETO in Freon, 66°C (150°F)

INSTALLATION
To assure optimum cartridge performance:
1. Eliminate back-pressure (water hammer).
2. Replace O-rings or gaskets.
3. Limit differential pressure to 80 psi (5.6 kg/cm²).
4. Consult this insert for chemical compatibility and for maximum operating temperature.
5. Avoid overtightening compression seal on double open-end cartridges.

OPERATING CHARACTERISTICS
Resistivity Recovery: No. 12570 reaches 18 megohms after
90 gallon flush
Maximum Operating Temperature: 88°C (190°F) in liquids
or gases
Maximum Differential Pressure: 5.6 kg/cm² (80 psi)
Maximum Back Pressure: 4.2 kg/cm² (60 psi)
Water Flow Rate: See Chart
Air Flow Rate: See Chart

Cartridge materials have been evaluated for biosafety in accordance with USP Class VI Plastic Tests to ensure safety of materials. Each cartridge is hot stamped with Gelman’s manufacturing lot number for easy traceability.

Typical Performance Data

Air Flow Rate

Water Flow Rate

Water Flow Rate

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CHEMICAL COMPATIBILITY

Conducting Your Own Compatibility Tests

If you can't find the answer to your compatibility question in the chart below, a simple but effective compatibility check can be made by soaking a cartridge in your test solution for 48 hours at the use temperature. Then examine the cartridge and solution for signs of visual change.

Indications of Chemical Attack:

- **Discoloration**
- **Surface Tackiness**
- **Dimensional Change**
- **Change of Color in Test Solution**
- **Loss of Strength**

The information contained in the chart is current data but is intended only as a guide. Conditions vary with each application, and users should carefully verify chemical compatibility.

**KEY**

- R = RESISTANT
- LR = LIMITED RESISTANCE
- NR = NOT RESISTANT

**Insufficient Data.**

**ACIDS**

- Acetic Acid, Glacial
- Acetic Acid, 30%
- Acetic Acid, 10%
- Hydrochloric Acid, Conc.
- Hydrochloric Acid, 3N
- Nitric Acid, Conc.
- Nitric Acid, 6N
- Sulfuric Acid, Conc.
- Sulfuric Acid, 9N
- Hydrofluoric Acid, 5N

**esters**

- Amyl Acetate
- Butyl Acetate
- Ethyl Acetate
- Isobutyl Acetate
- McIlvain
- Diethyl Ether
- Diisopropyl Ether
- Dioxane
- Tetrahydrofuran

**Glycols**

- Ethylene Glycol
- Glycol
- Propylene Glycol

**Aromatics**

- Aromatic Hydrocarbons
- Benzene
- Toluene
- Xylenes
- Chloroform
- Chloroform N

**Halogenated Hydrocarbons**

- Carbon Tetrachloride
- Dichloromethane
- Hexafluoropropylene

**BASES**

- Ammonium Hydroxide, 3N
- Ammonium Hydroxide, 8N
- Sodium Hydroxide, 8N
- Sodium Hydroxide, 4N

**KETONES**

- Acetone
- Chloroform
- Ethanol
- Isopropanol
- Methanol

**Miscellaneous**

- Aniline
- Dimethyl Formamide
- Dimethyl Sulfoxide
- Formaldehyde
- Hexane
- Isooctane
- Kerosene
- Phthalein
- Pyridine
- Silicon 500
- Turpentine

**ORDERING INFORMATION**

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<tr>
<th>Product</th>
<th>0.2</th>
<th>0.45</th>
<th>0.8</th>
<th>1.2</th>
<th>3</th>
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<tr>
<td>Size</td>
<td>µm</td>
<td>µm</td>
<td>µm</td>
<td>µm</td>
<td>SOE DOE</td>
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</tr>
<tr>
<td>25.4 cm</td>
<td>20 cm</td>
<td>15 cm</td>
<td>10 cm</td>
<td>7.5 cm</td>
<td></td>
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</tbody>
</table>

* WARNING: Do not use or apply the product for purposes or under conditions other than those specifically described in this brochure. Failure to comply with this warning may result in improper functioning of the product, personal injury, or damage to the product or property.

* For applications not listed in this brochure, contact Gelman Sciences.

**RELATED PRODUCTS**

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<thead>
<tr>
<th>Cartridge Filter Application</th>
<th>Range of Ratings</th>
<th>Cartridge Filter Characteristics</th>
<th>Product Name</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ACIDS, SOLVENTS, CHEMICALS</strong></td>
<td>0.6 µm–40 µm</td>
<td>All Polypropylene, Extended Service Life</td>
<td>Polyversol</td>
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<td>1 µm–5 µm</td>
<td>Polypropylene And/Or Glass Fiber</td>
<td>Preflow SR</td>
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<td>0.2 µm–1 µm</td>
<td>Teflon And Polypropylene</td>
<td>Sol-Vent</td>
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<td>0.8 µm</td>
<td>High Capacity, Three Stage Filtration</td>
<td>Acroflow B</td>
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<td><strong>BEVERAGES</strong></td>
<td>0.2 µm–0.45 µm</td>
<td>High Purity, All Plastic, Preflushed</td>
<td>Acroflow Super E</td>
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<tr>
<td><strong>DEIONIZED WATER</strong></td>
<td>Sub-µm–1 µm</td>
<td>Large Capacity Glass Fiber Prefilters</td>
<td>Preflow</td>
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<tr>
<td>0.45 µm–0.8 µm</td>
<td>Serial Filtration, Acrylic Membrane</td>
<td>Versaflow</td>
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<td>Sub-µm–10 µm</td>
<td>Non-Fiber-Releasing Prefilter</td>
<td>Preflow NFR</td>
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<td>Polysulfone Membrane, Sterilizable</td>
<td>Acroflow 121</td>
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<td><strong>TANK VENTING</strong></td>
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<td>Teflon And Polypropylene</td>
<td>Sol-Vent</td>
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</table>
**1407K**

