ABSTRACT

MANUEL S. CHUA. An Evaluation of the Acoustical Particle Sizing Device as a Counting Device for Particles with Diameters Below 5 μm. (Under the Direction of Professor Parker C. Reist, Sc.D.).

The particle counts of the Acoustical Particle Sizing Device (APSD) developed by Coover in 1978 was compared with that of the Climet 208 Optical Particle Analyzer (OPA) and the Gardner Condensation Nuclei Counter (CNC). The OPA was used as the reference machine in counting lycopodium spores using three different set-ups, as well as polystyrene latex spheres (PSL) of different diameters and concentration levels. The CNC was used as the standard in counting particles from cigarette smoke, magnesium strip fumes and the reaction of sodium hydroxide (NaOH) pellets and nitric acid. The mean difference in the number of particles per liter counted by both machines was computed for every trial, and the statistical significance was tested; the correlation coefficient was also determined. Results indicate the inability of the APSD to count particles with diameters below 5 μm.

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ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to Dr. Parker C. Reist, not only for his direction of this research project, but also for his patience and understanding during the preparation of this report. Gratitude is extended to both Drs. David A. Fraser and James E. Watson for their assistance and serving as members of my committee.

Special thanks to Donna Simmons for typing this report. I wish to express special thanks to the following people for their assistance and moral support given: Ms. Valeria Shropshire, Mr. Frank Cordero, Val Saludez, Ms. Angelina Sebial, Barbara Palacios, and other friends.

Utmost gratitude is expressed to Dr. Ophelia M. Mendoza and Ms. Ava McDaniel for their assistance in computer programming and data analysis; and to Mr. Prudencio Ubaldo for drawing the diagrams. Warmest thanks also given to "WEWO".

Finally, without the moral and financial support extended to me by my brother and sisters, especially my mother (Mrs. Maxima Sia Chua), this research project might have not been completed.

This investigation was conducted as part of a graduate training program and was supported in part by a National Institute of Occupational Safety and Health Traineeship,

Grant Number: 1 T15 OH 07101-01. Materials and apparatus used in this investigation were supported by a gift from the Mobil Oil Corporation given to the Department of Environmental Sciences and Engineering University of North Carolina at Chapel Hill.

1. INTRODUCTION

1.1 Small Particle Detectors

The extent to which minute particles in the atmosphere can affect our daily lives cannot be understated. When found in the wrong places, these particles can cause malfunction of a process, either within the human body or in the environment. Inhalation of these particles can adversely affect one's health, especially if they are contaminated with toxic, carcinogenic or radioactive substances. They can also affect the weather and visibility through coagulation in the atmosphere or through condensation (Chen and Mercer, 1985). Because of their far-reaching and varied effects, their properties have been of considerable interest to chemists, meteorologists, safety engineers and public health workers.

While the properties of these particles have been studied at length over the past 100 years, there is still much to be learned about them. One of the main reasons for this is their complex behavior. Another reason is the dearth of efficient and accurate instruments with which to detect and measure them.

A number of small particle detectors have been developed in the past few decades. Among the ones earlier developed

is one manufactured by Gardner Associates. It is a small portable device for measuring the concentration of condensation nuclei (CN) in the air in the range of $2x10^2$ to 10^7 particles/cc and can be used for the study of the size distribution of a sample with some difficulty. It operates on the principle of light transmission and is described in detail by Fawcett and Gardner (1959).

Another CN sampling device is one manufactured by the General Electric Company. The machine is an automatic nuclei counter which draws in aerosol sample automatically, first, through a humidification chamber and then into a cloud chamber where it is expanded by the automatic operation of a rotary valve. The cloud formed by condensation is detected by light scattering (Liu and Kim, 1977).

The Climet Optical Particle Analyzer is another commercially available counting device, one which uses the light scattered from small particles for counting and sizing the particle. The CI-208 model, which is the model used in this study, combines the patented elliptical mirror system along with stable low-noise electronics and precisely regulated flow system to count and size individual particles with maximum accuracy in concentrations up to 10 million particles per cubic foot and as small as 0.3 μm (CI-208 User's Manual, 1979).

A particle sizing device which was developed fairly recent is that of Coover and Reist (Coover, 1979; Coover and

Reist, 1980). The device was developed using a novel technique of sizing aerosol particles based on the acoustical principle. While the counting and sizing functions of this machine have been tested for large particles from 5 μm to 80 μm in diameter, further observations seem to indicate its potential as a small particle detector. For example, it has been observed to react to cigarette smoke which has a particle diameter of about 0.25 μm. This study is a first attempt to systematically explore the potential of the machine as a counting device for particles smaller than 5 μm.

1.2 Objectives of the Study

This study has the following general and specific objectives:

General Objective:

To evaluate the Acoustical Particle Sizing Device (APSD) as a counting device for particles with diameters below 5 μm.

Specific Objectives:

1. To compare the particle counts of the APSD with that of the Climet 208 Optical Particle Analyzer (OPA) for polystyrene latex spheres (PSL) of different diameters. The different diameters to be considered are:
    a) 0.357 μm
    b) 0.60 μm

c) 1.10 μm

d) 2.20 μm

2. To compare the particle counts of the APSD with that of the OPA for polystyrene latex spheres of different concentration levels.
3. To compare the particle counts of the APSD with that of the Gardner Condensation Nuclei Counter (CNC) for different types of particles. The different types of particles to be considered are:
    a) cigarette smoke
    b) magnesium (Mg) fumes
    c) acid-base reaction - i.e., particles produced by the reaction of sodium hydroxide (NaOH) pellets and nitric acid (HNO_3)
4. To compare the performance of the APSD as a counting device for small particles with diameters below 5 μm with its performance when counting lycopodium spores which have diameters of 28 μm

1.3 Review of Related Literature

Very few studies have been done on the evaluation of the APSD as a counting device. Coover (1978) determined the absolute detection efficiency of the machine using different types of allergens with diameters ranging from 6 μm to 45 μm. In this same study, he also explored the relationship between the diameter of a particle and the efficiency of counting, at a constant Reynolds number. In 1980, Gherman

evaluated the performance of the device as a pollen counter, by comparing its count with three types of counters, namely the Rotoslide sampler, the Durham sampler and the High Volume Filter sampler. This will be the first study evaluating the performance of the machine for small particles with diameters below 5 μm.

2. MATERIALS AND METHODS

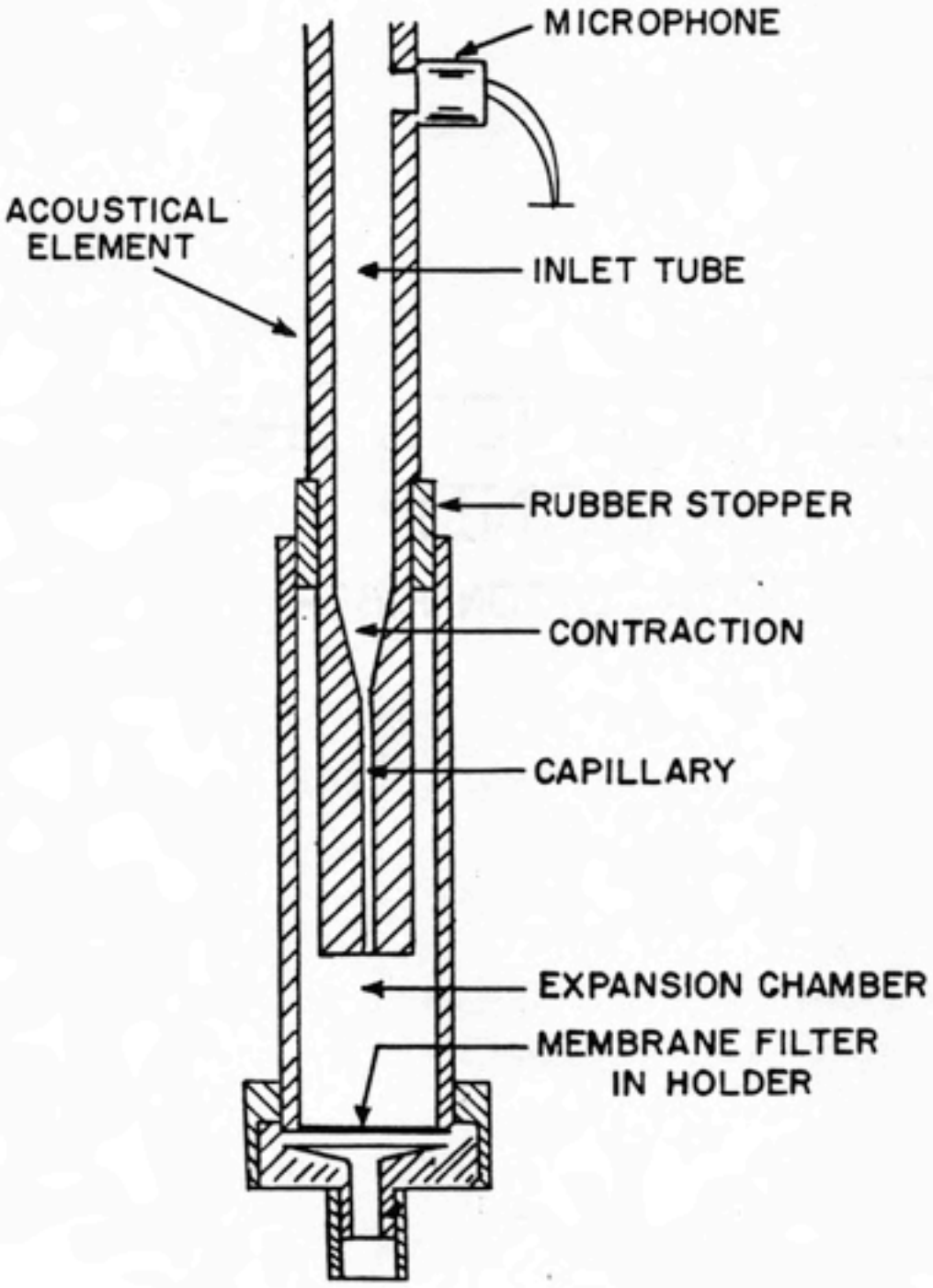
2.1 Counting Devices Used

In order to evaluate the Acoustical Particle Sizing Device (APSD) as a counting device for particles with diameters below 5 μm, the APSD counts for the different particles considered in this study were compared with those of the Optical Particle Analyzer (OPA) and the Gardner Condensation Nuclei Counter (CNC). Specifically, the OPA was the reference in counting lycopodium spores and polystyrene latex spheres. The CNC on the other hand was used to count particles of cigarette smoke, magnesium fumes, as well as the particles produced by the reaction of sodium hydroxide (NaOH) pellets and nitric acid (HNO_3). The following sections present a brief description of the different counting devices used in this study.

