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LOVELACE FOUNDATION

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AEC RESEARCH AND
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Albuquerque, New Mexico

OPERATING CHARACTERISTICS OF THE LAUTERBACH AND DAUTREBANDE AEROSOL GENERATORS

by

T. T. MERCER, M. I. TILLERY
AND
M. A. FLORES

February, 1963

ATOMIC ENERGY COMMISSION-
LOVELACE FOUNDATION
FISSION PRODUCT INHALATION PROJECT

Printed in USA. Price $0.75. Available from the Office of Technical Services, Department of Commerce, Washington 25, D.C.

LF-6
Instruments
TID-4500(19th Ed.)

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Submitted as a
Technical Progress Report
to
The Division of Biology and Medicine
United States Atomic Energy Commission
on
Contract No. AT(29-2)-1013
February 1963

From the Section of Aerosol Physics
Lovelace Foundation for Medical Education and Research
Albuquerque, New Mexico

ABSTRACT

The operating characteristics of the Lauterbach and Dautrebande aerosol generators have been studied. The output, in terms of microliters of solution aerosolized per liter of air passing through the jet, was not appreciably affected by either the diameter of the jet orifice or the concentration of the solution. The output increased with increasing pressure drop, ΔP, across the jet orifice, approaching an asymptote apparently negligibly greater than the output at $\Delta P = 50$ psi. The median diameters of the particle size distributions were unaffected by either orifice diameter or jet pressure. They varied with solution concentration but to a lesser extent than had been expected. Mass median diameters, however, showed an effect of jet pressure as well as solution concentration.

The air flow through the jet, the effect of a pre-humidifier on the water vapor content of the jet air, the cooling effect of the jet air on the generator solution, and the amount of water vapor carried away by the jet air were also determined and the results are discussed.

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OPERATING CHARACTERISTICS OF THE LAUTERBACH AND DAUTREBANDE AEROSOL GENERATORS

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INTRODUCTION

The exposure of experimental animals to an aerosol of a water-soluble, toxic material requires a reliable device for producing the aerosol at a constant concentration and with a constant particle size distribution for the duration of the exposure. When radioactive substances of high specific activity are involved, it is also wise to keep at a minimum the quantity of active material required to produce the aerosol.

The aerosol generators described by Lauterbach et. al.[3] and by Dautrebande[1] frequently have been used in studies of inhalation toxicity. Various commercial nebulizers have been employed also, but to a lesser extent, probably because of the large particle sizes they produce. The present work was carried out as part of an experimental program designed to expose animals to aerosols of several radioactive fission products. It was desired to use at least three different particle size distributions having mass median diameters that varied by a factor of about five. In order to determine if this could be done with the generators mentioned above, a series of tests was carried out in an effort to establish the relationships between the parameters of the jet system and those of the aerosol produced. This report summarizes the results obtained.

DESCRIPTION OF THE JET SYSTEMS

In the Lauterbach generator, a jet of air emerging at high velocity from a small orifice is directed across the surface of the solution to be aerosolized. The quantity of air issuing from the orifice depends on its diameter and the pressure drop across it. The jet of air entrains a filament of solution, drawing it out to some unstable length at which it breaks up to form droplets of various sizes. Depending on the dimensions of the aerosolization chamber, large droplets are impacted on the chamber wall and returned to the original solution; smaller droplets are swept out of the chamber and provide the particles for the aerosol. At the same time, the air stream carries away water vapor, causing the solution in the generator to become progressively more concentrated, unless steps are taken to compensate for this effect.

In the Dautrebande generator [1], Type D-30*, the action is similar, although the physical arrangement is somewhat different. The air jet flows from a tube protruding from the center of the solution. A combination Venturi effect and capillary action draws solution over the jet and the formation of droplets proceeds as with the Lauterbach generator. In this case, however, the droplets not only may impact on the chamber walls, but they are subjected to a scrubbing action as they pass through small holes over which solution is constantly draining. The particles that are available for the aerosol are consequently quite small. The problem of concentrating the aerosol due to the evaporation of water from the solution is the same as with the Lauterbach generator.

To reduce the effect of evaporation, the jet air can be passed first through a bubbler to saturate it with water vapor. This does not eliminate the problem of concentration of the solution, of course, because the relative humidity of the jet air drops as the air expands upon leaving the orifice. The expansion of the jet air and the evaporation of water cause the solution to cool, which helps retard the water loss.

In the present work, the quantities of main interest were the amount of material aerosolized per unit volume of air passing through the jet, the particle-size distribution of the aerosol, and the effect of water evaporation on the concentration of the generator solution. Since it was anticipated that very high concentrations of radioactivity in the air would be required to carry out the proposed exposures, it appeared essential that the system operate with as small a volume of air as possible. In order to minimize problems associated with the handling of the generator,

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*We are indebted to Dr. Lautrebande for generously providing us with two of these generators with which to experiment.

it was obviously necessary to reduce the volume of active solution as much as feasible. Thus the efficiency with which the jet aerosolized solution was considered of great significance. The importance of particle size distribution followed from the requirements for providing aerosols of markedly different mass median diameters. Since both the concentration and particle size distribution of the aerosol were expected to vary with the concentration of the generator solution, the rate of evaporation of water from the solution was of importance.

