MECHANICAL DIVISION

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ABSTRACT

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An apparatus designed to test aerosol filter efficiency at pressures equal to or less than atmospheric and at linear face velocities of 5 to 1000 ft/min is described. Aerosol collection efficiency studies were completed for IPC paper at 20,000 and 40,000 ft. Data developed in these studies indicate that in the impaction and diffusion regions collection efficiency increases with altitude for all linear face velocities less than 800 ft/min. A propeller-type flowmeter, calibrated to measure the volume of air moved by a blower in a balloon-borne system, was flown on five separate flights to obtain air flow data. These data are presented. Flowmeter air flow measurement data were approximately 10 per cent lower than telemetered data. The reason^{pe}(s) for this discrepancy are currently being studied. (auth)

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TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	ii
TABLE OF CONTENTS.	iii
LIST OF ILLUSTRATIONS.	iv
I. INTRODUCTION	1
II. DESCRIPTION OF TEST APPARATUS.	2
III. SYSTEM OPERATION	8
IV. FILTER EFFICIENCY.	12
A. Results at 20,000 and 40,000 Ft	12
B. Re-evaluation of IPC Filter Efficiency at Station Pressure	15
C. Future Filter Efficiency Test Program.	15
V. FILTRATION OF PARTICLES BY THE DIFFUSION MECHANISM . . .	17
VI. VOLUME MEASUREMENTS.	21
VII. REFERENCES	22

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Schematic Diagram of Low Pressure Filter Efficiency Testing Equipment	3
2	Vapornefrin Nebulizer	5
3	All-Glass Impingers	6
4	Filter Shield	10
5	IPC Filter Paper Collection Efficiency Versus Velocity for Various Sizes of Polystyrene Spheres at 20,000 ft Altitude.	13
6	IPC Filter Paper Collection Efficiency Versus Velocity for Various Sizes of Polystyrene Spheres at 40,000 ft Altitude.	14
7	IPC Filter Paper Collection Efficiency Versus Velocity for Various Sizes of Spherical Particles at Station Pressure.	16

I. INTRODUCTION

Since residual radioactive debris in the upper atmosphere may act as a reservoir for future fallout at the earth's surface, the size distribution and concentration of this aerial debris are of scientific interest. The purpose of the present study, sponsored by the Atomic Energy Commission, Division of Biology and Medicine under Contract AT(11-1)-401, has been to analyze our present sampling method; to study and develop more reliable sampling methods; and to effect cost savings where possible in equipment and operations without sacrificing reliability. This report covers the research and development work performed during the period 1 October 1957 through 31 January 1958. This report describes apparatus for testing aerosol filter efficiency, developed under this program, which is capable of functioning at pressures equal to or less than atmospheric and at linear face velocities of 5 to 1000 ft/minute. Filter efficiency tests for simulated altitudes of 20 thousand and 40 thousand feet are reported.

II. DESCRIPTION OF TEST APPARATUS

Although a survey of the scientific literature will disclose numerous experimental apparatus ^{1,2,3,4,5,6} for testing filter efficiency, none of the test methods are specifically designed to function at reduced pressures. The apparatus detailed herewith is rather unique in the sense that reasonably high velocities can be attained in a reduced atmosphere equivalent to 80,000 ft above sea level.

A schematic diagram of the filter testing apparatus is shown in Figure 1. The major system components are (a) an aerosol generating device, (b) a wind tunnel, (c) all-glass impingers for aerosol collection and (d) a high vacuum system. The air flow through the system is as follows: air enters the system through an aerosol filter, passes through a calibrated flowmeter and an aerosol generator, then expands through an orifice into a wind tunnel. Identical aerosol sampling devices are stationed on both sides of the filter under test. Adjustment of the vacuum systems permits total pressure within the system and the air flow through the aerosol samplers to be regulated with good accuracy.