2.1.1 Acoustical Particle Sizing Device (APSD)

The Acoustical Particle Sizing Device was developed by Coover and Reist in 1978. The principle involved in the detection of particle is based on the production of an acoustical pulse upon the passage of an aerosol particle through a specially designed orifice at a high velocity (Langer, 1965). A diagram of this orifice is shown in Figure 1. Aside from just counting large particles, Coover

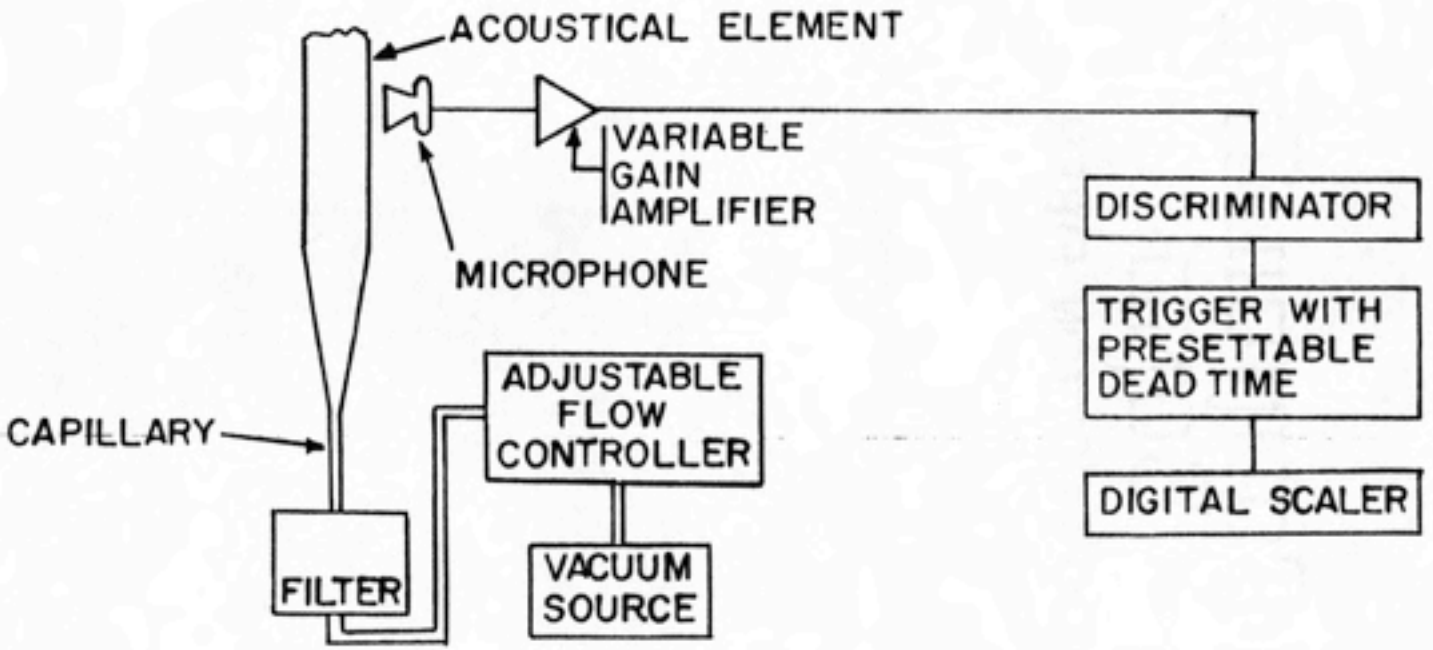
FIGURE 1. ACOUSTICAL PARTICLE SIZING DEVICE: ACOUSTICAL ELEMENT & FILTER ASSEMBLY [4]



has also shown that the APSD has the ability to size large particles by varying the flow rate through the acoustical element, which changes the detection threshold.

The basic mechanism behind the operation of the APSD can be described as follows: When air enters in a smooth gradual conical contraction of the acoustical element, it produces an unstable super-laminar flow in the capillary section. However, when a particle is introduced, it is accelerated at a slower rate than the air surrounding the particle because of its greater density compared to air. Since there is a difference in the acceleration between the particle and the air stream, a difference in velocity is developed. The particle in this air stream causes instability making the unstable superlaminar flow to become turbulent. This in turn will increase the flow resistance abruptly producing a temporary increase in pressure upstream and a temporary decrease in pressure downstream. This causes the air column in the inlet section to resonate which is perceived as an audible "click" (Gherman, 1980). As part of Coover's work in 1978, he added a miniature electret microphone as the acoustical element which relays the audible acoustical pulse to the analyzer. Thus the audible click is amplified and registered as a particle count. As the particle gets out of the capillary, the flow returns to its original super-laminar flow until the next particle enters the system and the cycle continues. A schematic diagram of the APSD is shown in Figure 2.

FIGURE 2. ACOUSTICAL PARTICLE SIZING DEVICE: BLOCK DIAGRAM [4]



2.1.2 Climet 208 Optical Particle Analyzer (OPA)

Optical particle counters have the ability to determine both the number concentration and the particle size distribution of aerosols. This is based on the scattering of light from single aerosol particles which are introduced into the device as a narrow stream into a beam of focused light. As each particle passes through the illuminated volume, it scatters a pulse of light which is detected by the photo detector. The signal from the photo-detector is processed electronically to produce a pulse height spectrum from which the particle size spectrum is deduced. The ability of the optical counter to resolve particles of different sizes is determined by electronic and optical noise and by the uniformity of the light intensity in the viewing volume. Figure 3 shows a diagram of the optical systems of the OPA.

The important characteristics of an optical counter are the sampling flow rate and the size of the optical viewing volume, in addition to the particle size range of the instrument. The sampling flow rate determines the minimum counting period needed to obtain a statistically accurate count, and the size of the optical viewing volume determines the maximum aerosol concentration the instrument can accept without loss of particle count due to "coincidence", i.e., the loss of particle count due to the presence of more than one particle in the optical viewing volume (Whitby and Liu, 1973).

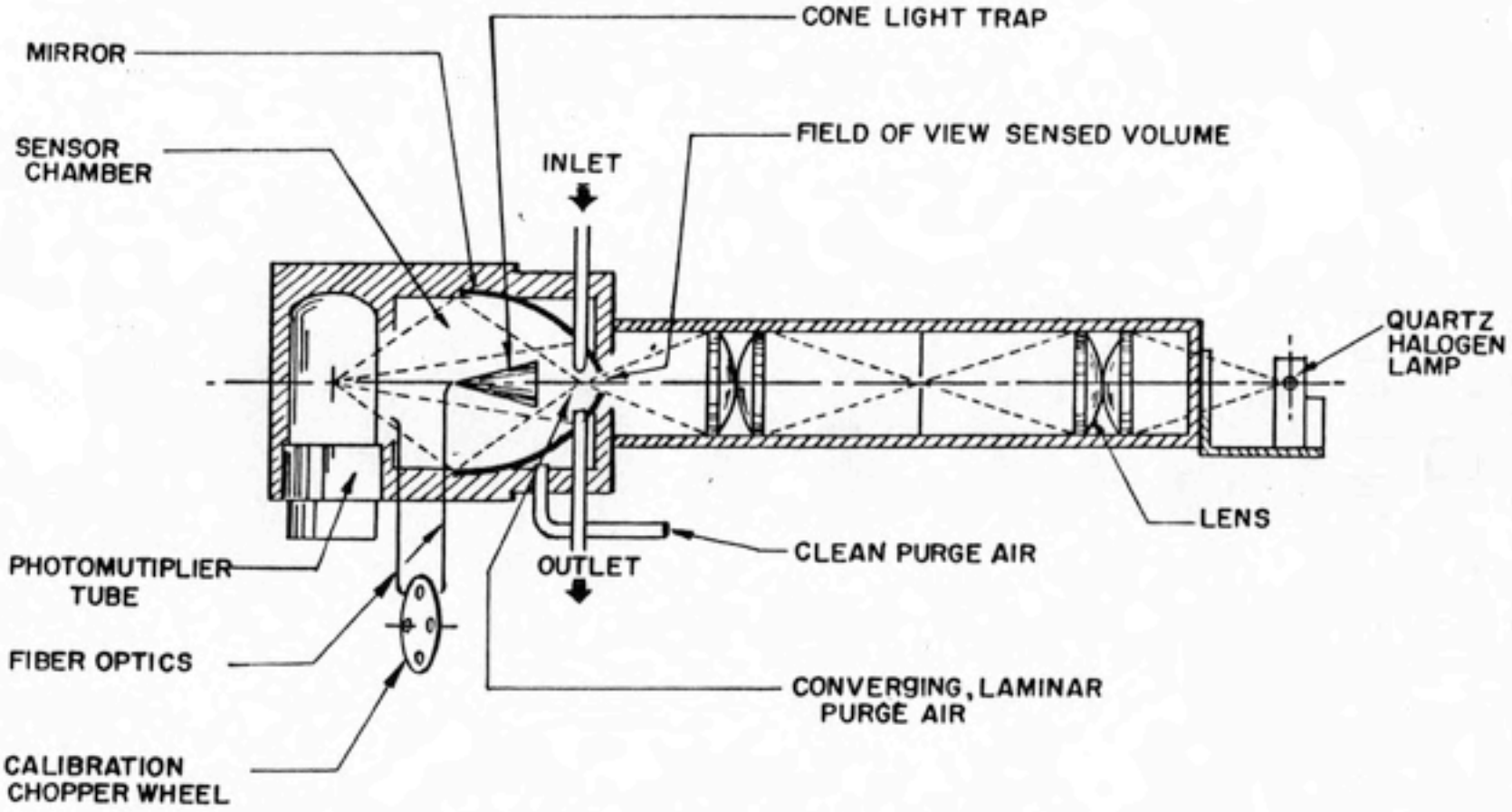


FIG. 3. CLIMET OPTICAL SYSTEM[3]

2.1.3 Gardner Condensation Nuclei Counter

The condensation nuclei counter (CNC) is a device used to measure the concentration of submicrometer aerosol particles. It has been utilized in the field of air pollution, cloud physics, and other scientific and technical work. It is capable of detecting very small particles (to about 20 Angstrom in diameter) over a wide concentration range (from about 100 particles/cc to 10^7 particles/cc) (Miller and Bodhaine, 1982).

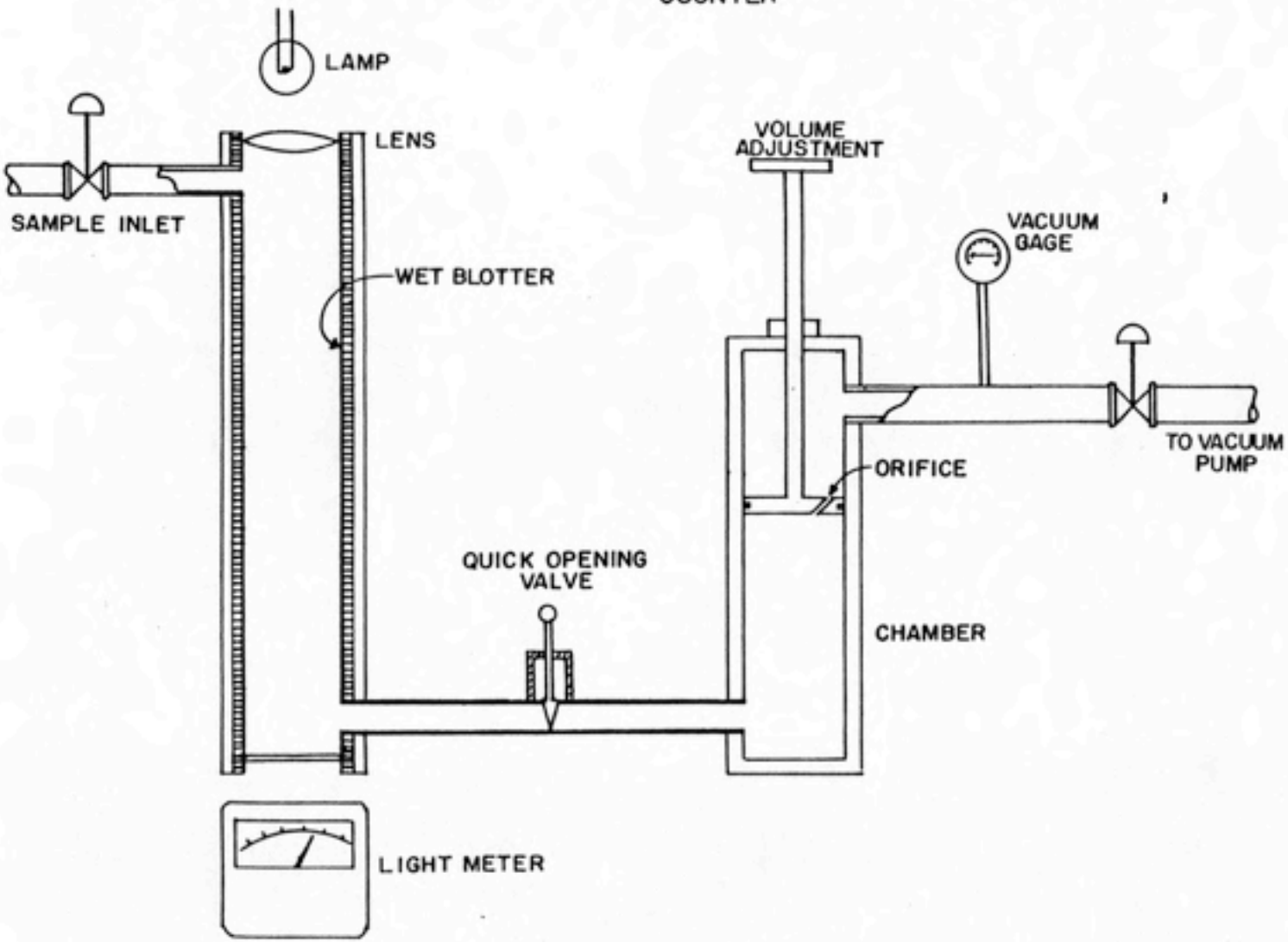
The operation of the Gardner condensation nuclei counter is dependent on the fact that small particles have the ability to serve as condensation centers for water vapor in proper conditions. When an aerosol is introduced into the device, it is saturated with water vapor and is subjected to expansion causing a supersaturated state. In this state, water condenses on the particle to form visible droplet. This droplet is measured optically by light transmission (ACGIH, 1966). Figure 4 shows a schematic diagram of the Gardner Condensation Nuclei Counter.