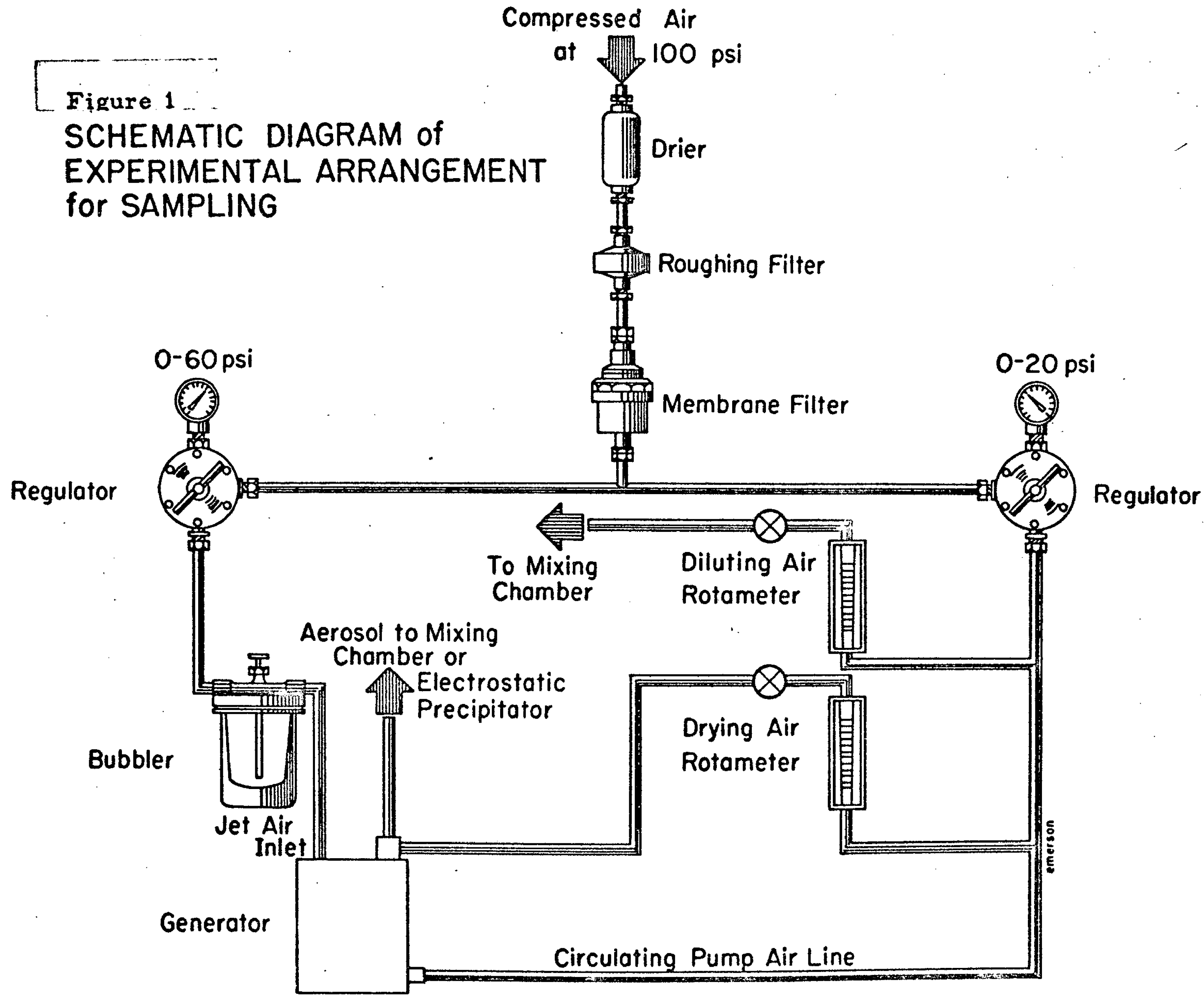
It was felt that a proper evaluation of the performance of the various jets would require a knowledge of the velocity of the jet as a function of pressure drop across the orifice; the effect of a pre-humidifier on the water vapor content of the jet air; the cooling effect of the jet air in the atomizer; and the amount of water vapor carried away by the jet air as a function of flow rate. In addition, of course, it would be necessary to determine the amount of aerosol produced and its particle size distribution as functions of orifice diameter, pressure drop across the orifice, and concentration of the solution being aerosolized. These things were determined for the Lauterbach and Dautrebande generators; the results are presented and discussed below immediately after a description of the experimental arrangement.

EXPERIMENTAL ARRANGEMENT

The experimental set-up is shown schematically in Fig. 1. Compressed air was dried and filtered through a membrane filter to remove all particulate material. The air was then passed through a bubbler and exhausted through the jet of the aerosol generator. The droplet-laden air was then mixed with clean, dry, diluting air and exhausted either into a 28-liter mixing chamber, or through an electrostatic precipitator which collected the total aerosol, or through an arrangement which made it possible to further dilute the air by a factor of ten before collecting samples for particle size analysis.

The initial work was carried out with a generator which in principle was the same as that described by Lauterbach et. al.[3] In detail, it was somewhat different, being constructed of lucite and having the jets set at an angle to the surface of the solution, in order to allow the aerosols to escape directly upwards. Details of its construction which are of concern

Figure 1
SCHEMATIC DIAGRAM of
EXPERIMENTAL ARRANGEMENT
for SAMPLING



in the aerosolization process are shown in Fig. 2. The Dautrebande generator is described in reference 1.

EXPERIMENTAL METHODS AND RESULTS

Air Flow Through the Jets. The jets used with the Lauterbach generator were made of stainless steel tubing either 1/4" or 1/8"* in diameter, closed at one end and having an orifice approximately 3/16" from that end. The orifice diameters, which varied between 0.0063" and 0.064", are indicated in Fig. 3. In the Dautrebande generator the orifice diameter was 0.043".

Clean, dry air was used in making the air flow measurements. The jets were exhausted into a dry test meter, the volume measurements being made at an ambient pressure of about 12.4 psi and at approximately 22°C. The pressure drop across the jet was measured with a mercury manometer up to about 18 psi. Above that, the gauge readings at the regulator were used, after correction for the pressure drop from the regulator to the jet as measured with a mercury manometer. The volume rates of flow were corrected to standard temperature and pressure and converted to apparent linear flow rates by dividing each by the cross-sectional area of the appropriate jet orifice. These apparent linear velocities are shown in Fig. 3 as functions of the ratio of the pressure drop, ΔP, across the jet orifice to the ambient pressure, P_a.

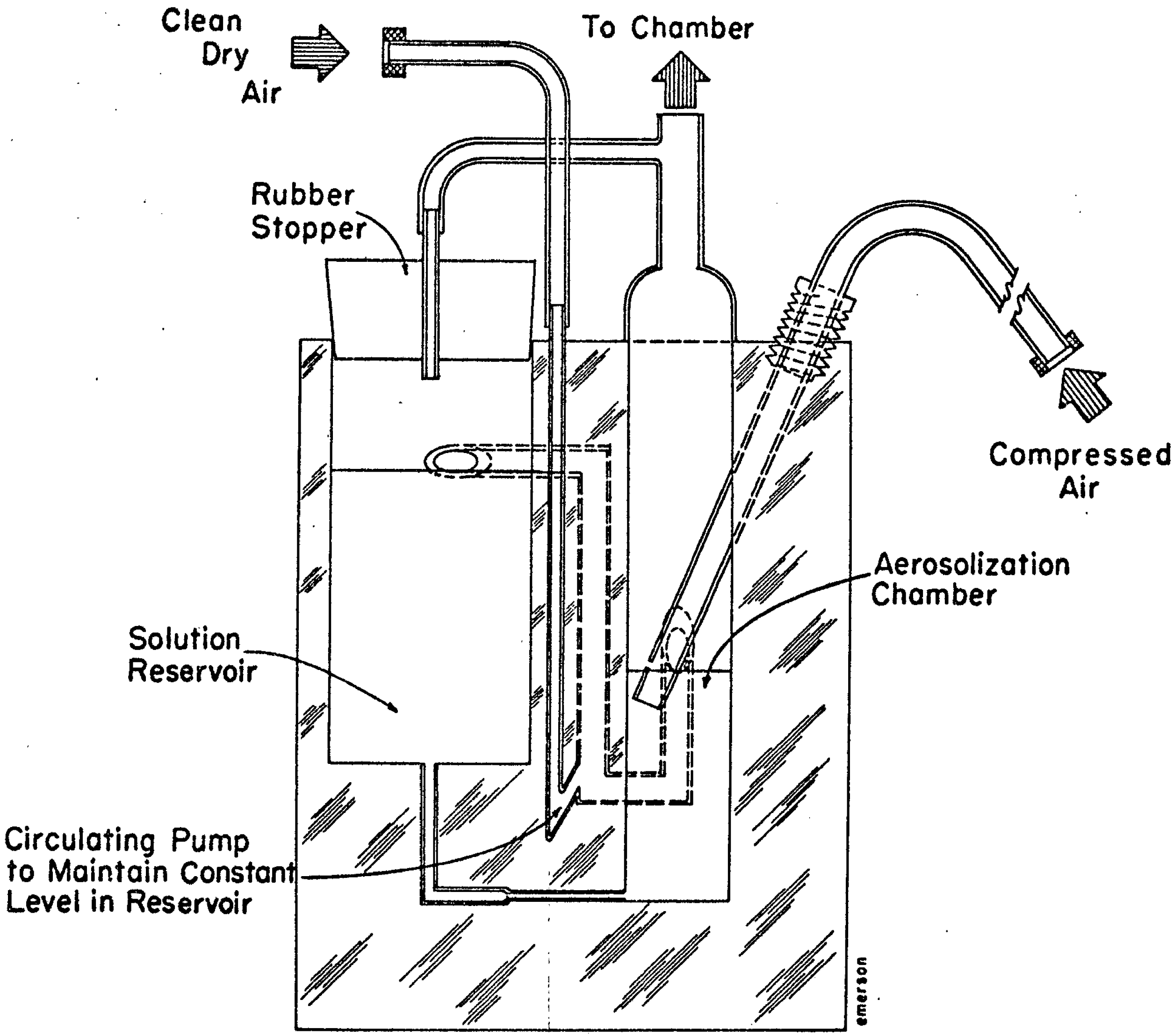
When a gas at temperature, T_1 °K, and pressure, P_1 psi, discharges through an orifice of area, a cm^2, into a region at a pressure $P_a \lesseqgtr \frac{1}{2} P_1$, the quantity of gas discharged per unit time is given by**