Since it is necessary to avoid contamination of the particles produced by the generator with particles normally suspended in the atmosphere, the air entering the test system must be cleaned. Chemical Corps aerosol canister filters, backed up by Hollingsworth and Voss high efficiency filter papers, are used for this purpose. Pressure drop through these filters is very low and particulate collection is 99.9% efficient. The Brooks flowmeter, used to measure air flow rate to the aerosol generator and wind tunnel, was calibrated in our laboratories against a wet test meter and readings are accurate to within $\pm 2\%$ for the range of .003 to 1.5 ft³/min.

FIGURE 1
SCHEMATIC DIAGRAM OF LOW PRESSURE FILTER EFFICIENCY TESTING EQUIPMENT

The aerosol generator shown in Figure 2 is a Vapornefrin nebulizer modified to remove large droplets. The nebulizer reservoir holds about 10 ml of a dilute colloidal suspension of polystyrene spheres in particle-free water. Upon aerosolization, the water envelope surrounding each particle evaporates, leaving a homogeneous polystyrene aerosol which is used to test filter efficiency in the wind tunnel section of the test apparatus.

The wind tunnel is fabricated from 4-inch I.D. aluminum tubing and consists of two sections forty-eight inches long and has an aerosol inlet tube located 10 pipe diameters upstream of the filter test stand and an axially centered aerosol sampling tube located 4 inches upstream of the filter. The other section of the tunnel is 16 inches in length and has one axially centered aerosol collector tube located 4 inches behind the filter. Three pressure taps are used in this apparatus. One tap is connected to a Wallace and Tiernan microbarometer and measures absolute pressure in the wind tunnel. The other taps are connected to a differential manometer which measures pressure drop across the filter paper. Each end of the tunnel has an airtight cap. "O" rings are used to seal the filter test stand between the sections and to prevent air leakage during test.

All-glass impingers (see Figure 3) are attached to the collector tubes before and after the filter to collect samples of the dynamically generated aerosol. Particulates are collected in the all-glass impingers in a liquid plasticizer, TOF, product of Union Carbon and Carbide Company. TOF has a very low vapor pressure, approximately 1 micron at 25°C. Tests in our laboratories have shown that TOF has a low scattering background and very little if any particulate debris contamination.

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VAPORNEFRIN NEBULIZER

FIGURE 2

650 - 010

GLASS IMPINGERS
FIGURE 3

The vacuum system exhausts air from the wind tunnel to maintain the desired pressure and also provides air flow through the all-glass impingers. Two Cenco high vacuum pumps are used; one is connected directly to the exhaust of the wind tunnel and has a capacity of 150 liters/min; the other is connected to the all-glass impingers and has a capacity of 100 liters/min.

III. SYSTEM OPERATION

Ten milliliters of an aqueous suspension of uniformly sized polystyrene spheres are placed in the reservoir of the aerosol generator. The number concentration of this particulate suspension is determined by a turbidity measurement in the following manner. For small particles, the intensity of a transmitted beam of light of wavelength λ decreases exponentially with the number concentration according to the following expression:

$$I = I_0 e^{-Sn\ell}$$

where:

I = intensity of beam through the hydrosol

I_0 = intensity of beam through particle-free liquid

S = scattering area per particle

n = number concentration

ℓ = path length of the beam through the hydrosol

I_0 and I are readings obtained from the microphotometer, ℓ is a constant for the apparatus and S can be obtained from reference 7. Since the maximum diameter of the effluent water droplets from the aerosol generator is 2 to 3 microns, the polystyrene concentration can be controlled by a dilution process to reduce statistically the probability of more than one polystyrene particle being present in any one water droplet. If the ratio of particle number concentration with respect to the water droplet number concentration due to aerosolization is maintained at one to ten, statistically the chance of any two polystyrene spheres being present simultaneously in one water droplet becomes one to 100 and the effluent from the generator is essentially 99 per cent homogeneous for one particle size.

In practice the wind tunnel is first evacuated to the simulated altitude and then an aerosol is generated by admitting air into the nebulizer. Valves to the impingers are then opened and the inlet and outlet control valves are regulated so that the vacuum pumps can maintain a desired reduced pressure for test conditions. Tests are conducted for approximately 30-minute periods and the pressure drop across the filter under study is never permitted to increase beyond 1 per cent of the initial pressure drop.

