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STUDIES OF PORTABLE AIR-OPERATED AEROSOL GENERATORS

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ABSTRACT

Four simple, portable, air-operated aerosol generators have been developed by NRL. These generators are used to produce polydisperse liquid aerosols. At a given pressure and the consequent flow rate, the polydispersion produced by each generator is reproducible both in term of particle-size distribution and aerosol mass concentration but each generator model differs significantly from the others in total aerosol output as well as particle-size distribution at the same operating pressure.

Three of these generators are of the same design using a hole-type nozzle to generate the aerosol. Model I is a small-capacity single-nozzle generator with a jet impactor. Model II is a multinozzle generator of larger capacity without a jet impactor. Model III is an improved single-nozzle generator with a larger capacity than Model I. The Model III has a jet impactor and produces a smaller average particle size than Models I and II. Model IV has a different slit-type nozzle which produces a greater quantity of aerosol at the same airflow and with approximately the same average particle size.

The only requirements for operation of the aerosol generators are on adequate, filtered, and well-regulated compressed air supply and the liquid to be disseminated. When DOP (di(2-ethylhexyl)-phthalate) is used as the liquid, the dispersed phase of the aerosol system has a light-scattering geometric mean diameter of the magnitude of one-half micron. Other suitable liquids, either compounds or mixtures, may be disseminated with these generators provided the liquid used is chemically inert to the materials of the generators.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

NRL Problem C08-10
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STUDIES OF PORTABLE AIR-OPERATED AEROSOL GENERATORS

INTRODUCTION

Four different models of portable air-operated aerosol generators have been developed at NRL. These generators are used to produce polydisperse liquid aerosols which are reproducible both in terms of particle-size distribution and aerosol mass concentrations. The aerosols are useful in evaluating high-efficiency filter systems; integrity of gas masks and gas mask components, glove boxes, and air lock systems; ventilation distribution; and electrostatic precipitators. When di(2-ethylhexyl)phthalate (DOP) is the liquid medium, the dispersed phase of the aerosol system has a light-scattering geometric mean diameter (LSGMD) of the magnitude of one half micron.

In 1954, Thompson (1) reported on the first portable air-operated aerosol generator (Model I) designed and utilized at NRL. Since then three additional models (Models II, III, IV) have been under development by the Laboratory. Model II is a larger capacity generator while Models III and IV are improved aerosol generators of the same general type.

All four of the aerosol generator models have found wide application in those studies not requiring a monodisperse liquid aerosol. In contrast to the standard condensation-type apparatus (used for the production of monodisperse liquid aerosols), these air-operated aerosol generators incorporate portability, simplicity, and inexpensiveness.

The aerosol generators considered in this report may be used to disperse pure liquids or solutions other than DOP but DOP is utilized because of its suitable physical properties (e.g., low vapor pressure, viscosity, high flash point, nonhygroscopic, and chemical inertness).

DESCRIPTION OF AEROSOL GENERATORS

Model I

The Model I aerosol generator as shown in Fig. 1 consists of (in order of air flow): the liquid reservoir (A), a pint-size, friction-top can in which the atomizer nozzle (B) is mounted, and another pint-size can (C), which serves as a spray trap. The two small cans (A,C) are mounted on a 5-gallon lug-top can (D) which acts as a surge tank. A jet impactor (E) is located in the supply tube to the surge tank.

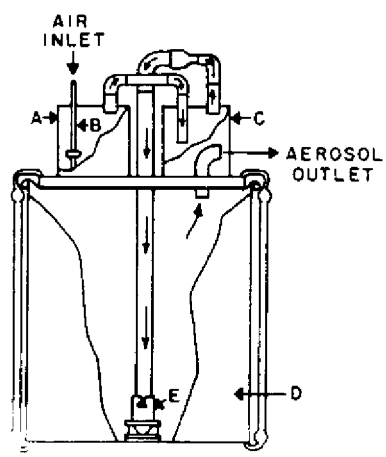


Fig. 1 - Model I aerosol generator (cutaway view)

The important dimensions for the atomizer nozzle (B) are 0.040-inch diameters for both air and liquid feed holes. The rectangular dimensions of the jet impactor orifice are 0.039 by 0.394 inch. The jet impactor plate, located beneath the jet impactor orifice, is not more than three impactor slit widths or 0.117 inch from the jet slit (2).

All connections between the three cans are standard copper or brass plumbing materials. With one exception, all junctions are soldered; at the junction between the spray can (C) and the 5-gallon surge tank (D), a rubber tube is used (with clamps) to connect the metal tubing. Thus, when the liquid reservoir (A) requires more DOP or the spray can (C) must be emptied, this can be simply and easily done. For greater detail of construction of the Model I aerosol generator, Ref. 1 should be consulted.