$$W = 26.4\, \alpha\, a \frac{P_1}{\sqrt{T_1}} \text{ gm/sec}$$

where α is a constant introduced to relate the true area of the orifice to its effective area. Taking $T_1 = 295°$ K, $P_1 = P_a + \Delta P$, and $P_a = 12.4$ psi, and expressing the discharge in terms of the volume flow rate, Q, of air

*A modified version of the generator in Fig. 2 was built which could operate with much smaller volumes of solution. It used the 1/8" jets and the air flows through these jets are included here.

**See reference 7, page 267.



CUTAWAY SCHEMATIC of a
MODIFIED LAUTERBACH TYPE
AEROSOL GENERATOR

Figure 2

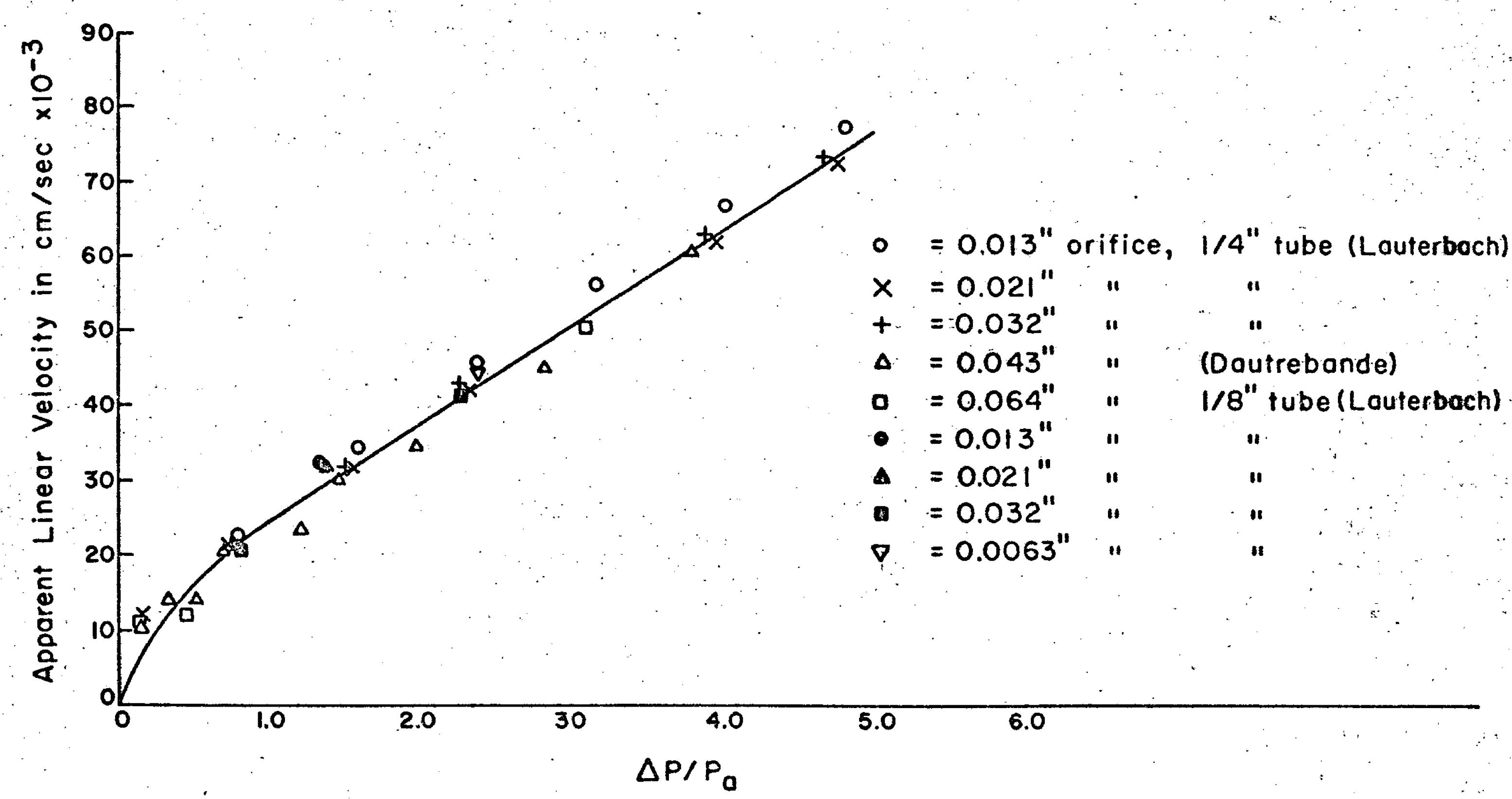


Fig.3 The Relationship Between Air Flow Through a Jet Orifice and the Pressure Drop Across It.

at standard temperature and pressure, the following equation is obtained for the apparent linear velocity

$$Q/a = 1.49 \times 10^4 \, \alpha \, (1 + \frac{\Delta P}{P_a}) \text{ cm/sec.}$$

For $P_a > \frac{1}{2} P_1$, Q/a is no longer linearly related to ΔP, but becomes proportional to $\sqrt{\Delta P}$.

The experimental results shown in Fig. 3 yield a straight line segment for which

$$Q/a = 1.32 \times 10^4 \, (1 + \frac{\Delta P}{P_a}) \text{ cm/sec}$$

suggesting a value of 0.89 for α, which is quite reasonable if this constant is interpreted as a coefficient of contraction. For $P_a > \frac{1}{2} P_1$, the curve deviates from the straight line in the expected manner.

Cooling Effect of the Aspiration Process. Since it was intended to study the degree of saturation of the jet air during the aspiration process, the cooling effect of this process on the temperature of the solution was first determined. This was done by using dry air to generate an aerosol and measuring the temperature of the solution after it had come to equilibrium. The results are shown in Fig. 4 for the Lauterbach generator using three different jet sizes, and for the Dautrebande generator. The differences between the two generators in this respect are probably due to differences in geometry and solution volume.