According to the calibration obtained by Liu and Kim (1977), results of condensation nuclei measurements are subject to large uncertainties and should be interpreted with care.

2.2 Aerosol Generation and Sampling

In order to generate and sample aerosols for data collection in the study, a separate set-up was used for

FIGURE 4. SCHEMATIC DRAWING SHOWING ELEMENTS OF THE GARDNER CONDENSATION NUCLEI[7] COUNTER



every type of particle that was considered. These are described in detail in the following sections.

2.2.1 Lycopodium Spores

In order to ensure that the machines were working properly at the onset of the study, it was decided to first observe their counts using a particle where the efficiency, especially that of the APSD, is already established. Since lycopodium spores were among the test particles used by Coover when he developed the APSD, it was decided to use these as the test particle for the study.

Lycopodium spores have a diameter of 28 um and are hence outside the range of particles being considered. The data collected here was used as baseline information or basis of comparison on the performance of the machines when particles larger than 5 um were being counted.

2.2.1.1 Generation of Lycopodium Spores

The generation and collection of lycopodium spores were patterned after the design employed by Coover in 1978 with some modification.

An air blast solid particle resuspension technique was utilized to generate these spores. With this method, a small centrifugal fan was used to disperse the different amounts of spores. The outlet of this centrifugal fan was attached to one end of a rectangular 1.06 m^3 acrylic plastic chamber with a length, height and width equal to 153.5 cm., 119 cm. and 58 cm., respectively.

The orifices of the tygon tubing which served as the inlet of particles into the OPA and the acoustical element were placed on a ringstand with the inlet facing vertically upward. The two inlets were spaced 9.5 cm. away from one another. A baffle made of cardboard measuring 20.5 cm. x 25.5 cm. was placed over the sample inlets. This was positioned perpendicular to the flow of air and at a distance of 4 cm. from the mouth of the inlets. This baffle was used to prevent large agglomerates from being sampled.

Three different set-ups were explored. All of these utilized the set-up mentioned above but differed in that there was a difference in the location of the blower fan in the chamber. This blower fan was used to keep the spores suspended in air for a longer period of time after being dispersed by the small centrifugal fan attached to the rectangular 1.06 m^3 acrylic plastic chamber.

For set-up A, the blower fan was located 24 inches above the chamber floor facing inward, with a distance of 15 inches away from the chamber door. For set-up B, the blower fan was lowered to 12 inches above the chamber floor and faced inward, with a distance of 15 inches away from the chamber door. For set-up C, there were 2 blower fans. Both were placed on the chamber floor, with one stationed 6 inches away from chamber door, while the other was placed 8 inches away from the opposite end of the chamber. These 2 fans faced each other, so that when activated, they blew the particles toward the center of the chamber. All of the fans

for each of the three set-ups were operated for the entire sampling period of 30 minutes. Set-up C is shown in detail in Figure 5.

Under each set-up, different concentration levels of the lycopodium spores were tested. For set-up A, these were 0.5 gram, 1.0 gram, and 1.5 grams. For set-up B, three different concentration levels were also tested but their amounts varied from that of set-up A. Specifically, these were 0.5 gram, 1.5 grams and 2.5 grams. For set-up C, 5 different concentration levels were considered namely, 0.5 gram, 1.0 gram, 1.5 grams, 2.0 grams, and 2.5 grams.

2.2.1.2 Aerosol Sampling and Data Collection

During the data collection, precisely weighed samples were placed in the center of the fan wheel of the small centrifugal fan for dispersion into the chamber. This centrifugal fan was operated for a period of one-minute. One minute after the spores were dispersed, counts per minute were recorded at 2-minute intervals for a sampling period of 30 minutes. Three trials were made for each sample being tested for the three different set-ups. Results were reported as counts per liter by dividing the counts per minute by the respective flow rates of 17 liters per minute for the APSD and 7.08 liters per minute for the OPA.

The data collection was arranged in the following fashion. Sampling using set-up A was done first, then set-up B, and finally set-up C. In each of the three, sampling was done starting with the lowest concentration of spores

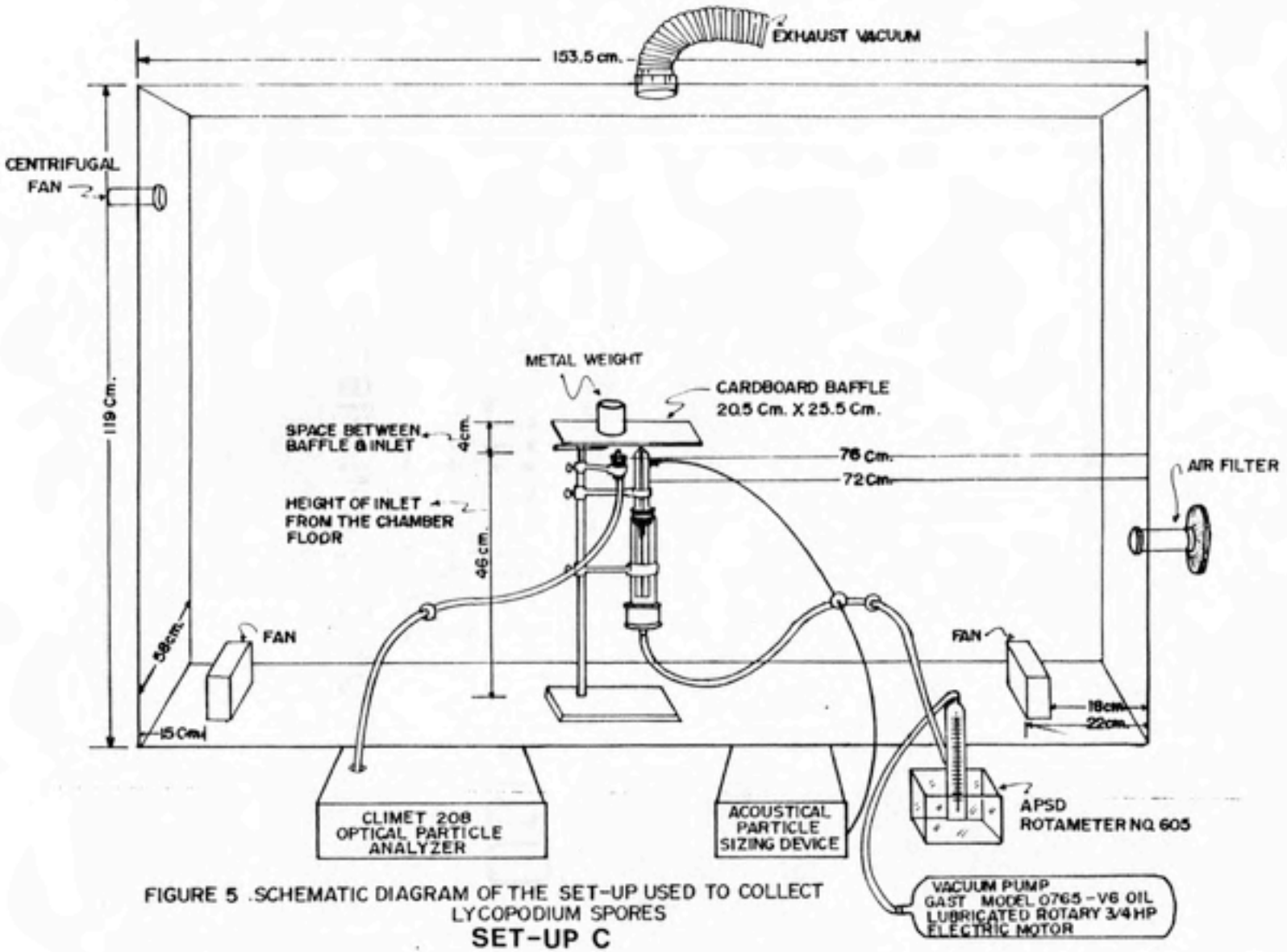


FIGURE 5 .SCHEMATIC DIAGRAM OF THE SET-UP USED TO COLLECT LYCOPODIUM SPORES

SET-UP C

while the maximum concentration level was done last. This arrangement was done to minimize the relative number of particles left-over in the chamber which may affect the count of the next sampling. After each run, the interior surfaces of the chamber were cleaned using an industrial vacuum cleaner and were wiped off using a wet-cloth. The chamber was then left to dry. The air in the chamber was replaced with air filtered with the filter attached to the chamber before the next trial was executed.

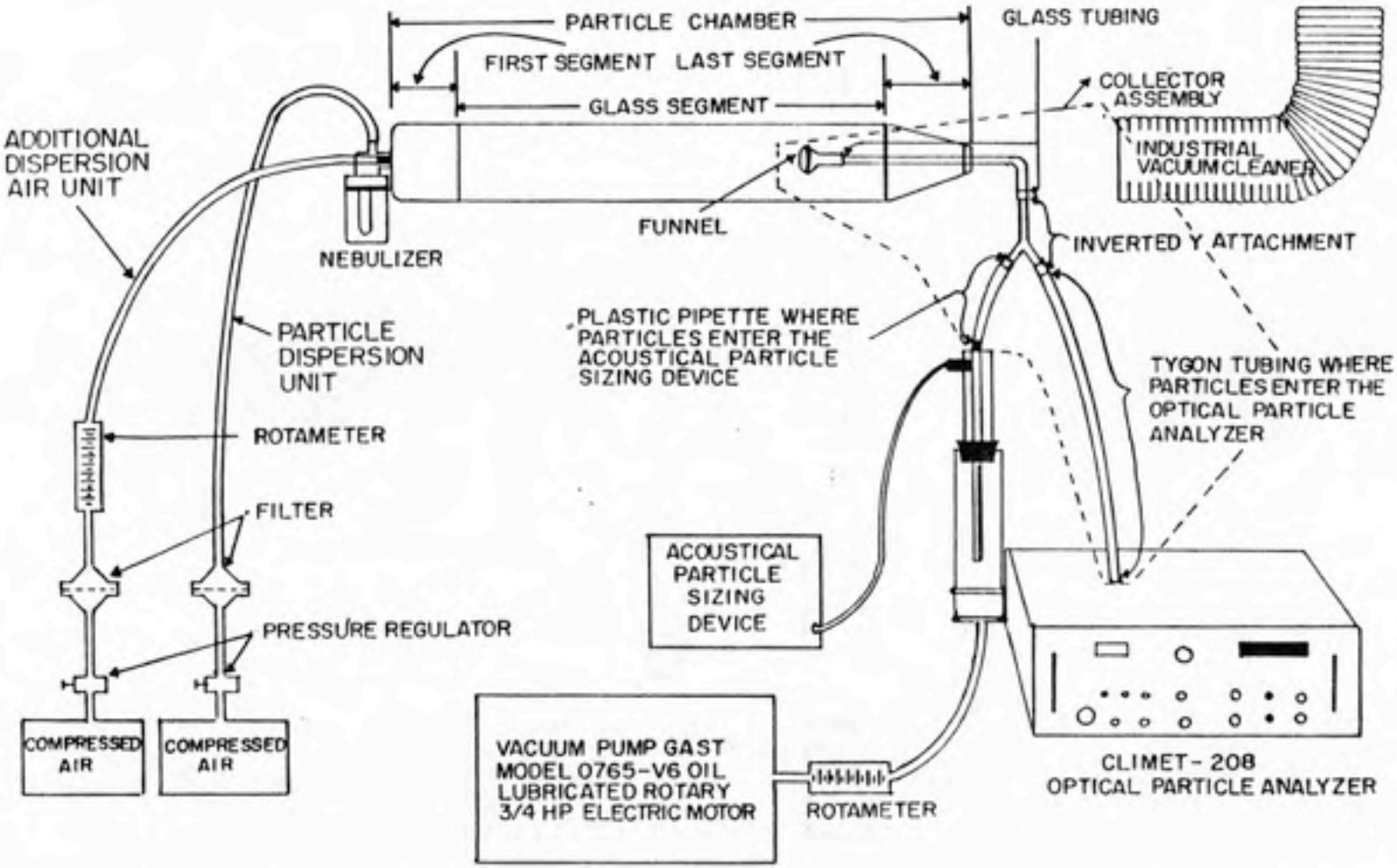
2.2.2 Polystyrene Latex Spheres (PSL)

Four different sizes of polystyrene latex spheres were utilized as test aerosols. To sample these monodisperse spheres, the Climet Instrument Model 208 Optical Particle Analyzer (OPA) was chosen as the primary standard for comparing the counts registered by the Acoustical Particle Sizing Device (APSD). This was chosen in sampling PSL because Climet 208 has the capability to size particles in the range of interest in this study.