Model II

As shown in Fig. 2, the Model II aerosol generator is simply an array of six nozzles symmetrically arranged around a center feedpipe within a partly open 5-gallon lug-top can. A floor flange bolted to the bottom of the can supports the air supply pipe and nozzle array. To prevent leakage of the liquid DOP from the generator can, the floor flange, in addition to being bolted, is soldered to the bottom of the can. Standard plumbing connections, some with slight modification, are used throughout. The atomizer nozzles (same as in Model I) are arranged symmetrically and oriented vertically so that the collars of the nozzles are located within a few inches of the bottom of the can. A tee is affixed to the upper position of the air supply pipe so that a pressure gage, gate valve, and compressed air couplings may be attached. In order to reduce the effects of splashing, a perforated metal plate or baffle is situated within the generator a few inches above the whole nozzle array.

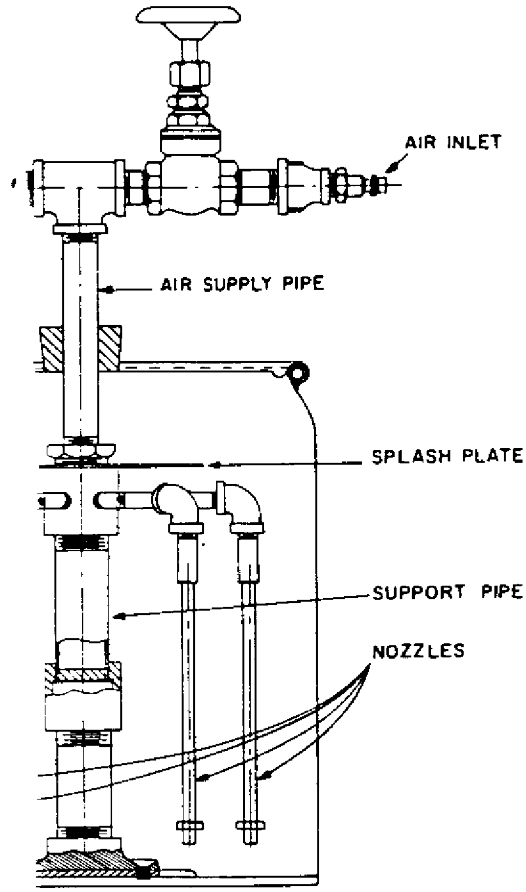
The nozzles originally used in the Model II aerosol generator had the same orifice dimensions as those in the Model I generator. The modified nozzle of the Model III generator, which has larger liquid feed holes, or the slit-type nozzle of the Model IV will be used in the Model II aerosol generator in the future. This modification (enlargement of the liquid feed holes) increases dispersed phase production, while use of the slit-type nozzle decreases the volume of compressed air required. Jet impactors are not used in the Model II aerosol generator.

Model III

The Model III aerosol generator is a single-nozzle, single-impactor aerosol generator similar in some respects to Model I. It has been designed to reduce the average particle size and, under the limitation imposed by the use of the jet impactors, to optimize aerosol output. To achieve these desired characteristics several modifications were required. A cutaway view of the Model III generator is shown in Fig. 3. The major differences between the Model I and the Model III generators are: (a) the liquid feed holes in the atomizer nozzle collar have been increased in diameter from 0.040 to 0.080 inch (Fig. 4 is a sketch of the improved atomizer nozzle); (b) the jet impactor has also been modified, the impactor slit having been reduced to 0.031 by 0.364 inch and the plate of the impactor has been set at 0.072 inch from the jet exit; and (c) the surge tank has been eliminated. The elimination of the surge tank required that the jet impactor be mounted in what was the spray can of Model I. The quart-size cans and larger connections employed for the Model III, in contrast to the pint-size cans and smaller connections used in the Model I, were adopted principally to increase liquid reservoir capacity and to reduce wall losses.

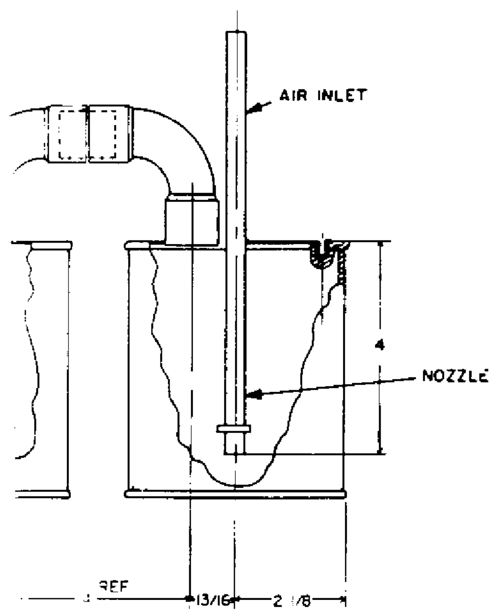
As shown in Fig. 3, the Model III aerosol generator is composed of two quart-size friction-top cans. One can serves as the liquid reservoir and contains the submerged atomizer nozzle. The other contains the jet impactor. The connection between the nozzle