Water Loss as a Function of Flow Rate. The water vapor content of the jet air was determined by connecting to the outlet of the generator a glass wool filter followed by a calcium chloride drying train. The glass wool filter removed the aerosol from the air stream. The drying train consisted of two similar tubes, filled with identical amounts of calcium chloride, arranged in series. It was assumed that for a given run each tube collected the same fraction, f, of the water vapor entering it. If ΔW_1, and ΔW_2 are the weight increases of the first and second tubes respectively after the collection of water vapor from a known volume of air containing a total of W grams of water vapor, then

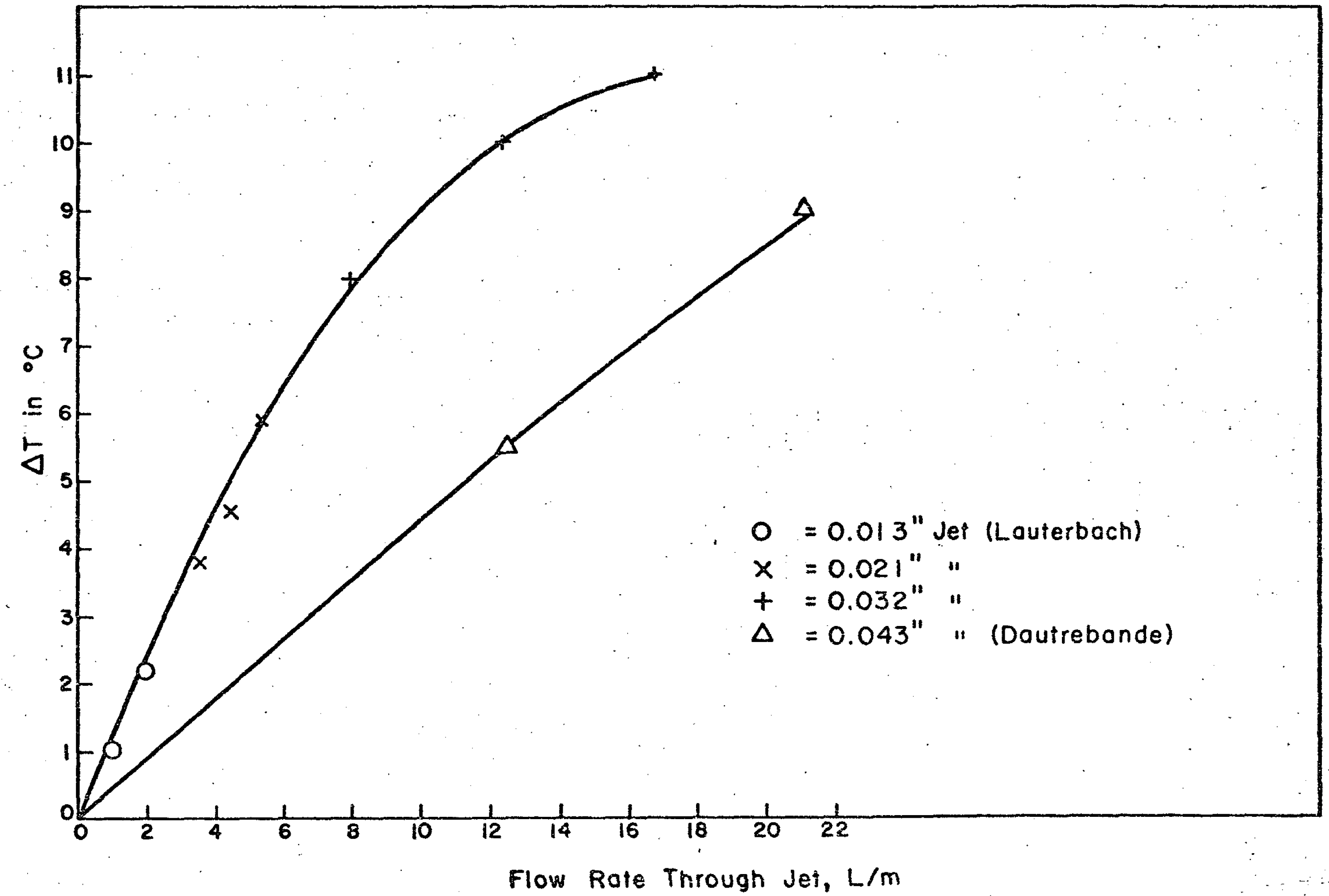


Fig. 4 The Depression of the Temperature of the Generator Solution as a Function of Volumetric Air Flow Through the Jet.

$$\Delta W_1 = fW$$

$$\Delta W_2 = fW\ (1-f)$$

From these equations, $f = 1 - \frac{\Delta W_2}{\Delta W_1}$, and $W = \frac{\Delta W_1}{f}$.

The volume of air in which W was contained was determined by passing the air from the drying train through a dry test meter. The mass of water vapor per liter of air could then be determined. The pressure in the aerosolization chamber was actually greater than ambient, due to the presence of the filter and drying train. This pressure difference was determined as a function of volume flow rate using a mercury manometer. The water vapor content of the air was then corrected to the pressure of the aerosolization chamber, with the results shown in Fig. 5. The solid line represents the values for saturated air at the equilibrium temperature for the flow rates given. At the higher flow rates, the deviations of the points from the expected values are probably due to the relatively short sampling times which had to be used. Thus the solution was not at temperature equilibrium for a good deal of the sampling period. Similar results were obtained with the Dautrebande generator.

On the basis of these results, it was concluded that the jet air becomes saturated at the temperature of the generator solution.

Effect of Bubbler on Jet Air. The problem of progressive concentration of the solution being aspirated can be relieved to some extent by humidifying the jet air before it reaches the aspirator. This is done by the inclusion of a bubbler in the compressed air line. The degree of humidification of the jet air was determined at three different pressures for one jet. The jet air was exhausted through a filter-drying train-dry test meter arrangement and its water vapor content determined in a manner similar to that above. The results are shown in the following table:

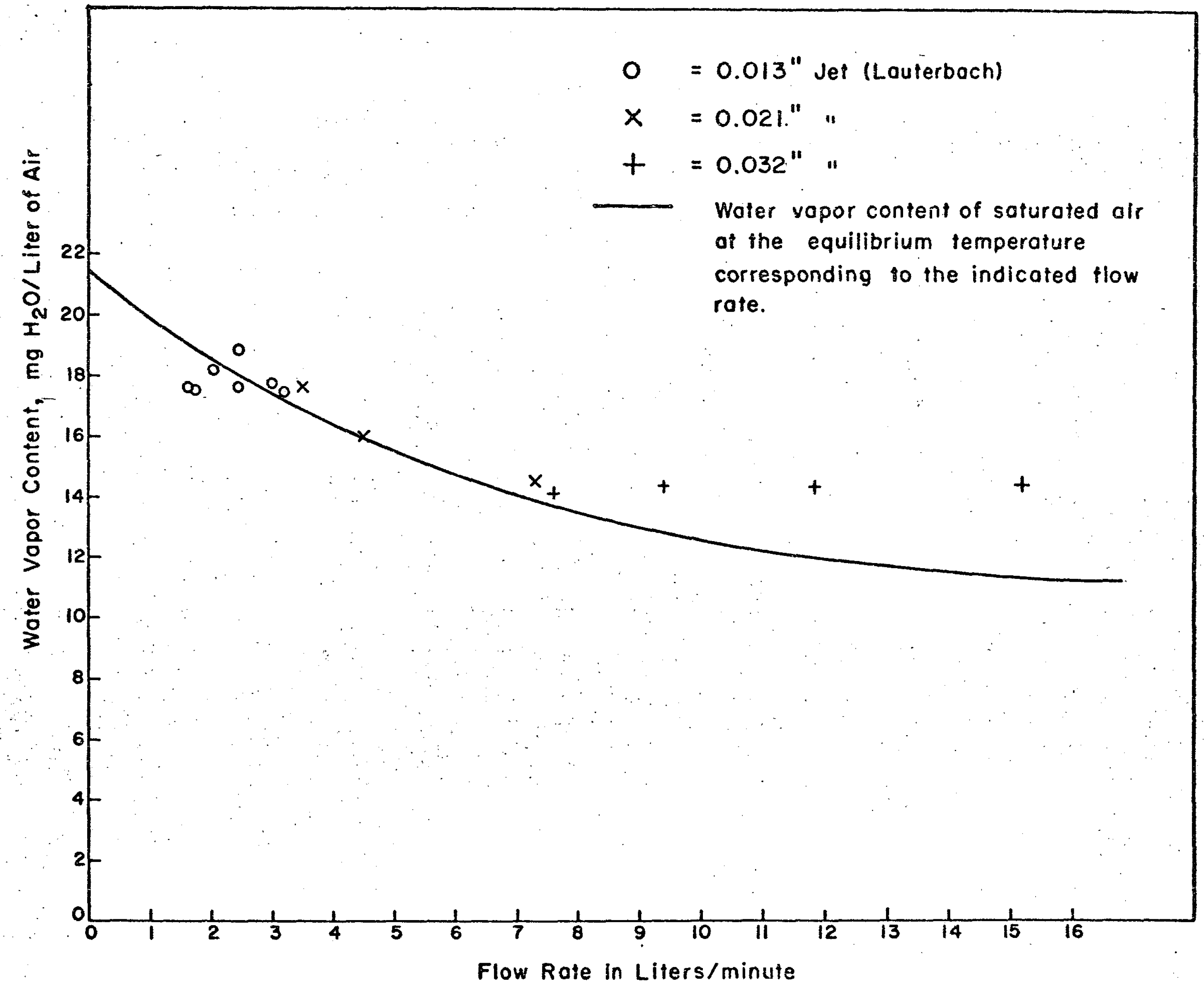


Fig.5 Water Vapor Content of Jet Air as a Function of Volumetric Flow Rate of Air Through the Jet.

TABLE 1. Humidification of Jet Air by Means of a Bubbler

Gauge Pressure, ΔP, at bubbler, psi	Flow rate* in liters/min	Water vapor** content of air, mgm/liter	Equivalent saturation temperature
30	15.3	18.8	21.6° C
20	11.5	18.3	21.3°
10	7.2	19.1	21.9°

*Flow rate measured at ambient pressure, P_a = 12.4 psi.

**Total air volume corrected to bubbler pressure by factor $\frac{P_a}{P_a + \Delta P}$.

The bubbler was at room temperature, 22-23° C, at the start of a run, and dropped to 19° C at the end of a run. From this it was concluded that air passing through the bubbler was saturated at the temperature of the bubbler. Other jets, for which the volume flow rates at these pressures was less than for the jet used, could be expected to show a similiar degree of humidification.

Aerosol Outputs of the Various Jets. Initially, the aerosol output was passed through a baffle, consisting of a short length of glass tubing with several constrictions in it, and into a 28-liter mixing chamber, where it was mixed with dry air entering at approximately 20 liters per minute. The baffle was intended only to take out very large drops of solution. After mixing, air samples were taken from the chamber using membrane filters and the amount of aerosol collected was determined from the increase in the filter weight. The concentration of aerosol in the chamber was calculated and corrected for the effect of diluting air to give the output of solute per liter of jet air. Sodium chloride solutions of different strengths were used. On the basis of the salt concentration in the generator solution, the jet output could be expressed in terms of microliters of solution aerosolized per liter of jet air. This was done for each of three jets at several different jet pressures and the results are shown in Fig. 6, in which the output is expressed as a fraction of the average output at 50 psi. These results clearly show that the volume of solution aerosolized per liter of jet air is not significantly affected by the size of the orifice in the range of sizes used here.