2.2.2.1 The Test System

A simple and inexpensive test system was developed to sample the PSL particles. Figure 6 shows a diagram of this test system. For descriptive purposes, the set-up can be divided into 5 components, namely, (1) The Particle Dispersion Unit, (2) The Additional Dispersion Air Unit, (3) The Chamber Unit, (4) The Collector Assembly, and (5) The Exhaust Collection Unit. These are discussed briefly as follows:

FIGURE 6. TEST SYSTEM TO SAMPLE POLYSTYRENE LATEX SPHERES



(1) The Particle Dispersion Unit

To disperse the synthetic aerosols which are suspended in aqueous medium, a Single Jet Nebulizer was utilized. The opening or mouth of the nebulizer was attached to the first portion of the chamber. The air used to run the nebulizer in dispersing the test aerosols was breathing quality compressed air supplied in 300 ft^3 cylinders.[1] Before air entered the nebulizer, it was filtered by a 37 mm diameter membrane filter with a 0.8 micrometer pore size, supported by a metal backing plate. A pressure regulator attached to the compressed air tank was used to control and monitor the flow rate of air.

(2) The Additional Dispersion Air Unit

An additional air dispersing unit was attached with air flowing in the same direction as that of the particles as they were dispersed by the nebulizer. This was done because earlier tests conducted showed this to be one way of increasing the particle counts registered by both counters. This increase in particle count may be explained by the nature of the PSL spheres after they are dispersed by the nebulizer. Generally, they are wet as they leave the nebulizer, and because of this wetness, some particles are probably not capable of traversing the length of the chamber and thereby can not reach the funnel which serves as the

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1(National Welders) and distributed by the Scientific Supply at the University of North Carolina at Chapel Hill.

entrance to the particle counters. It is possible that with the drying effect of the additional air supply, as particles are blown within the chamber, they are dried-off faster and are blown toward the funnel hence more particles are collected.

The air used in the additional dispersion air unit is the same quality and the same supplier as the air used in the nebulizer, and was filtered by a 47 mm diameter membrane filter with a 0.8 micrometer nominal pore size. A rotameter was used to control the flow rate.

(3) The Chamber Unit

The chamber consist of 3 segments, namely, the particle entrance, the main chamber, and the excess particle exit.

The particle entrance was made of hard plastic which was originally a plastic beaker having the same diameter as the main chamber. It was cut and fitted to the main chamber, and was connected together by using a 3-inch clear scotch tape. This served as the location where the nebulizer and the additional dispersion air unit were attached together, and the particles were introduced into the test chamber.

The main chamber was a glass cylinder measuring 30 1/2 inches in length and 4 inches in internal diameter. In this segment the particles were further mixed and dried by the additional dispersion air before being collected by the funnel which served as entrance to the two particle counters. The funnel was located toward the end of this chamber.

The last section was made of hard plastic cut from a plastic Erlenmayer flask. This had a conical shape, and measured 4 inches in diameter at its biggest part and about 2 inches in diameter on its smallest part with a total length of about 3 1/2 inches. The conical shape of the segment was chosen to prevent contaminants from entering the system. This also facilitated the capture of excess particles leaving this chamber by the use of an industrial vacuum.

(4) The Collector Assembly

Four parts comprised the collector assembly, the funnel, the glass tubing, the inverted Y attachment, and the separate lines leading to the particle counters.

The funnel was made of hard plastic measuring 1 1/4 inch at the opening and tapering to about 3/16 inch which connected to the glass tubing. This funnel served both particle counters.

The glass tubing measured 1 foot in length, with an internal diameter of 3/16 inch. At about 8-inch mark away from the funnel, this tubing was bent gradually downward forming a 90^{o} angle. This end portion of the tubing was then connected to the inverted Y attachment.

The inverted Y attachment was actually a three-way connector which was made of hard plastic. It was at this point where the tubing bifurcated with one line connected to the Optical Particle Analyzer, while the other line led to the Acoustical Particle Sizing Device.

The line that connected to the Optical Particle Analyzer was tygon tubing which measured 15 inches in length and 5/16 of an inch in internal diameter. The line for the APSD however was made of a clear hard plastic pipette 4 inches in length and 5/16 of an inch in diameter. This pipette was bent gradually in a downward position forming an angle of about 135^{o}.

(5) The Exhaust Collection Unit

An industrial vacuum cleaner served to prevent contaminants from entering the test chamber, and to capture the exhaust leaving the test chamber.

2.2.2.2 Preparation of PSL Samples

The PSL spheres utilized in this study came from different companies. Both the 0.357 μm and 0.600 μm spheres were made by Dow Chemicals while the 1.0 μm and 2.02 μm spheres were brought from Duke Scientific in Palo Alto, California. All of these synthetic particles were monodisperse and were supplied in aqueous media in dropper tip vials.

Five concentration levels of samples were made and tested for each particle size. For the 0.357 μm and 0.600 μm spheres the following formulation was utilized:

$$\text{Sample Solution} = X + Y \qquad (1)$$

where X = amount (in ml) of the initial concentration

Y = amount (in ml) of the solvent

The specific values corresponding to X and Y in Eq. (1) corresponding to each of the five concentration levels used in the study are as follows:

Concentration Level	X (in ml)	Y (in ml)
1	1	9
2	2	8
3	3	7
4	4	6
5	5	5

In addition, the initial concentration was prepared using the following formula:

$$\text{Initial Concentration} = \frac{\text{5 drops of stock solution}}{\text{+ 30 ml of solvent}} \qquad (2)$$

where the solvent consisted of 50:50 (% by volume) mixture of 90% ethanol and distilled water. The original concentration from the supplier was the stock solution.

For the 1.1 μm and 2.02 μm spheres the sample solutions were prepared differently. The following formula was used:

$$\text{Sample Solution} = Z + \text{10 ml. solvent} \qquad (3)$$

where Z = number of drops of stock solution, using the original concentration from the supplier.

The specific values used corresponding to each of the five concentration levels used in the study were as follows:

Concentration Level	Z (in drops)
1	2
2	4
3	6
4	8
5	10

The solvent was the same as that used for the smaller size PSL spheres.

Just before the particles were dispensed from their dropper tip vials, the vials were gently shaken or agitated to insure uniformity. Care was taken not to vigorously shake the vials to prevent production of bubbles, which may give misleading results (Duke Scientific Corp. Analytical Reference Particles Bulletin 81).

2.2.2.3 Procedure for Sampling PSL:

The following operation procedures were found to be suitable based on preliminary work.

a) The additional dispersion air source was operated at a flow rate of 1.9 cubic feet per minute. This air source was turned-on first before the actual runs in order to clean the test chamber of contaminants.

b) The nebulizer was operated at 40 PSI, corresponding to 0.18 ml per minute nebulizer output. It was cleaned after every run.

c) The APSD vacuum was maintained at 17.0 Lpm.

d) Background counts were recorded before each run.

e) The filter for the acoustical element was replaced for each run.

f) Particles were collected starting with the smallest to the biggest diameter, and from the most dilute to the most concentrated sample solution.

g) The temperature and relative humidity were recorded.

Using the above standard operating procedures, counts were recorded every minute for a 10-minute sampling period.

2.2.3 Cigarette Smoke

The standard particle counter for sampling cigarette smoke particles was the Gardner Condensation Nuclei Counter (CNC). This was selected because it has the capability to detect very small particles (i.e., cigarette smoke particles) as well as to count these fine particles at high concentration ranges.

After preliminary tests it was realized that it was necessary to increase the concentration of cigarette smoke being sampled in order to evaluate the Acoustical Particle Sizing Device (APSD). Since the 1.06 m^3 rectangular acrylic plastic chamber used in the preliminary tests required more cigarettes to attain a higher concentration level, it was decided to use an inverted 4-liter beaker instead, as particle collecting chamber. By simply placing the inverted beaker on a ringstand near the center of the 1.06 m^3 rectangular acrylic plastic chamber, and by taking some

precautionary measures to prevent air contaminants from entering it, a simple and inexpensive particle collecting chamber was constructed. The door of the plastic chamber was kept detached from the chamber in order to facilitate the performance of procedures in the study. The upper half of the plastic chamber was covered by some sheets of computer paper taped to the plastic chamber wall. By placing the 4-liter beaker within this rectangular plastic chamber, the amount of air contaminants, if present, that mixed with the samples in the study was minimized. In addition, both the tygon tubing, which served as the inlet for the CNC and the acoustical element were placed 2 inches within the inverted beaker. A 2-inch space was also provided between the two inlets in order not to disturb the flow of air into the APSD. As an additional step in safeguarding air quality around the particle collection chamber, the windows and the door of the room, where the experiment was being conducted, were kept closed.

Four 1-minute samples of air within the 4-liter beaker were taken prior to the introduction of the test samples to monitor the quality of air before the test. By using a match, a cigarette was ignited outside the plastic chamber and then positioned beneath the inverted beaker. The cigarette was inserted in the space between the mouth of the beaker and the clamp which supported the beaker and served to hold the lighted cigarette. Counts were recorded every

minute during a 30-minute sampling period. Figure 7 shows details of the apparatus.

The APSD air flow was set a 17.0 lpm. It was observed for all the trials that at around the 9th minute of sampling the air flow decreased and adjustments were made to bring the flow back to its original rate.

After each run, the acoustical element was cleaned with soap and water and the filter for the acoustical element replaced prior to each run. Four additional trials were made using the same procedures.

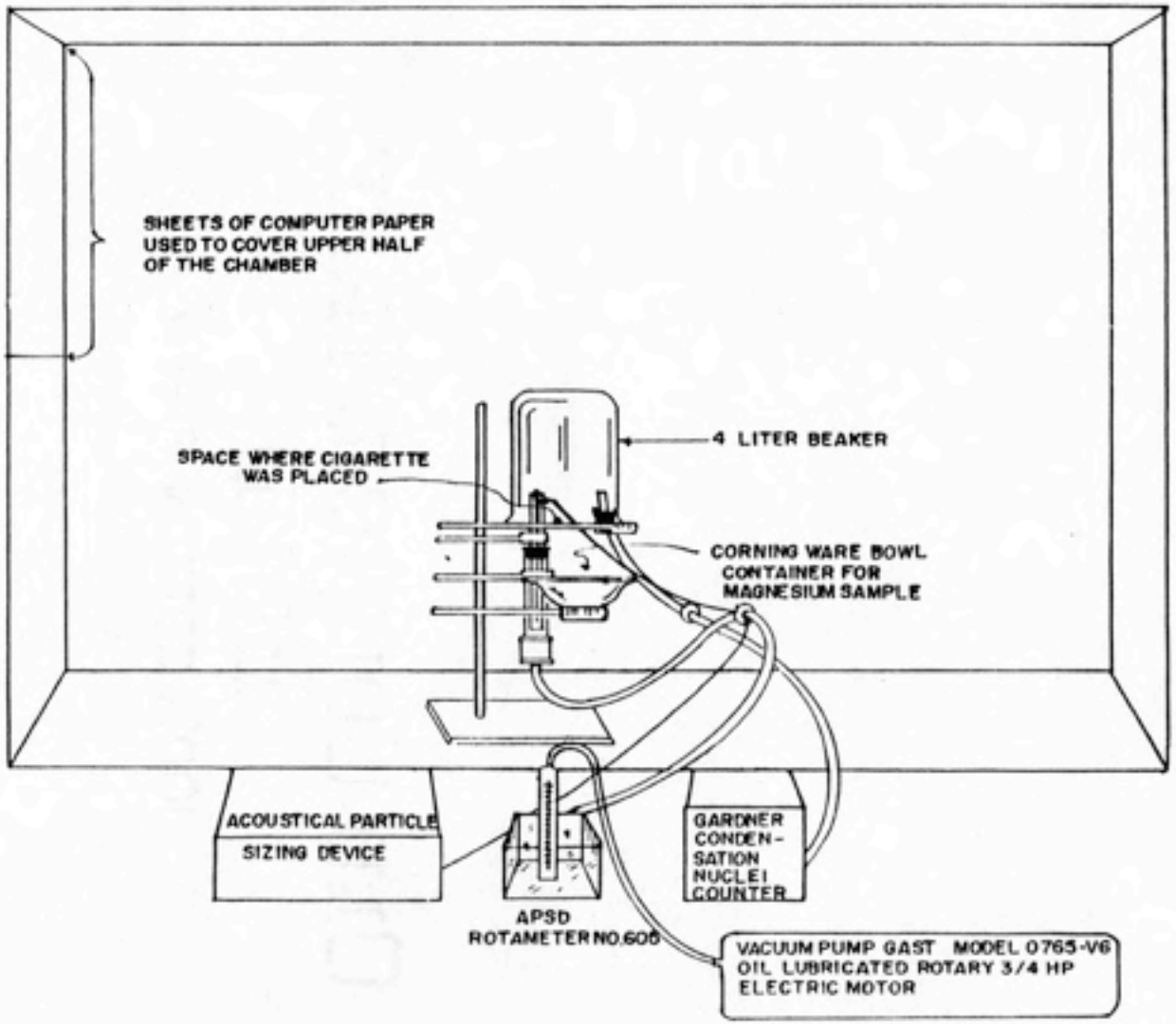
2.2.4 Magnesium Smoke

The Gardner Condensation Nuclei Counter was selected as the standard particle counter in the sampling of smoke produced by the ignition of strips of magnesium. It was chosen for the same reasons as that of cigarette smoke - i.e., it is the more appropriate device considering the size of the particles and levels of concentration used in this study.