CONNECT



iI aerosol generator assembly

JET
IMPACT



F: aerosol generator (cutaway view)

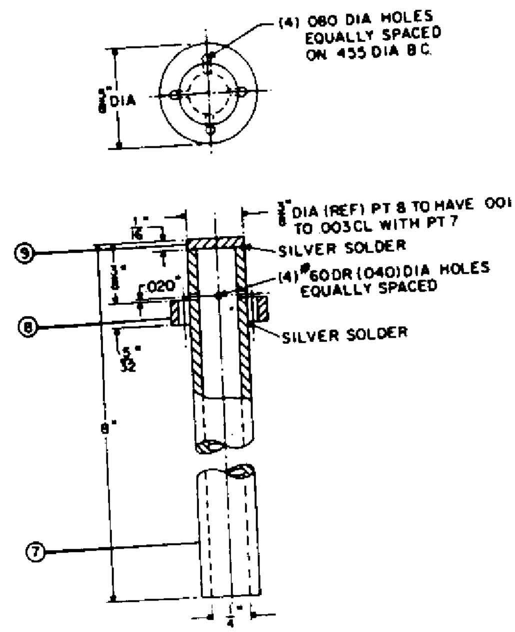


Fig. 4 - Improved atomizer nozzle

can and impactor can is 3/4-inch-I.D. standard copper or brass plumbing stock. A short straight length of tubing or an ell of the proper size is used for the aerosol exit duct. The atomizer nozzle, when soldered to the generator can lid, is positioned about an inch from the bottom of the can. Likewise, the jet impactor should be at least an inch from the bottom of its can. When the generator has been in use, care should be taken to insure that accumulated DOP does not reach the level of the impactor plate.

Model III-A

The Model III-A is simply an impactorless Model III with the impactor can left intact to remove occasional gross particles. The dispersion it will produce is similar in quality to that of the Model II aerosol generator.

Model IV

Outwardly, the Model IV aerosol generator resembles the Model III. However, an entirely different type of nozzle is employed. Instead of utilizing the effect of air passing at relatively high velocities through small holes, a narrow slit 0.001 inch wide, which extends around the periphery of a tube 0.625 inch in diameter, is utilized to achieve the same effect. The only difference between Model III and Model IV generators is the use of the slit-type nozzle (Fig. 5).

Model IV-A

The Model IV-A aerosol generator is analogous to the Model III-A. It is a Model IV with its jet impactor removed.

COMPONENTS

Atomizer Nozzle (Hole Type)

Models I, II, III, and III-A aerosol generators all have a nozzle similar in design to the Laskin submerged aerosol unit (3). The nozzle as shown in Fig. 4 is simply a brass tube approximately 8 inches in length, sealed on one end, and having a brass collar

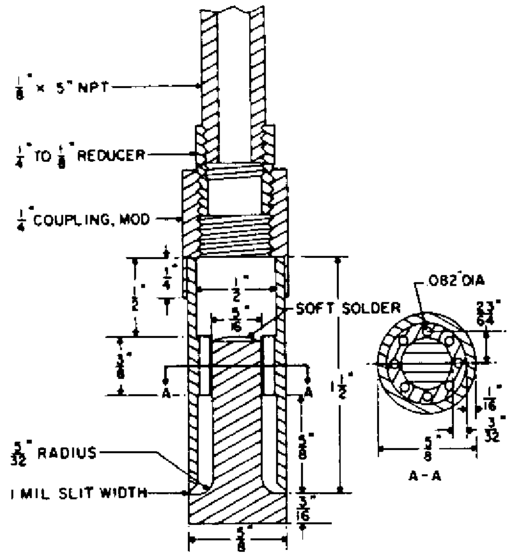


Fig. 5 - Cross section, circular slit nozzle, Model IV

3/4 inch from the closed end. In the brass tube are four small air holes, equally spaced radially and at right angles to the tube axis. These four air holes are 0.040 inch in diameter and are centered 0.020 inch below the brass collar. There are four liquid feed holes in the brass collar which are longitudinal with respect to the brass tube and immediately next to it. In addition, the liquid feed holes are in line with the radial air holes in the brass tube. Thus, when the nozzle is vertically mounted in the generator with the capped end down, the liquid feed holes are located immediately above the air holes. Except for the new Model III as well as the Model III-A, all liquid feed holes and air hole sizes are 0.040 inch. (Model IV is excluded here as it has a different kind of nozzle.) In the recently developed Model III aerosol generator, the liquid feed hole sizes have been doubled to 0.080 inch.