Under these conditions, some anomalies with respect to particle size

Fig. 6

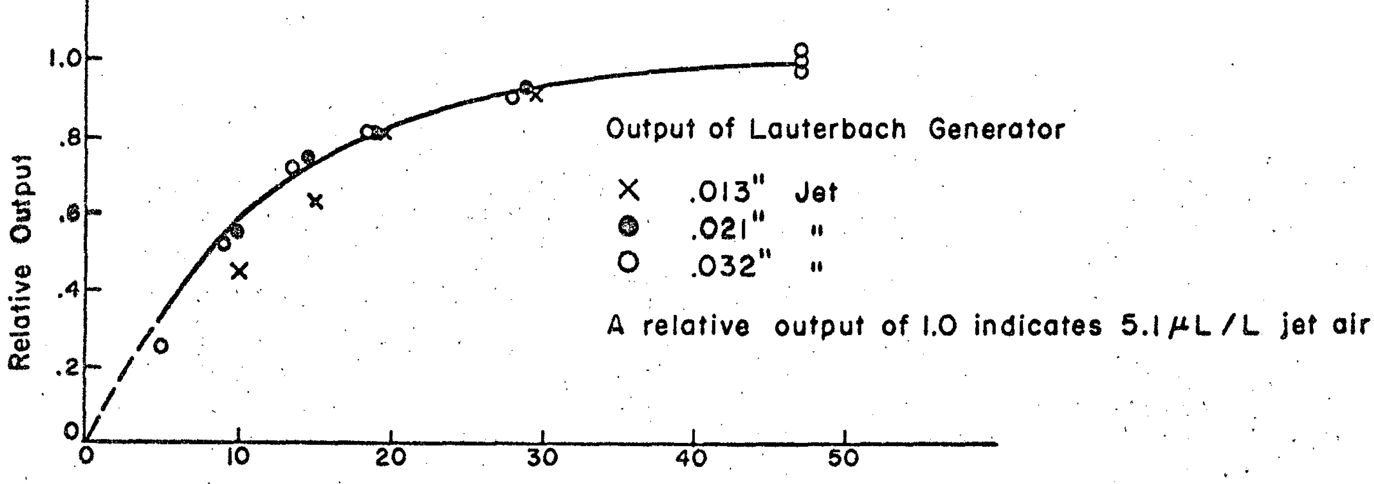


Fig. 7

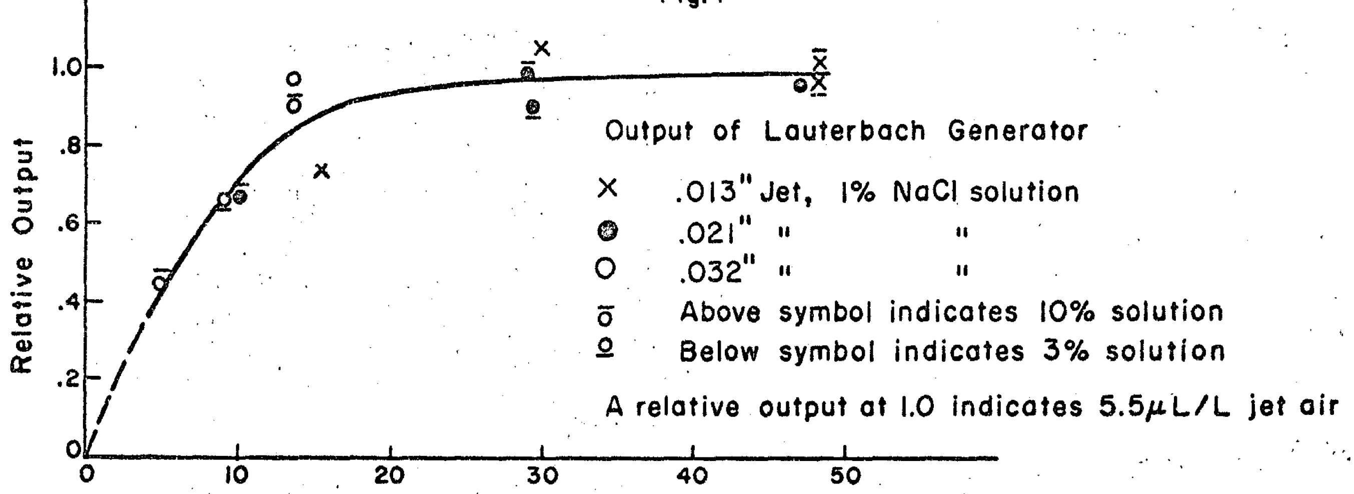


Fig. 8

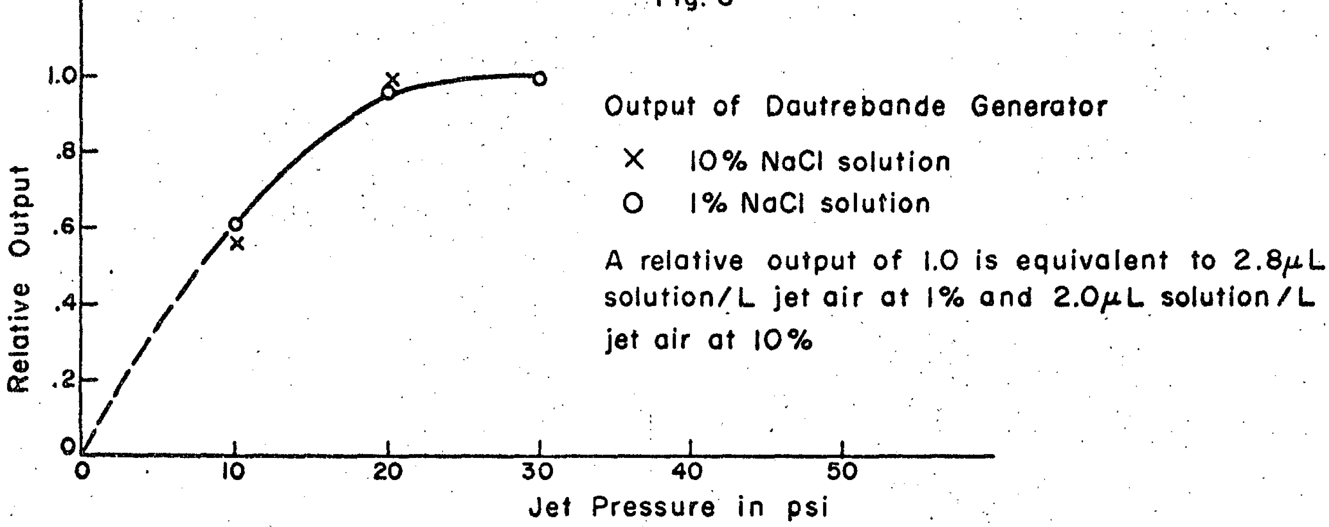


Fig. 6,7,8 Relative Mass Outputs of the Lauterbach and Dautrebande Generators as Functions of the Pressure Drop Across the Jet Orifice.

distribution were observed and it was decided to make similar measurements of the aerosol as it left the glass baffling tube. To simplify the sampling problem, an M.S.A. electrostatic precipitator was used to collect the aerosol. The collected sodium chloride was washed from the precipitator into a volumetric flask, the solution was brought up to volume and aliquots were taken for analysis of the chloride ion content, using the method described by Smit[8].

Different solution concentrations were used in order to see if this factor was important to the generator output. The results are shown in Fig. 7. Although the scatter is considerably greater, the overall result is very similar to that of Fig. 6, indicating that for the range of values studied neither jet size nor concentration has any marked effect on the output of the Lauterbach generator. There was a concentration effect noted with the Dautrebande generator (see Fig. 8), although the relative output varied with jet pressure in a similar manner for the aspiration of both 1% and 10% solutions of sodium chloride.

Particle Size Distributions. Merrington and Richardson[6] obtained the following empirical relationship for the mean diameter of the droplets formed upon the breakup of a jet of liquid issuing from a nozzle into the atmosphere:

$$D = 500\ \nu^{1/5}/V$$

where ν is the kinematic viscosity of the liquid and V is the speed of the jet relative to the air. On this basis, it would appear that the output of a generator, in terms of droplet size distributions, should not be affected to any great extent by the concentration of the solution being aerosolized. After a droplet of diameter, D_s, evaporates to dryness, the solid particle remaining should have a diameter, D_p, given by

$$D_p = .806\ D_s\ (f\ \rho_o/\alpha_v\rho_p)^{1/3}$$

where ρ_o and ρ_p are the densities of the solution and the particle respectively, f is the mass fraction of solute in the original solution, and α_v is the ratio of the volume of the dry particle to D_p^3. Assuming a lognormal distribution of particle sizes, the median diameter should vary as $f^{1/3}$, while the geometric standard deviation should remain the same. Lauterbach et. al. found that the mass median diameters of the aerosols varied as $f^{1/3}$, but the geometric standard deviation did not remain constant, increasing with increasing values of f. Dautrebande [1], on the other hand, found no difference in particle size distribution for values of f between 0.01 and 0.35. The particle size work reported here was intended to investigate both this effect and the effect of jet pressure and orifice diameter with respect to particle size.

Initially, the output of the aerosol generator was mixed with dry air to dilute the particle concentration and introduced into a 28-liter mixing chamber, from which it was subsequently exhausted through a sampling chamber in which the particle concentration could be further diluted. Most of the sampling for particle size measurement was carried out using a small electrostatic precipitator [5], although a few samples were taken with a Casella thermal precipitator.

All particles collected were deposited directly on carbon coated electron microscope grids. The samples were shadowed with chromium at 30° and electron micrographs were obtained at the center of each grid opening across the deposit, moving along the axis of flow. Enlargements were made from the micrographs and particle size measurements were made directly from the prints. For the distributions reported in Tables 2 and 5, the length of the side of the cubical particle was measured with a ruler to the nearest millimeter greater than the particle size. For the distributions reported in Tables 3 and 6, the diameter measured was that of a circle having the same area as the projected area of the particle. The measurements were made with the aid of the Zeiss TGZ-3 particle size analyzer. The latter measurement is about 13% larger than the former.