To determine the linear face velocity at the filter, the orifici of the impingers must be calibrated to determine their volume rate of flow. Filter face velocities are calculated from the following equation:

$$V = \frac{Q_1 P_1}{P_2} - C_1$$

A

where:

V = linear face velocity

Q = air flow rate determined from inlet rotameter

P₁ = station pressure

P₂ = reduced pressure in tunnel

C₁ = air volume flow through one all-glass impinger

A = exposed filter area

Since the nebulizer and vacuum pumps have limited capacity, the filter test area is changed to obtain variations in linear face velocity. To reduce the exposed filter size, filter shields as shown in Figure 4 were designed.

FIGURE 4
FILTER SHIELD

A solid rubber gasket is cut to the size of the wind tunnel and serves as an air seal. A plastic ring of slightly smaller diameter serves as a back-up to the rubber gasket. The shields shown are made in matched pairs from a smooth phenolic board and have an opening of the desired cross sectional area. As shown in Figure 4, a matched pair of phenolic rings with a filter disk insert can be bolted to the rubber gasket and backing to provide a given filter cross section to the dynamic aerosol in the wind tunnel.

IV. FILTER EFFICIENCY

Filter efficiency was calculated from the output of a light-scattering photometer which measured right angle scattering from aliquots obtained from the all-glass impingers placed before and after the filter. Matched photometer cells were used and in all cases the background scattering intensity of the TOF was subtracted. Laboratory tests indicated that TOF did not react chemically or physically with polystyrene in the sense that the particle size of the polystyrene spheres did not change with time and the light-scattering output of test concentrations of polystyrene and TOF was invariant with time.

Filter efficiency was calculated from the following equation:

$$E = 1 - \frac{S_2 - S_B}{S_1 - S_B}$$

where:

E = efficiency

S₂ = scattering intensity of sample after filter

S₁ = scattering intensity of sample before filter

S_B = scattering intensity of clear collecting fluid

A. Results at 20,000 and 40,000 Ft

During the current report period, aerosol collection efficiency studies were completed for IPC paper at 20 thousand and 40 thousand feet for several dynamically generated homogeneous aerosols. These data have been summarized in Figures 5 and 6. At least three tests were conducted for every flow rate. Deviations between individual observations were of the order of a few per cent.

FIGURE 5

FIGURE 6

In general, these data indicate that in the impaction and diffusion regions, collection efficiency increases with altitude for all linear face velocities less than 800 ft/min. Between 800 to 1000 ft/min, very little change in collection efficiency is apparent, regardless of particle size. These data also illustrate very strikingly the transition from diffusion to true impaction with increase in linear face velocity.

B. Re-evaluation of IPC Filter Efficiency at Station Pressure

The aerosol collection efficiency for IPC paper at station pressure, detailed in our second quarterly progress report as a function of linear face velocity and particle size, contained several anomalies. Because of these apparent discrepancies, the filter paper has been re-evaluated. The correct data are now found in Figure 7. It will be noted that in both diffusion and impaction regions collection efficiency follows accepted theory.

C. Future Filter Efficiency Test Program

The next report period will detail the collection efficiency studies obtained with IPC paper at 60,000 and 83,000 ft. At these simulated altitudes considerable data will be reported for smaller homogeneous particles, 88 m μ and 45 m μ in diameter. Some data will also be reported in the diffusion range for particles 26 m μ in diameter.

V. FILTRATION OF PARTICLES BY THE DIFFUSION MECHANISM

General Mill's Report No. 1695, covering the period 1 January 1957 through 30 April 1957, contained a theoretical solution, based on statistical consideration, for the problem of collection efficiency of a fibrous mat in the diffusion regime. Although the theoretical equation thus derived appeared to be reasonably successful in predicting the experimental results for various velocities, particle sizes and pressures, careful examination has revealed an erroneous assumption which cannot be justified. The model chosen to simulate a fibrous filter was that of an assembly of channels. The probability of a particle hitting the wall of a channel during the time of passing through the filter was computed from the probability function:

$$p(s) = \frac{1}{\sigma \sqrt{2 \pi}} e^{-s^2 / 2 \sigma^2} \quad (1)$$

where:

$$\sigma = \sqrt{\frac{2 c \kappa T \delta}{3 \pi \eta d_p V}}$$

κ = Boltzmann's constant

c = Cunningham's slip correction

T = absolute temperature

δ = filter thickness

η = gas viscosity

d_p = particle diameter

V = gas velocity

The probability that a particle would move a distance s to the wall was computed as:

$$P = \int_s^{\infty} p(s) ds \quad (2)$$

Although in general (2) is the correct expression for the probability that a particle in Brownian motion will be found a distance greater than s from the starting point in the time τ , it is not strictly applicable to finding the probability that a particle will reach a boundary such as a wall. Equation (2) contains all possibilities including that in which the particle crosses the boundary and returns. This possibility is not permitted in the present problem since it is assumed that once the particle reaches the boundary it is removed or collected. Equation (2) would therefore considerably underestimate the probability of a particle being removed from the gas stream by diffusion. Thus, despite the success of the theoretical expression previously reported in predicting the results, it must be admitted that the theoretical basis for the relation is not well grounded.

Continuing the study of the collection efficiency of particulates in the diffusion region, another semi-empirical expression for the penetration of small particles through a fibrous mat composed of parallel circular channels has been developed and compared with experimental data. This expression has the functional relationship:

$$\ln \frac{C}{C_0} = -2 \left(\frac{2}{3} \frac{c k T}{\pi \eta d_p} \right)^{\frac{1}{2}} \frac{t^{\frac{1}{2}}}{r}$$

where:

- C = concentration of particulates downstream of the filter
- C_o = concentration of particulates upstream of the filter
- c = Cunningham's slip correction
- K = Boltzmann's constant
- T = absolute temperature
- η = gas viscosity
- d_p = particle diameter
- t = transit time through filter
- r = hydraulic radius of filter material

The hydraulic radius, r , of a fibrous mat may be calculated from the relationship:

$$r = \frac{(\rho_f - \rho_b) d_f}{4 \rho_b}$$

where:

- ρ_f = density of the filter fiber elements
- ρ_b = bulk density of the filter
- d_f = fiber diameter.

For IPC paper the following values have been determined experimentally:

$$\rho_f = 1.5 \text{ gms/cm}^3$$

$$\rho_b = 0.14 \text{ gms/cm}^3$$

$$d_f = 2 \times 10^{-3} \text{ cm}$$

$$\text{filter thickness} = 0.1 \text{ cm}$$

Hence $r = \frac{1}{325}$ and $t^{\frac{1}{2}} = 2.39 \times 10^{-1} \text{ sec}$ when the linear face velocity is 3.5 ft/min.

For a particle of 0.138 micron diameter, the following empirical values of collection efficiency have been compared with experiment for simulated altitudes of 20,000 and 40,000 ft and a linear face velocity of 3.5 ft/min.

<u>Height</u>	<u>Calculated Efficiency</u>	<u>Observed Efficiency</u>
Station Pressure	40%	47%
20,000 ft	47%	54%
40,000 ft	60%	63%

Further comparisons between calculated and observed efficiency will be made in the next report.

VI. VOLUME MEASUREMENTS

As reported in the previous progress report (General Mills Report No. 1695), a propeller-type flowmeter was calibrated to measure the volume of air moved by a blower in a balloon-borne system. The flowmeter was flown on five separate flights to obtain air flow data. Data obtained are presented below in Table I. With the exception of the first test flight, flowmeter air flow measurement data are approximately 10 per cent lower than telemetered data.

The reason(s) for the discrepancy in these data is not known as yet. A test performed on the complete balloon-borne system with flowmeter attached, however, indicated that possibly a calibration inaccuracy had been introduced as a result of the small size of the altitude chamber used for calibration.

TABLE I

<u>Flight No.</u>	<u>Altitude</u>	<u>Flowmeter</u>	<u>Telemetered</u>	<u>% Difference</u>
1	45,500	21,200	21,500	1.5
2	64,000	41,200	45,700	10
3	63,500	39,200	45,000	13
4	77,500	32,900	37,000	11
5	93,000	58,900	67,300	13

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