**PUMP OIL** — High Vacuum, Sargent-Welch DuoSeal®.

Fractionated especially for use in Sargent-Welch vacuum pumps. DuoSeal pump oil is the only oil recommended for DuoSeal, DirectTor, and all pumps, and the vacuum guarantee for these pumps applies only when this oil is used. Use of any other oil causes inferior performance and, in time, may even cause permanent pump damage. DuoSeal oil is checked frequently and carefully against rigid standards for proper vapor pressure, chemical stability, viscosity, and other essential characteristics.

<table>
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<td>1407K-15</td>
<td>1 gallon</td>
<td>17.30</td>
<td>63.50</td>
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<td>1407K-20</td>
<td>5 gallon</td>
<td>69.30</td>
<td>140.70</td>
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<tr>
<td>1407K-25</td>
<td>55 gallon (drum)</td>
<td>571.70</td>
<td></td>
</tr>
</tbody>
</table>

B-29
1. Close BOTH shut-off valves.

2. Press the Pressure Relief Button on the top of the housing to release pressure. Hold until pressure has been relieved.

3. Turn housing clockwise with easy-change wrench (included with water filter housing) to loosen. Remove wrench when loose. Hand turn housing to remove, using care not to spill the water contained in the housing. Lift out and discard dirty cartridge. Drain and thoroughly rinse filter housing. Insert new cartridge and reassemble by reversing the above procedure.

IMPORTANT: Be sure "O" ring is in proper position before turning housing into threads.

Contents: 2 Filter Cartridges
NOTE: These water filter cartridges are designed to filter only sediment and not to kill bacteria.

FILTER LIFE: Generally, the filter cartridge life varies from 6 weeks to 6 months, depending upon the amount of contaminants in the raw drinkable water supply. When the cartridge has trapped all the particles it can hold, a substantial drop in water pressure at the faucets will be noticed. When this occurs, a fresh water filter cartridge should be installed. Always keep several water filter cartridges on hand.
THE SG-40 SMOKE GENERATOR

INSTRUCTION MANUAL

The VirTis Co. Inc., PPI Div., Gardiner, N.Y. 12525

With the growth of clean room technology the detection, measurement and control of airborne particulates has become increasingly important. The SG-40 Aerosol Generator meets this challenge, enabling you to determine penetration rates and locate leaks in air filtration systems. Simple and easy to use, it requires only a safe test material such as DOP (Dioclylphthalate) and clean air to operate.

The SG-40 Aerosol Generator design is based on a Laskin-type nozzle apparatus. By shearing the liquid plasticizer with air it creates a liquid aerosol of consistent particle size and distribution. When used with the Phoenix JM Series Photometers, this aerosol generator will quickly and efficiently test and evaluate air filtration systems in HEPA filters, work stations, clean rooms and filter banks.

The JM and SG series test equipment is applicable in a wide variety of contamination controlled environments - manufacturing to aerospace, bioscience, pharmaceuticals and medicine, even computing and food processing. This equipment is recommended for filter testing in compliance with Federal Standard No. 209B, for clean room and work station requirements in controlled environments.

SPECIFICATIONS

| Undiluted Smoke Output: | Variable by selection of from one to six nozzles |
| Test Smoke Material: | Dioclylphthalate (DOP) is standard; however, any safe liquid may be used. |
| Particle Size Distribution: (using DOP) | 99% = less than 3.0 microns <br> 95% = less than 1.5 microns <br> 92% = less than 1.0 microns <br> 50% = less than 0.72 microns <br> 25% = less than 0.50 microns <br> 11% = less than 0.35 microns |
| Operating Temperature: | Ambient |
| Dimensions: | 15"H x 9-1/2"W x 9-1/2"D |

Capacity: Up to 4200 CFM systems
Air Requirements: 2 to 12 SCFM at 20 psi
Construction: Stainless Steel chamber and nozzle, aluminum head plate.
Weight: 15 pounds

OPERATION

CAUTION: Do not operate unit with smoke outlet capped. Note also that air pressures greater than 25 psi can cause liquid carry-over from the smoke outlet.

1. Remove smoke outlet cap located on the top of the Generator

2. Unscrew fill cap at the top rear of the unit, and fill with test grade Dioclylphthalate (DOP) or any safe liquid until Liquid Level Indicator reads "Full". Upper mark indicates 'full', lower mark, 'add'.

3. Connect clean compressed air to the fitting located on the head plate. Air pressure should not exceed 25 psi.

4. Open desired combination of valves for proper aerosol challenge.

For shipping the unit, cap the smoke outlet and close all six regulating valves, thus preventing DOP leakage.

Note: please include model and serial numbers in all correspondence concerning your unit, by mail or phone.
END

FILMED

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DTIC