The same set-up and procedures for sampling cigarette smoke were employed in sampling the magnesium smoke. The only difference was in the container used to hold the samples.

Four 1-minute samples of air inside the inverted beaker were collected prior to the introduction of the test smoke. Immediately after the air sampling, an eight-inch strip of magnesium was lighted and immediately placed in the Corningware bowl beneath the inverted beaker. Counts for

FIGURE 7. SET-UP USED TO SAMPLE CIGARETTE AND MAGNESIUM SMOKE.



every minute were recorded for the 30-minute sampling period.

It was observed that immediately after igniting the magnesium strip, some smoke overflowed the inverted beaker. No steps were taken to correct this. At different occasions, the flame of the magnesium strip died prematurely. Immediately the unburned portion of the strip was re-ignited. A sudden decrease in the flow rate of the acoustical element was encountered sometimes. Readjustments of the flow in the acoustical element were made.

2.2.5 Acid-Base Reaction

As with cigarette smoke and magnesium strip fumes, the Gardner Condensation Nuclei Counter was chosen as the standard or reference.

With the exception of the sample containers utilized, the two set-ups employed in this part of the study were the same as in the case of the cigarette smoke and magnesium smoke. Method 1 utilized a 30-ml beaker to hold the reagents during sampling while Method 2 used a 50-ml graduated cylinder. The apparatus employed for the 2 methods are shown in Figure 8 and Figure 9.

2.2.5.1 Method 1: (30-ml Beaker)

Prior to the introduction of samples, four 1-minute samples of air in the inverted beaker were collected. Ten pellets of NaOH were then placed in the 30 ml beaker beneath the beaker and 5-ml of concentrated HNO_3 were poured into

FIGURE 8. SET-UP USED TO SAMPLE ACID-BASE REACTION
(BEAKER METHOD)

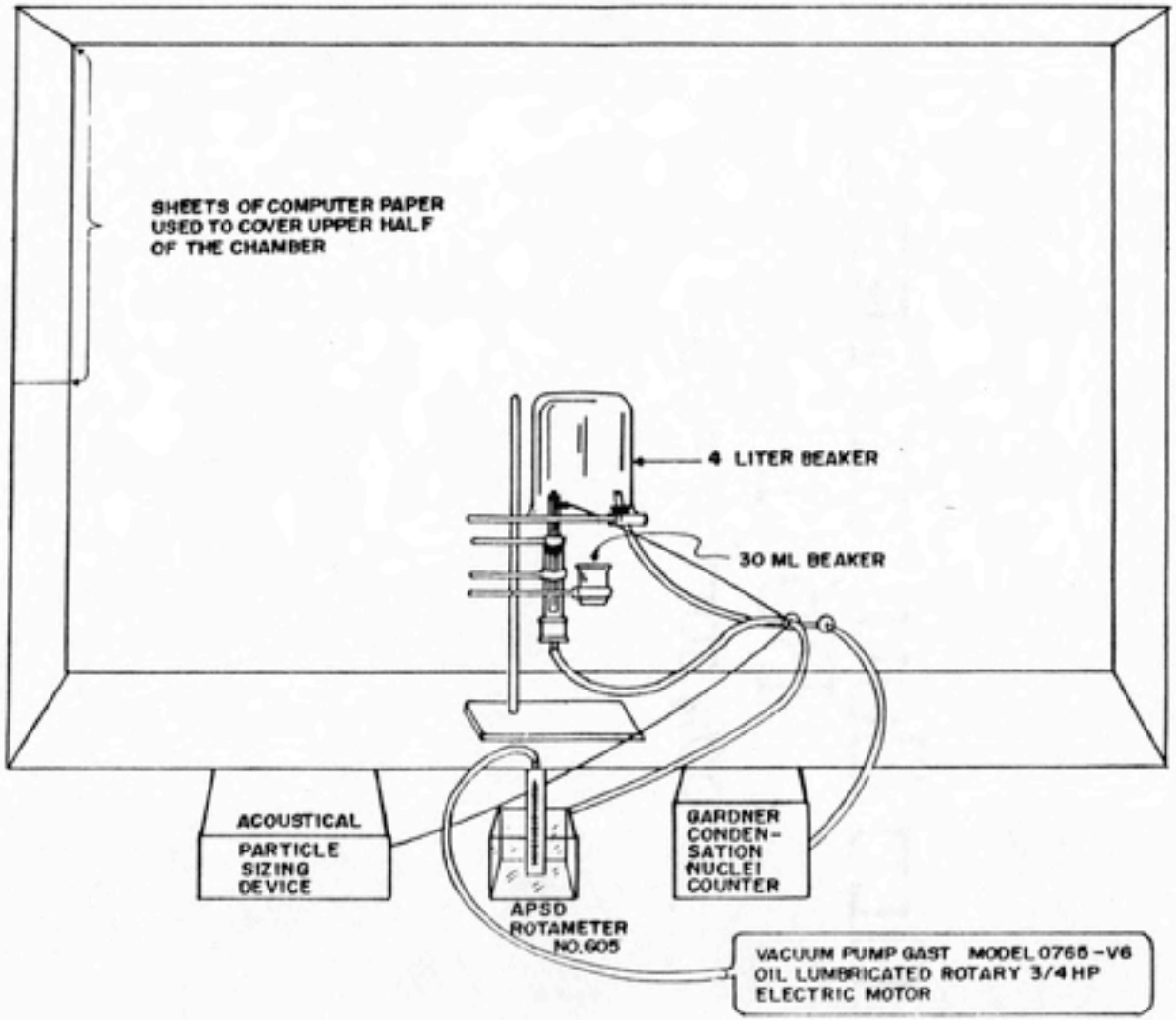
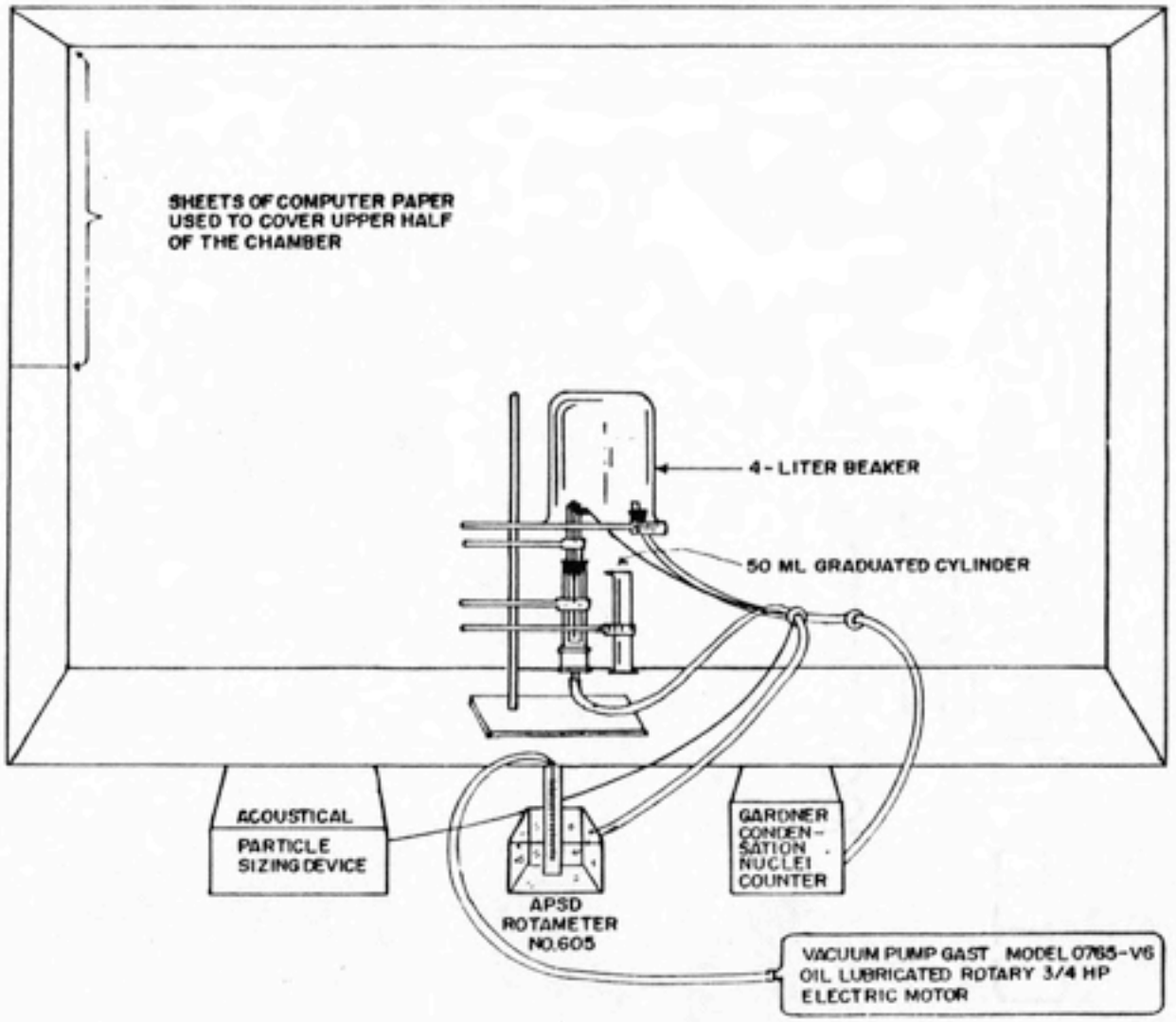


FIGURE 9. SET-UP USED TO SAMPLE ACID-BASE REACTION
(GRADUATED CYLINDER METHOD)



the beaker using a 10-ml pipet. Counts were recorded every minute for a period of 30 minutes.

2.2.5.2 Method 2: (50-ml Graduated Cylinder)

In method 2 a 50-ml graduate cylinder was used instead of the 30-ml beaker.

In both methods, it was observed that the flow rate of the acoustical element decreased slightly after the introduction of the acid. To maintain the original flow rate, the rotameter was reset. For both methods, four additional trials were conducted utilizing the same procedures mentioned above.

2.2.6 Titanium Tetrachloride

It was originally intended to include titanium tetrachloride among the test particles for this study. Preliminary tests conducted to sample titanium tetrachloride however showed that the flow rate in the acoustical element was markedly decreased after the introduction of the smoke. Attempts were made to readjust the flow rate but they failed. It is probable that the fume produced by the sample blocked the pores of the membrane filter of the acoustical element. For this reason, no further tests were performed on the sample.