The particle size analysis yielded a series of measurements showing N_1 particles of size D_1, N_2 of size D_2, ..., and N_k of size D_k. It was assumed that the measurements represented a random sample of particle sizes from a lognormal distribution and the following quantities were calculated:

$$\ln D_g = \sum_{i=1}^{k} N_i \ln D_i / \sum_{i=1}^{k} N_i$$

$$\ln \sigma_g = \sum_{i=1}^{k} N_i (\ln D_i - \ln D_g)^2 / (\sum_{i=1}^{k} N_i - 1)$$

D_g is the median diameter of the frequency distribution and σ_g is the geometric standard deviation. To avoid errors in arithmetic, a program was written for the Bendix G-15 computer and all distribution statistics were calculated by the computer.

The results of samples taken from the 28-liter mixing chamber are shown in Table 2 for the Dautrebande generator and in Table 5 for the Lauterbach generator.

Because the effect of concentration on particle size was less than expected, a second series of samples were taken after eliminating the 28-liter mixing chamber and the ducting leading to it. The diluting and drying air was mixed with the aerosol as it left the generator. Samples were taken at a point downstream from the generator outlet such that the time elapsing between the mixing and the entrance of the aerosol into the sampler was about 0.1 second. Particle size analyses were made as already described and the results are shown in Table 3 for the Dautrebande generator and in Table 6 for the Lauterbach generator.

An effort was also made to make a direct determination of the mass distributions of the aerosols. The radioactive isotope, Na^{24}, was added to the sodium chloride as a tracer and samples were obtained by means of a cascade impactor[4]. The sampling conditions were similar to those described in the preceding paragraph. The statistics obtained for each of the distributions were the mass median "aerodynamic diameter", $\sqrt{\rho C}\, D_m$, and the geometric standard deviation, σ_g, where ρ is the particle density, C is the slip factor, and D_m is the mass median diameter. In this case, the geometric standard deviation refers to the distribution of mass with respect to "aerodynamic diameters" and is somewhat less than it would be for the distribution of mass with respect to geometric diameters. The results of these measurements are shown in Table 4 for the Dautrebande generator and in Table 7 for the Lauterbach generator.

TABLE 2. Particle Size Distributions Obtained with the Dautrebande Generator Exhausting into a 28-liter Mixing Chamber

ΔP PSI	Number of particles measured*	Percent NaCl in generator	Count median diameter, D_g**	Geometric standard deviation, σ_g
10	1560	0.1	.06 μ	1.82
10	1507	10.0	.11	2.16
10	1128	3.0	.09	1.96
20	2569	3.0	.10	1.92
30	2238	3.0	.10	1.94

* Samples collected by electrostatic precipitator.

** "Diameter" refers to the length of the side of the cubical particle.

TABLE 3. Particle Size Distributions Obtained with the Dautrebande Generator for Samples Collected at Generator Outlet

ΔP PSI	Number of Particles Measured*	Percent NaCl in Generator	Count Median Diameter, D_g**	Geometric Standard Deviation, σ_g	Calculated Mass Median Diameter, D_m
10	614	0.1	.05 μ	1.91	.18 μ
10	620	10.0	.06	2.28	.45
20	2013	0.1	.05	2.01	.20
20	981	10.0	.07	2.26	.48
30	9063	0.1	.04	1.74	.09

*Samples collected by electrostatic precipitator.

**"Diameter" means the projected diameter as measured by means of a Zeiss TGZ-3 particle size analyzer.

TABLE 4. Mass Distributions for the Dautrebande Generator as Determined by Cascade Impactor

ΔP PSI	Percent NaCl in generator	Mass Median "Aerodynamic Diameter"	Geometric Standard Deviation, σ_g	Mass Median Diameter, D_m
10	0.05	$0.32\mu - (gm/cm^3)^{1/2}$	1.55	0.14μ
10	1.0	0.42	1.76	0.20
10	10.0	0.82	1.90	0.46

TABLE 5. Particle Size Distributions Obtained with the Lauterbach Generator Exhausting into a 28-liter Mixing Chamber

Jet Orifice Diameter	ΔP PSI	Number of Particles Measured	Percent NaCl in Generator	Count Median Diameter, D_g**	Geometric Standard Deviation, σ_g
.013"	10	888	3.0	.09 μ	1.97
"	20	1197	3.0	.09	2.01
"	20	632	0.1	.06	1.92
"	20	1272	0.1	.06	1.88
"	20	1338	10.0	.10	2.11
"	30	1313	0.1	.05	1.79
.021"	10	1132	3.0	.09	2.00
"	20	991	3.0	.11	2.02
"	20	929*	3.0	.10	2.05
"	30	438	3.0	.10	2.23
.032"	10	923	3.0	.08	1.97
"	20	1700	3.0	.10	2.08
"	20	1944*	3.0	.10	1.90
"	20	2024	3.0	.11	2.01
"	30	1627	3.0	.12	1.96

*Samples collected by thermal precipitator; all others collected by electrostatic precipitator.

** "Diameter" refers to the length of the side of the cubical particle.

TABLE 6. Particle Size Distributions Obtained with the Lauterbach Generator for Samples Collected at the Generator Outlet.

Jet Orifice Diameter	ΔP PSI	Percent NaCl in Generator	Number of Particles Measured*	Count Median Diameter, D_g**	Geometric Standard Deviation, σ_g	Calculated Mass Median Diameter
.013"	10	0.1	1449	.04 μ	1.77	.11 μ
"	30	0.1	1079	.03	1.63	.07
"	30	10.0	2370	.12	2.17	.74
"	50	0.1	2753	.04	1.69	.08
"	50	10.0	3616	.10	2.08	.52
.021"	10	10.0	2914	.10	2.06	.46
"	20	0.1	154	.04	1.72	.10
"	20	10.0	1612	.10	2.06	.46
"	50	0.1	345	.04	1.56	.07
"	50	10.0	2966	.10	2.06	.47
.032"	5	0.1	412	.05	1.82	.14
"	5	10.0	586	.10	2.09	.48
"	5	10.0	1286	.09	2.02	.39
"	10	0.1	1311	.04	1.78	.11
"	30	10.0	3143	.10	2.08	.51

* Samples collected by electrostatic precipitator.

** "Diameter" means projected diameter as measured by means of a Zeiss TGZ-3 particle size analyzer.

TABLE 7. Mass Distributions for the Lauterbach Generator as Determined by Cascade Impactor.

ΔP* PSI	Percent NaCl in generator	Mass Median "Aerodynamic Diameter"	Geometric Standard Deviation, σ_g	Mass Median Diameter, D_m
10	0.05	0.69 μ - $(gm/cm^3)^{1/2}$	2.04	0.39 μ
10	1.0	1.35	2.45	0.83
20	0.05	0.61	1.85	0.34
20	0.25	0.88	2.18	0.51
20	2.0	1.30	2.18	0.79
30	0.05	0.51	2.02	0.26
30	1.0	0.89	2.61	0.52

*All aerosols were generated with the 0.013" diameter jet orifice and sampled at generator outlet.