2.3 Mode of Data Analysis

To analyze the data collected from this study, the following statistical techniques were applied:

a. Conversion of the absolute counts of the number of particles detected by each machine per minute to the number of particles counted per liter was done to standardize and hence ensure the direct comparability of the results for the different instruments, in the light of the differences in the flow rate of air needed to operate them.

b. For each trial, mean particle count per liter (X) with the corresponding standard deviation(s) and coefficients of variation (C.V.) was calculated. The coefficient of variation was used as a measure of relative variability between the particle counts of the instruments being compared and was computed to determine which gave the more variable counts, especially in cases where the particle counts differed greatly in magnitude. The corresponding formulas are:

Mean: $\bar{X} = \frac{\sum X}{n}$

Standard Deviation: $s = \sqrt{\frac{\sum x^2 - (\sum X)^2/n}{n - 1}}$

Coefficient of Variation: $C.V. = \frac{s}{\bar{X}} \times 100$

where X = particle count per liter for a given instrument in a given reading;

n = number of readings in a given trial.

c. Testing of the null hypothesis that there is no significant difference between the mean particle count per liter of the APSD and that of the reference machine. Since the design of the study was such that both machines counted particles for the same samples, the paired t-test was used to test the above null hypothesis. The formulas for the test-statistic is:

$$t = \frac{\bar{d}}{s_{\bar{d}} / \sqrt{n}}$$

where $\bar{d} = \sum d/n$, the mean of the differences between the the two machines;

$d = X_{APSD} - X_{OPA \text{ or } CNC}$;

$$s_{\bar{d}} = \sqrt{\frac{\sum d^2 - (\sum d)^2/n}{n-1}}$$, the standard deviation of the differences;

n = the number of readings in a given trial.

d. Computation of Pearson's correlation coefficient, r. This was used to determine the direction and the magnitude of the relationship between the particle counts of the machines being compared. The formula for r is:

$$r = \frac{n\sum XY - \sum X \sum Y}{\sqrt{n\sum X^2 - (\sum X)^2}\sqrt{n\sum Y^2 - (\sum Y)^2}}$$

where X and Y represent the particle counts per liter of the APSD and the reference machines, respectively. After the r values were computed, each one was tested for statistical significance, using the t-test with the following formula:

$$t = r\sqrt{\frac{n - 2}{1 - r^2}}$$

3. RESULTS AND DISCUSSION

3.1 APSD Versus OPA

The OPA was used as the reference when particle counts for lycopodium spores and polystyrene latex spheres were determined. The results are presented and discussed below.

3.1.1 Lycopodium Spores

While lycopodium spores have diameters of 28 um, they were included in the study to provide baseline information on the comparative performance of the APSD and the OPA when counting particles larger than 5 um.

Tables 1 to 3 show the mean lycopodium spore counts per liter for each of the two instruments under three different conditions, different concentration levels of the particles, and for several trials. In the table, sample size refers to the number of readings or counts recorded per trial or test. Readings were made every minute within the duration of the test. In addition, the baseline count of particles before the introduction of the lycopodium spores was also noted for both instruments at each trial. Since the baseline counts were found to be essentially zero particles per liter for both the APSD and the OPA, these were no longer reflected in the tables.

Table 1. Selected Statistics for APSD and OPA Counts of Lycopodium Spores Under Different Concentrations Set-Up A.

Concentration/ Test No.	Sample Size (n)	APSD $\bar{X}$ (per liter)	APSD Standard Deviation (s)	APSD C.V. (in %)	OPA $\bar{X}$ (per liter)	OPA Standard Deviation (s)	OPA C.V. (in %)	Mean Difference ($\bar{d}$)[1]	t value[2]
0.5 gms.									
Test 1	12	4.0	2.8	71.0	2.0	1.7	83.0	2.0	4.94[3]
Test 2	12	3.5	1.9	53.4	1.9	1.4	72.5	1.6	5.35[3]
Test 3	12	3.2	1.9	61.3	2.0	1.5	73.6	1.2	5.54[3]
1.0 gms									
Test 1	14	7.2	5.0	69.1	3.9	3.0	76.3	3.3	5.17[3]
Test 2	14	5.2	4.2	99.3	4.0	4.9	122.7	1.2	3.17[3]
Test 3	14	4.6	3.3	71.8	2.8	2.2	80.7	1.8	4.82[3]
1.5 gms.									
Test 1	14	7.0	4.3	61.6	5.1	3.6	71.2	1.9	5.70[3]
Test 2	14	4.9	3.5	71.7	3.1	3.1	100.0	1.8	9.51[3]
Test 3	14	4.1	2.6	64.4	2.9	2.8	96.6	1.2	5.83[3]

[1] $\bar{d} = \sum(X_{APSD} - X_{OPA})/n$

[2] The t-value was derived using the test-statistic for the paired t-test.

[3] Significant at = .05.

Table 2. Selected Statistics for APSD and OPA Counts of Lycopodium Spores Under Different Concentrations: Set-Up B.

Concentration/ Test No.	Sample Size (n)	APSD $\bar{X}$ (per liter)	APSD Standard Deviation (s)	APSD C.V. (in %)	OPA $\bar{X}$ (per liter)	OPA Standard Deviation (s)	OPA C.V. (in %)	Mean Difference ($\bar{d}$)[1]	t value[2]
0.5 gms.									
Test 1	14	3.9	2.5	64.1	2.3	1.4	60.9	1.6	4.32[3]
Test 2	14	1.3	0.8	61.5	0.7	0.7	100.0	0.6	3.66[3]
Test 3	14	1.4	1.1	78.6	0.8	0.6	75.0	0.6	3.24[3]
1.5 gms.									
Test 1	14	3.1	1.8	58.1	1.6	1.4	87.5	1.5	7.64[3]
Test 2	14	2.6	1.5	57.7	1.8	1.8	100.0	0.8	5.68[3]
Test 3	14	2.2	1.7	77.3	1.6	1.3	81.3	0.6	2.89[3]
2.5 gms.									
Test 1	14	3.8	2.4	63.2	2.7	2.7	100.0	1.1	4.69[3]
Test 2	14	3.3	2.0	60.6	2.4	2.0	83.3	0.9	4.90[3]
Test 3	14	3.9	2.6	66.7	2.6	2.8	107.7	1.3	6.72[3]

[1] $\bar{d} = \sum(X_{APSD} - X_{OPA})/n$

[2] The t-value was derived using the test-statistic for the paired t-test.

[3] Significant at = .05.

Table 3. Selected Statistics for APSD and OPA Counts of Lycopodium Spores Under Different Concentrations: Set-Up C.

Concentration/ Test No.	Sample Size (n)	APSD $\bar{X}$ (per liter)	APSD Standard Deviation (s)	APSD C.V. (in %)	OPA $\bar{X}$ (per liter)	OPA Standard Deviation (s)	OPA C.V. (in %)	Mean Difference $(\bar{d})^1$	t value[2]
0.5 gms.									
Test 1	14	3.4	2.7	79.4	2.5	2.2	88.0	0.9	4.07[3]
Test 2	14	5.9	4.2	71.2	3.1	2.3	74.2	2.8	4.97[3]
Test 3	14	5.4	5.0	92.6	2.7	2.3	85.2	2.7	3.68[3]
1.0 gms.									
Test 1	14	9.7	7.6	78.4	4.5	3.9	86.7	5.2	6.34[3]
Test 2	14	8.7	6.1	70.1	4.5	3.4	75.6	4.2	7.21[3]
Test 3	14	10.2	7.8	76.5	4.9	4.0	81.6	5.3	4.95[3]
1.5 gms.									
Test 1	14	11.7	8.0	68.4	5.8	4.9	84.5	5.9	6.78[3]
Test 2	14	11.6	7.7	66.4	5.2	4.7	90.4	6.4	6.51[3]
Test 3	14	11.7	8.2	70.1	5.5	4.4	80.0	6.2	5.59[3]
2.0 gms.									
Test 1	14	15.8	11.4	72.2	7.6	6.2	81.6	8.2	5.77[3]
Test 2	14	14.4	9.1	63.2	7.3	5.7	78.1	7.1	7.26[3]
Test 3	14	14.5	11.0	75.9	6.8	5.8	85.3	7.7	5.29[3]
2.5 gms.									
Test 1	14	20.1	11.6	57.7	9.4	6.7	71.3	10.7	7.61[3]
Test 2	14	19.7	12.0	60.9	11.0	7.7	70.0	8.7	6.78[3]
Test 3	14	18.7	12.0	64.2	9.7	8.0	82.5	9.0	7.55[3]

[1] $\bar{d} = \sum(X_{APSD} - X_{OPA})/n$

[2] The t-value was derived using the test-statistic for the paired t-test.

[3] Significant at = .05.

An examination of the data presented in Tables 1-3 lead to the following observations:

a. APSD counts tend to be higher than OPA counts, as evidenced by the positive signs of all of the mean differences ($\bar{d}$).

b. For all the three set-ups the mean lycopodium spore counts of the APSD are significantly higher than that of the OPA, in all of the 3 trials done under each of the different concentration levels considered.

c. The mean difference ($\bar{d}$) of set-up C tends to be higher than that of set-ups A and B.

The different results exhibited under set-up C, as compared to set-ups A and B imply that the comparative performance of the APSD and the OPA as counting devices for lycopodium spores is dependent on the set-up used. The main difference between set-ups A, B and C was the number and position of the blower fans used inside the chamber which affected the direction of the movements of the particles after they were dispersed, and eventually, their probability of entering the inlet of the APSD or the OPA and be counted. Under set-up A for instance, the single fan placed 2 feet above the floor directed them to the opposite end of the chamber and hence particles entered through the inlet of the counting devices basically through suction. In contrast, the two fans placed on the floor facing each other under set-up C allowed the particles to settle down and be blown up again after

dispersion. Since the opening of the inlet of the APSD is larger than that of the OPA, it has a higher probability of catching more particles in the natural process of settling down or being blow-up again, in addition to those which enter the inlet through suction. This can probably explain the significantly higher particle counts for the APSD under set-up C.

Another way of comparing the particle counts of the APSD and the OPA is by looking at their correlation - i.e., by investigating whether APSD counts are high when OPA counts are high, and vice versa. Pearson's correlation coefficient (r) was computed for this purpose. Thirty out of 33 trials done for lycopodium spores had correlation coefficients of at least 0.90 implying a very high positive correlation between APSD and OPA particle counts. Figure 10 shows the scatterpoint diagram of the two counts for lycopodium spores at 0.5 gms. concentration during the first trial of the different set-ups. The computed correlation coefficients for the 33 different trials and their corresponding t-values are shown in Table A1 of the Appendix.

3.1.2 Polystyrene Latex Spheres (PSL)

The only particle with diameter below 5 um for which the APSD was tested against the OPA was polystyrene latex spheres (PSL). In order to see how the APSD perform under different conditions, four different diameters and five different concentrations were considered, resulting in 20 different trials of 10 readings each. For each diameter

FIGURE 10 -a. SET-UP A , TEST I

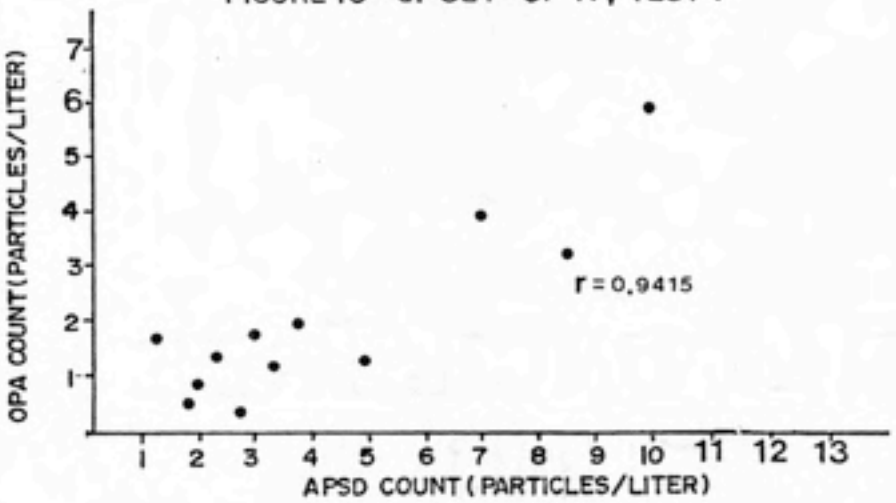


FIGURE 10 -b. SET-UP B , TEST I

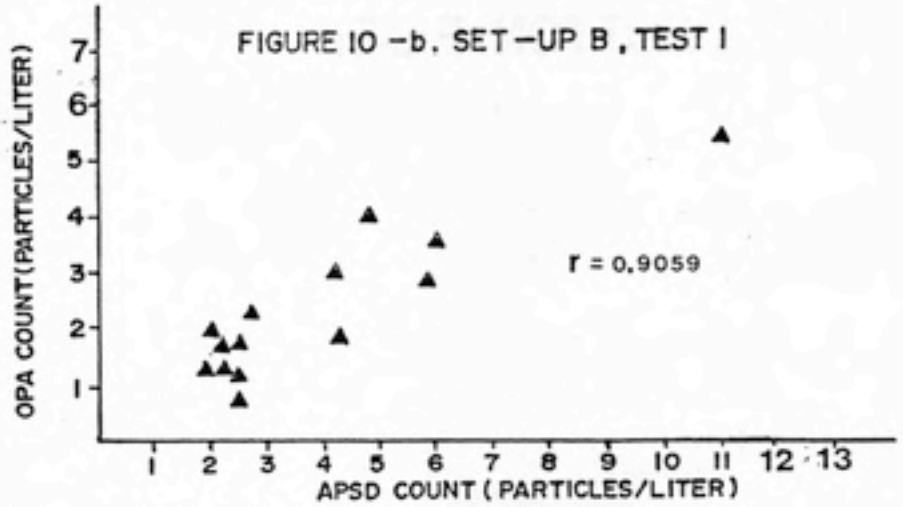


FIGURE 10 -c. SET-UP C, TEST I

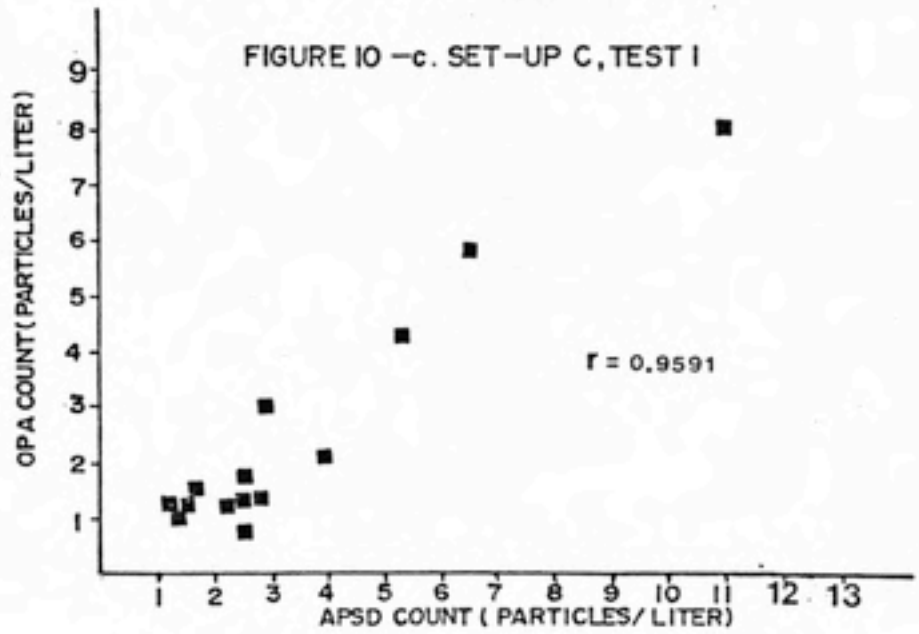


FIGURE 10 a-c. CORRELATION BETWEEN APSD AND OPA LYCOPODIUM SPORE COUNTS PER LITER AT 0.5 GMS. CONCENTRATION.

size, a baseline particle count was determined by counting the number of particles in the solvent, before the addition of the PSL. As in the lycopodium spores, the mean difference between the APSD and OPA PSL counts per liter was determined for each trial, and tested for statistical significance by using the paired t-test.

Table 4 shows the results of the APSD and OPA counts under different conditions. Among the important observations that can be made from the table are as follows:

a. For the APSD, there is no significant difference between the mean number of particles counted per liter at baseline (i.e., for solvent only) and the mean number counted after the addition of PSL. In contrast, the mean number of particles in the solvent detected by the OPA is nil compared to the derived means after the addition of PSL.

b. There is very little variation in the mean number of PSL spheres detected per liter by the APSD, between the different concentration levels. In the case of OPA however, the mean number of PSL spheres counted per liter varies greatly and consistently increases as one changes the concentration from the most dilute (Conc. 1) to the most concentrated (Conc. 5). For example, for PSL spheres with a diameter of 0.357 um, the mean count per liter increased from 236,924.9 particles per liter for concentration 1 to 419,117.2 particles per liter for concentration 5.

Table 4. Selected Statistics for APSD and OPA Counts of Polystyrene Latex Spheres at Different Concentrations and Diameters.

Diameter/ Concentration	Sample Size (n)	APSD $\bar{X}$ (per liter)	APSD Standard Deviation (s)	APSD C.V. (in %)	OPA $\bar{X}$ (per liter)	OPA Standard Deviation (s)	OPA C.V. (in %)	Mean Difference ($\bar{d}$)	t value
0.357 um[1]									
Solvent Only	5	37.4	0.3	0.8	93.4	8.6	9.2	-56.0	-15.1[3]
Conc. 1	10	39.5	1.8	4.6	236,924.9	6,358.9	2.7	-23,885.3	-118.5[3]
Conc. 2	10	39.0	2.0	5.1	317,199.2	1,870.9	0.6	-317,159.2	-536.0[3]
Conc. 3	10	38.3	1.0	2.6	368,947.7	1,605.1	0.4	-365,230.8	-100.6[3]
Conc. 4	10	34.4	1.5	4.4	396,579.1	3,639.0	0.9	-396,544.7	-344.6[3]
Conc. 5	10	34.4	1.4	4.1	419,117.2	2,434.5	0.6	-415,704.1	-111.3[3]
0.6 um[1]									
Solvent Only	5	37.4	0.3	0.8	14.7	1.5	10.2	22.7	31.3[3]
Conc. 1	10	36.4	1.4	3.8	43,997.2	1,008.0	2.3	-43,960.7	-138.0[3]
Conc. 2	10	37.0	1.1	3.0	76,926.8	1,058.7	1.4	-76,889.8	-229.7[3]
Conc. 3	10	37.4	1.0	2.7	99,245.3	1,238.9	1.2	-99,208.0	-253.3[3]
Conc. 4	10	37.4	1.5	4.0	116,268.8	670.8	0.6	-116,231.4	-547.3[3]
Conc. 5	9	37.3	1.1	2.9	131,468.1	1,511.0	1.1	-131,430.9	-275.0[3]

[1] Conc. 1 = 1 ml. initial concentration + 9 ml. solvent
Conc. 2 = 2 ml. initial concentration + 8 ml. solvent
Conc. 3 = 3 ml. initial concentration + 7 ml. solvent
Conc. 4 = 4 ml. initial concentration + 6 ml. solvent
Conc. 5 = 5 ml. initial concentration + 5 ml. solvent

[3] Significant at = .001.

Table 4 (Continuation)

Diameter Concentration	Sample Size (n)	APSD $\bar{X}$ (per liter)	APSD Standard Deviation (s)	APSD C.V. (in %)	OPA $\bar{X}$ (per liter)	OPA Standard Deviation (s)	OPA C.V. (in %)	Mean Difference ($\bar{d}$)[1]	t value
1.10 um^2									
Solvent Only	5	40.7	1.2	2.9	1.4	0.3	21.4	39.3	80.6[3]
Conc. 1	10	41.3	1.4	3.4	612.2	37.1	6.1	-570.9	-49.1[3]
Conc. 2	10	41.7	1.6	3.8	1,087.4	35.6	3.3	-1,045.7	-93.4[3]
Conc. 3	10	40.4	1.6	4.0	1,768.4	42.9	2.4	-1,727.9	-127.8[3]
Conc. 4	10	41.8	1.2	2.9	2,060.4	63.2	3.1	-2,018.6	-101.5[3]
Conc. 5	10	41.8	1.4	3.3	2,827.0	84.5	3.0	-2,785.2	-103.9[3]
2.02 um^2									
Solvent Only	5	40.7	1.1	2.7	1.4	0.3	21.4	39.3	80.7[3]
Conc. 1	10	42.0	2.0	4.8	276.8	15.5	5.6	-234.8	-49.3[3]
Conc. 2	10	42.8	1.6	3.7	546.5	16.2	3.0	-503.8	-101.3[3]
Conc. 3	10	43.5	1.4	3.2	780.7	39.3	5.0	-737.2	-58.7[3]
Conc. 4	10	43.1	1.4	3.2	1,120.2	32.6	2.9	-1,077.2	-106.9[3]
Conc. 5	10	41.8	1.2	2.9	1,282.6	51.1	4.0	-1,240.7	-76.5[3]

[2] Conc. 1 = 2 drops initial concentration + 10 ml. solvent
Conc. 2 = 4 drops initial concentration + 10 ml. solvent
Conc. 3 = 6 drops initial concentration + 10 ml. solvent
Conc. 4 = 8 drops initial concentration + 10 ml. solvent
Conc. 5 = 10 drops initial concentration + 10 ml. solvent

[3] Significant at = .001.

c. There is a tremendous difference in the number of particles counted by the APSD and the OPA. In addition, the smaller the diameter of the PSl, the larger the difference in the counts between the two machines.

The above findings seems to lend empirical evidence to some observations made that the APSD is not a sensitive counting device for detecting small particles. In fact, the above results seem to indicate that the counts registered by the APSD do not reflect PSL counts at all but probably some other phenomenon already present even when it was just counting particles for the solvent only. The results of the correlation analysis, which are shown in Table 5, further support this finding. From the table, one can immediately observe the absence of a consistent pattern with respect to the direction and strength of the relationship between APSD and OPA counts of PSL spheres. While in the case of lycopodium spores the computed correlation coefficients between the APSD and OPA particle counts were all positive with values of at least 0.7046, in the case of PSL spheres the absolute values of r ranged from 0.0615 to 0.7134, about half of which were negative implying an inverse relationship, and none of which turned out to be statistically significant. These findings imply that, using the set-up used in this study, the APSD cannot be used as a counting device for PSL spheres both in the quantitative (i.e., determining actual numbers) or in the qualitative

Table 5. Pearson's Correlation Coefficient (r) and Corresponding t-Values Between APSD and OPA Counts for Polystyrene Latex Spheres at Different Concentrations and Diameters.

Particle Size/ Concentration	Sample Size (n)	Pearson's r	t Value
0.357 um			
Conc. 1	10	-0.7134	-2.88
Conc. 2	10	-0.0615	-0.17
Conc. 3	10	-0.2794	-0.82
Conc. 4	10	-0.0910	-0.26
Conc. 5	10	-0.1100	-0.31
0.600 um			
Conc. 1	10	0.4653	1.49
Conc. 2	10	0.1530	0.44
Conc. 3	10	0.4375	1.38
Conc. 4	10	-0.5411	-1.82
Conc. 5	9	-0.3470	-0.98
1.10 um			
Conc. 1	10	0.2722	0.80
Conc. 2	10	0.1579	0.45
Conc. 3	10	0.1429	0.41
Conc. 4	10	0.2418	0.70
Conc. 5	10	-0.2074	-0.60
2.02 um			
Conc. 1	10	0.2835	0.84
Conc. 2	10	0.3162	0.94
Conc. 3	10	-0.2825	-0.83
Conc. 4	10	0.5624	1.92
Conc. 5	10	-0.1593	-0.46

(i.e., as a rough indicator of whether the levels are high or low) sense.

Since the counts registered by the APSD seem not to be affected at all by the amount of PSL particles in the chamber, an important point to consider is what they actually represent. Although the analysis of the set-up vis-a-vis the counts produced was no longer part of the scope of this study, observations made on the machines during the study tend to suggest the hypothesis that the use of the Y-attachment to join the inlets of the tubings of the APSD and the OPA may have affected the air flow entering the acoustical element capillary and eventually the resulting counts. It is possible that a different set-up may have elicited different results.

3.2 APSD Versus CNC

In addition to PSl spheres, the study tried to evaluate the comparative performance of the APSD as a counting device for more minute particles like that of cigarette smoke magnesium smoke, and acid-base test. As mentioned in the earlier sections, the Gardner Condensation Nuclei Counter (CNC) was used as the reference machine for this purpose since it is more appropriate than the OPA in counting very fine particles at high concentration levels.