DISCUSSION

Mass Concentrations. Since the mass output is a function of jet pressure, generator construction, and the geometry of the accessory ducts and chambers introduced between the point at which the aerosol is formed and that at which it is sampled, the results obtained with different generators can be expected to be only roughly comparable. Thus Lauterbach et. al.[3] obtained an output of 6.8 microliters/liter of jet air at 20 psi with no appreciable effect due to the concentration of the generator solution. In the present case, an output of about 5.0 microliters/liter of jet air was obtained under similar circumstances. The difference is almost certainly due to the fact that the diameter of the aerosolization chamber of the present generator was 5/8", whereas the aerosolization chamber of Lauterbach's generator was several inches in diameter.

The advantage in output gained by increasing the pressure drop, ΔP, across the jet orifice must be weighed against the disadvantage due to the increased loss of water vapor. If a bubbler is used as a pre-humidifer, then, ignoring the cooling of the solution, the expanding jet air will have a water vapor deficit per liter of air proportional to $\Delta P/(\Delta P + P_a)$; where P_a is the ambient pressure. Since the output does not increase appreciably above 30 psi, and since particle size distribution is not markedly affected by jet pressure, there appears to be little advantage in operating at jet pressures greater than 30 psi.

The data presented above make it possible to design an aerosolizing system to fit the demands of a given exposure set-up for inhalation toxicity studies. For a given rate of flow of contaminated air, the jet size can be determined from Fig. 3. The required water vapor content of the air can be determined from Fig. 5 and the water vapor deficit calculated if a pre-humidifier is used. For a generator of the Lauterbach type, the water deficit can be made up in the following way. A distilled water reservoir is set up in parallel to the solution reservoir and connected to it through a small hole at the base of the reservoirs. The liquid levels of the two reservoirs are initially the same. As solution is used up, the levels decrease together, feeding distilled water into the solution reservoir. The rate at which the distilled water is fed in is determined by the relative cross-sectional areas of the two reservoirs. Using this system, a miniature Lauterbach generator was constructed, which operated on an initial volume of solution of four milliliters. It was found to work satisfactorily, with a negligible back flow of active solution into the distilled water reservoir. However, before a thorough investigation of this generator could be carried out, it was made superfluous when it was found that an appropriate baffling system on the jet could greatly increase the generator output and minimize water vapor losses. This system will be the subject of a separate report.

Because of its low mass output per liter of jet air, no effort was made to adapt the Dautrebande generator to the present problem.

Particle Size Distributions - Dautrebande Generator. The results with the Dautrebande generator are not in agreement with Dautrebande's work[1], since there is a definite change in the count median diameter as the solution concentration changes. Two factors may be contributing to this disagreement. The conclusion reached by Dautrebande was apparently based on the qualitative similarity of the distribution curves, which might well have exhibited differences quantitatively (see, for example, ref. 1, p. 11). Also, he attributes the similarity of his particle size distributions to "obligatory liquid filtration", which may not have been functioning optimally in the present case. This form of filtration occurs when droplets of solution, suspended in air bubbles, are carried through a column of water. In the saturated atmosphere of the bubble, the droplets grow at a rate which depends, among other things, on the concentration of the solute in the droplet. Thus, for a given droplet size, the greater the initial concentration the greater will be the rate of growth of the droplet and the greater will be the likelihood of its loss in the water column. The D_{30} generator used in this study has a minimum water "column" and filtration is doubtless less effective than in most of the generators used in the work cited by Dautrebande.

The mass median diameters obtained by cascade impactor agree surprisingly well with those calculated from the frequency distributions, leaving no doubt of a concentration effect.

Particle Size Distributions - Lauterbach Generator. Although they did not make direct measurements of the mass distributions, Lauterbach et. al.[3] expressed their results in terms of the mass median diameters and geometric standard deviations of the particle size distributions, deriving these quantities from measurements made on electron micrographs of samples obtained by means of a thermal precipitator. When corresponding count median diameters are calculated, they are found to be 0.09μ and 0.04μ respectively for 10% and 0.1% sodium chloride concentrations. These are in reasonably good agreement with the values shown in Table 5 for samples taken under similar conditions (i.e., a 0.013" diameter jet orifice and a ΔP of 20 psi).

The jet orifice diameter and the pressure drop have little effect on either the median diameter or the geometric standard deviation of the frequency distribution. The concentration of the solution affects the count median diameter to a lesser extent than expected on the basis of an $f^{1/3}$ relationship. For instance, 100-fold increases in concentration usually caused changes of about 2.5 times in the counted median diameters, compared with an expected value of 4.65 times. On the other hand, the geometric standard deviations, which were not expected to be affected by concentration changes, were found to increase with increasing concentration. Both of these observations suggest that the assumption of a log-normal distribution of particle sizes may not be valid.

Unlike the count median diameters, the mass median diameters, as obtained by cascade impactor, show effects due to jet pressure as well as those due to solution concentration. For a given concentration change, the change in mass median diameter was found to be 75-85% of the expected value. For a given concentration, the mass median diameter decreased with increasing jet pressure, being about 1-1/2 times as large at 10 psi as at 30 psi.

SUMMARY AND CONCLUSIONS

The operating characteristics of the Lauterbach and Dautrebande aerosol generators have been studied with respect to the amount of aerosol produced and its particle size distribution as functions of the diameter of the generator's orifice (jet), pressure drop across the orifice, and the concentration of the solution being aerosolized. The air flow through the jet, the effect of a pre-humidifier on the water vapor content of the jet air, the cooling effect of the jet air on the generator solution, and the amount of water vapor carried away by the jet air were also studied.

It was found that the output of the generators, expressed in microliters of solution aerosolized per liter of air passing through the jet, increased with the pressure drop, ΔP, across the jet, approaching an asymptote which was apparently negligibly greater than the output at $\Delta P = 50$ psi. Above 30 psi there was relatively little increase in output with increasing ΔP. Neither the diameter of the jet orifice nor the concentration of the solution had an appreciable effect on this output.

With respect to the particle size distribution, the count median diameters were not affected by either orifice diameter or jet pressure. Changes in solution concentration affected the count median diameters, but not as much as had been expected on the assumption that they should vary as the cube root of the concentration. Moreover, geometric standard deviations, which, on the same assumption, should have been unaltered by concentration changes, were found to increase with increasing concentration. Mass median diameters, obtained by cascade impactor, showed similar changes with respect to concentration, but exhibited an effect of jet pressure, decreasing with increasing pressure. The results indicated that the assumption of a lognormal frequency distribution may not have been valid.

A pre-humidifier was found to saturate the jet air at the pressure behind the orifice, leaving a post-expansion water vapor deficit per liter of jet air proportional to $\Delta P/(\Delta P + P_a)$. Depending largely on the geometry of the aerosolization chamber, this deficit was somewhat reduced by the cooling effect of the expanding jet air and the evaporating water; however, a progressive concentration of the generator solution still occurred.

An empirical relationship between the apparent linear velocity of air through the jet and the ratio of pressure drop across the jet to ambient pressure was obtained which, combined with the other information available with respect to the output of the jets, makes it possible to design generators of predictable operation.

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