3.2.1 Cigarette Smoke

The results for the 5 trials done on cigarette smoke are shown in Table 6. At baseline, before the introduction of

Table 6. Selected Statistics for APSD and CNC Counts of Cigarette Smoke and Magnesium Smoke Particles

Type of Particle/ Test No.	Sample Size (n)	APSD				CNC				Mean Difference ($\bar{d}$)
		Baseline: Count/liter[1]	$\bar{X}$ (per liter)	Standard Deviation (s)	C.V. (in %)	Baseline Count/liter[1]	$\bar{X}$ per liter	Standard Deviation (s)	C.V. (in %)	
Cigarette Smoke										
Test 1	30	0.04	0.65	1.00	153.8	3.7×10^6	2.6×10^9	2.7×10^9	103.8	-2.6×10^9
Test 2	30	0.06	0.60	1.10	183.3	3.4×10^6	2.1×10^9	2.6×10^9	123.8	-2.1×10^9
Test 3	30	0.13	0.23	0.39	169.6	4.1×10^6	2.1×10^9	2.7×10^9	128.6	-2.1×10^9
Test 4	30	0.09	0.44	0.98	222.7	3.8×10^6	2.6×10^9	2.8x109	107.7	-2.6×10^9
Test 5	30	0.04	0.81	1.76	217.3	3.8×10^6	1.7×10^9	2.3×10^9	135.3	-1.7×10^9
Magnesium Smoke										
Test 1	30	0.10	1.03	4.9	475.7	8.2×10^6	2.5×10^9	1.3×10^9	52.0	-2.5×10^9
Test 2	30	0.06	2.02	8.3	410.9	8.2×10^6	6.2×10^7	1.9×10^8	306.4	-6.2×10^7
Test 3	30	0.10	0.51	1.7	333.3	5.0×10^6	1.0×10^7	2.5×10^7	250.0	-1.0×10^7
Test 4	30	0.04	0.75	3.0	394.7	5.0×10^6	2.0×10^7	4.0×10^7	200.0	-2.0×10^7
Test 5	30	0.10	0.49	2.4	489.8	6.0×10^6	2.5×10^8	1.3×10^9	520.0	-2.5×10^8

[1] Baseline count refers to the initial count registered by the machines before the introduction of the particles. Indicated figures reflect the mean of the readings of four one-minute runs.

cigarette smoke, the APSD detected practically no particles at all in the air while the CNC detected 3 to 4 million particles. After the introduction of cigarette smoke, the CNC counts tremendously increased to at least 1.7 billion particles per liter. The APSD counts on the other hand were slightly higher than that at baseline, but the means were still less than 1 particle per liter. Since the difference in the mean particle counts between the two machines were so large, the paired t-test was no longer done. Obviously, the APSD was not able to detect at all the cigarette smoke particles.

The correlation analysis done on the data showed at most only a moderate relationship between the APSD and CNC counts. Although 4 out of the 5 runs had r values which turned out to be statistically significant, the maximum value attained was only 0.596. These are shown in Table 7.

3.2.2 Magnesium Smoke

The results for magnesium smoke particles are similar to those of cigarette smoke. At baseline, the APSD practically did not detect any particles in the air. After the introduction of magnesium smoke, the mean values were larger than that at baseline although the maximum mean number of particles detected was only 2.02 per liter. On the other hand, the CNC had a mean count of at least 5 million particles per liter at baseline. This increased to at most 2.5 billion particles after the introduction of magnesium smoke. The results are in the second portion of Table 6.

Table 7. Pearson's Correlation Coefficient (r) and Corresponding t-Values Between APSD and CNC Counts for Different Types of Particles.

Type of Particle/ Test No.	Sample Size (n)	Pearson's r	t Value
Cigarette Smoke			
Test 1	30	0.506	3.10*
Test 2	30	0.596	3.93*
Test 3	30	0.182	0.98
Test 4	30	0.547	3.46*
Test 5	30	0.475	2.86*
Magnesium Smoke			
Test 1	30	0.999	118.23*
Test 2	30	0.938	14.31*
Test 3	30	0.778	6.55*
Test 4	30	0.325	1.82
Test 5	30	0.999	118.23*
Acid-Base Test (Set-Up A)			
Test 1	27	0.906	10.70*
Test 2	30	0.253	1.38
Test 3	30	0.960	18.14*
Acid-Base Test (Set-Up B)			
Test 1	30	0.699	5.17*
Test 2	30	0.981	26.76*
Test 3	30	0.958	17.68*

* Highly significant, $p < .001$.

When the counts of the two machines were correlated with each other, correlation coefficients of at least 0.94 were derived in three out of the five trials done, implying a very strong positive linear relationship between the APSD and CNC counts of magnesium smoke particles. This means that although there was a very large difference in the actual magnitudes of their counts, when the CNC count was high, the APSD count also tended to be high; when the CNC was low, the APSD count also tended to be low. Hence the APSD can be used to detect the presence of magnesium smoke particles only from the qualitative viewpoint (i.e., high versus low) through comparison with counts made at other time points.

3.2.3 Acid-Base Reaction

Two set-ups were used to test performance of the APSD as a counting device for particles from the reaction of sodium hydroxide (NaOH) pellets and nitric acid (HNO_3). For each set-up, three trials or tests were done for 30 minutes each, resulting in 30 readings per trial. The results are shown in Table 8.

The patterns exhibited in the case of cigarette and magnesium smoke particles also apply to particles from the acid-base reaction. While the mean count per liter of the CNC was at least 4 million particles, the most that the APSD was able to detect was a mean of 7.46 particles per liter, which was derived during the first trial of Set-Up A. It was also observed that the mean particle counts under set-up

Table 8. Selected Statistics for APSD and CNC Counts of Particles from the Acid-Base Reaction Using Two Different Set-Ups.

Type of Set-Up/ Test No.	Sample Size (n)	APSD Baseline: Count/liter[1]	APSD $\bar{X}$ (per liter)	APSD Standard Deviation (s)	APSD C.V. (in %)	CNC Baseline Count/liter[1]	CNC $\bar{X}$ per liter	CNC Standard Deviation (s)	CNC C.V. (in %)	Mean Difference ($\bar{d}$)
Set-Up A (Beaker)										
Test 1	27	0.46	7.46	21.5	288.2	6.0×10^6	5.9×10^7	2.6×10^8	440.7	-5.9×10^7
Test 2	30	0.62	5.78	24.4	422.1	6.0×10^6	9.4×10^6	1.1×10^7	117.0	-9.4×10^6
Test 3	30	0.60	5.01	16.7	333.3	5.5×10^6	7.9×10^6	6.6×10^6	83.5	-7.9×10^6
Set-Up B (Graduated Cylinder)										
Test 1	30	0.31	0.70	2.5	357.1	3.4×10^6	5.2×10^6	3.0×10^6	57.7	-5.2×10^6
Test 2	30	0.34	0.73	1.6	219.2	4.1×10^6	5.5×10^6	7.0×10^6	127.3	-5.5×10^6
Test 3	30	0.78	0.73	1.5	205.5	3.4×10^6	4.2×10^6	3.1×10^6	73.8	-4.2×10^6

[1] Baseline count refers to the initial count registered by the machines before the introduction of the particles. Indicated figures reflect the mean of the readings of four one-minute runs.

A was at least 7 times higher than the means under set-up B. This was an expected finding however which resulted from the difference in the shape and the size of the mouth of the beaker and the graduated cylinder.

The correlation analysis between the APSD and CNC particle counts showed that of the six trials done for both set-ups, four had a correlation coefficient, r, of at least 0.91 while another trial had an r value of 0.69. All of these were highly significant ($p < .001$). Therefore, as in the case of magnesium smoke particles, the APSD can be used as a crude detector of particles from an acid-base reaction only in the qualitative sense.

4. SUMMARY OF RESULTS AND RECOMMENDATIONS

The best way to summarize the results of this study is to go back to its specific objectives and enumerate the pertinent findings under each of them. These are presented in tabular form below.

Table 9. Specific Objectives of the Study with Corresponding Findings.

	Specific Objective	Result
1.	To compare the particle counts of the APSD with that of the OPA for polystyrene latex spheres of different diameters (0.357 um, 0.60 um, 1.10 um and 2.02 um).	The mean OPA particle counts per liter were significantly higher than the corresponding APSD counts. The smaller the diameter, the larger the mean difference in the counts, with the differences ranging from 235 particles per liter (2.02 um, Conc. 1) to 415,704 particles per liter (0.357 um, Conc. 5).
2.	To compare the particle counts of the APSD with that of the OPA for polystyrene latex spheres of different concentration levels.	There was very little variation in the mean number of PSL spheres detected per liter by the APSD, between the different concentration levels. In the case of the OPA however, the mean number of PSL spheres counts per liter varied greatly and consistently increased, as the concentration level was changed from the most dilute to the most concentrated.

Table 9. (Continuation)

	Specific Objective	Result
3.	To compare the particle counts of the APSD with the CNC for particles from the following: cigarette smoke, magnesium strip fume, acid-base reaction.	The mean particle counts between the two machines differed at least by millions of particles, with the APSD mean counts per liter ranging only from 0.23 particles (cigarette smoke) to 7.46 particles (acid-base, set-up A). In the case of particles from magnesium smoke and acid-base reaction however, there was a very strong positive linear correlation between APSD and CNC counts.
4.	To compare the performance of the APSD as a counting device for small particles with diameters below 5 um with its performance when counting lycopodium spores which have diameters of 28 um.	The APSD cannot detect particles with diameters below 5 um, using the different set-ups used in this study. In the case of lycopodium spores, there was significant difference between the APSD and OPA counts. However, there is a very strong positive linear correlation between APSD and OPA counts. Care must be taken in interpreting and utilizing counts since the resulting figures are also set-up specific, even for larger particles.

This study is simply a scratch on the surface, in terms of exploring the full potentials of the APSD as a counting device for small particles. By providing empirical evidence on the comparative performance of the machine for different types of particles under different conditions, hopefully it

can be used as a basis for generating hypotheses which will stimulate further work. However, in the attempt to maximize the types of particles and variety of conditions covered within the time constraints of doing this study, crude measures of machine performance were resorted to like the simple comparison of the mean particle counts per liter. A second step towards this end would be to assess machine performance by using more sensitive indicators like the determination of its absolute sampling efficiency or its absolute detection efficiency for the different particles considered in this study. The data could also be analyzed considering the efficiency of the reference machines. Finally, the analysis of the results presented has been focused on the quantitative findings. A more complete picture can be presented if an in-depth analysis can be done on the qualitative aspects of the study such as relating the resulting counts to the different mechanisms and principles behind each set-up used.

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Table A1. Pearson's Correlation Coefficient (r) and corresponding t-values Between APSD and OPA Counts for Lycopodium Spores Under Different Set-Ups and Concentrations.

Concentration/ Test No	Set-Up A			Set-Up B			Set-Up C		
	Sample Size (n)	Pearson's r	t value	Sample Size (n)	Pearson's r	t Value	Sample Size (n)	Pearson's r	t Value
0.5 gram									
Test 1	12	0.9415	8.83*	14	0.9059	7.41*	14	0.9591	11.74*
Test 2	12	0.8439	4.97*	14	0.7046	3.72*	14	0.9716	14.22*
Test 3	12	0.9473	9.35*	14	0.8138	4.85*	14	0.9601	11.89*
1.0 gram									
Test 1	14	0.9445	9.96*	-	-	-	14	0.9878	21.97*
Test 2	14	0.9661	12.96*	-	-	-	14	0.9814	17.71*
Test 3	14	0.9389	9.45*	-	-	-	14	0.9663	13.00*
1.5 grams									
Test 1	14	0.9662	12.98*	14	0.9204	8.16*	14	0.9837	18.95*
Test 2	14	0.9849	19.71*	14	0.9605	11.96*	14	0.9355	9.17*
Test 3	14	0.9656	12.86*	14	0.9188	8.06*	14	0.9551	11.17*
2.0 grams									
Test 1	-	-	-	-	-	-	14	0.9913	26.09*
Test 2	-	-	-	-	-	-	14	0.9841	19.19*
Test 3	-	-	-	-	-	-	14	0.9808	17.42*
2.5 grams									
Test 1	-	-	-	14	0.9422	9.74*	14	0.9619	12.19*
Test 2	-	-	-	14	0.9415	9.68*	14	0.9760	15.53*
Test 3	-	-	-	14	0.9698	13.77*	14	0.9784	16.40*

* Highly significant, $p < 0.05$.