In order to operate the nozzle, DOP is added to the generator can until the liquid level is just above the upper portion of the collar. It is important that the collar be beneath the liquid to be dispersed. The maximum submergence, however, should not exceed 1 inch.

As air under pressure is applied to the atomizer nozzle, four high velocity streams of air emerge from the holes in the nozzle head. As the pressure on the nozzle is increased, the air streams emerging from the nozzle attain higher velocities. The bulk liquid is aspirated through the liquid feed holes, and the liquid column, droplets, or film appearing in and near the region of the vena contracta is atomized by the shearing action of the high velocity air stream. The feed holes are utilized to supply liquid into the region of highest air stream velocity.

With liquid DOP as the bulk phase, particles in the range of submicron to about 15 microns in diameter are generated with this particular nozzle. The greatest number of particles, however, is in the 1 micron or less size range.

Atomizer Nozzle (Slit Type)

A different type of atomizer nozzle is used in the Model IV aerosol generator. Instead of four high-velocity streams (as is the case with the other nozzle), a sheathlike stream of air at high velocity emerges from the peripheral orifice. Fabrication of this nozzle has been accomplished by machining from brass two separate sections, which, when assembled have a peripheral slit approximately 1 mil wide by 1.960 inches in length.

One principal section of the atomizer nozzle is a 5/8-inch-diameter brass tube which has been machined from a rod to accommodate a snugly fitting piston 5/16 inch in diameter. Eight small holes (No. 45 drill) are then drilled longitudinally through the wall of the tube between the hole accommodating the rod and the exterior wall to permit passage of compressed air. As depicted in Fig. 5, the interior lip at the lower end of this section is beveled 45 degrees to make the slit more suitable aerodynamically.

The other principal section of the atomizer nozzle is machined from a brass rod 5/8 inch in diameter and 1-5/32 inches long) so that it fits snugly into the 5/16-inch-diameter chamber. The 3/16-inch-long by 5/8-inch-diameter cylindrical section has the same diameter as the female fitting and, in addition, the reduction from the 5/8-inch-diameter section to the 5/16-inch-diameter rod is a smooth radial transition so as to minimize turbulence and eddy formation. As shown in Fig. 5, a modified 1/4-inch NPT brass coupling as well as a 1/4-inch to 1/8-inch brass reducer are used to accommodate a 1/8-inch NPT brass pipe. The full length of the nozzle unit is approximately 8 inches. One-mil Mylar or another suitable material of similar thickness may be used as a spacer. The combined unit is submerged in water to the extent that the spacer is below the water level. The nozzle is then soft soldered at the end opposite the circular slit. Properly machined, the peripheral slit has a constant width and the exterior and interior edges are aligned.

Jet Impactor

The dispersion of particle sizes produced by the aerosol generator may be selectively reduced in size range using a jet impactor of the proper dimensions. The jet impactor is used in this instance to alter the particle-size distribution of a given polydisperse liquid aerosol by removing particles larger than a certain size range. The jet impactor and the stepwise detail for fabricating it are shown in Fig. 6. The impactor consists of a 3/4-inch-I.D. brass tube which has a small rectangular outlet or slit at the lower end. A brass plate is mounted at a suitable distance beneath the jet outlet. The aerosol is passed through the jet impactor, and in the region below the jet orifice each particle is subjected to inertial forces in a swiftly moving gas stream which is changing direction. Depending on a number of factors, an individual liquid particle is either impacted on the brass plate or remains airborne. The jet impactor thus narrows the particle-size spectrum of a given polydisperse liquid aerosol by removing larger particles by means of the inertial mechanism. Removal efficiency is dependent on the velocity, diameter, and density of the particle, and the jet to plate distance. At a given flow rate each jet impactor can be said to have a characteristic diameter, i.e., from a given polydisperse aerosol, 50 percent of all particles of a certain diameter are removed (2). The characteristic diameter is fixed by the dimensions of the jet impactor and the velocity of the air stream through the jet opening.

EXPERIMENTAL METHODS

Particle-Size Distribution

To determine the particle-size distribution of the aerosols produced by the various models described in the report, the jet impactor-light scattering technique was utilized (4). The method requires the use of a series of calibrated jet impactors, several critical pressure orifices, a vacuum pump, and a light-scattering photometer. In order to characterize a given polydispersion, the aerosol is passed through each of a series of suitable jet impactors at specified flow rates. Each jet impactor at a given flow rate removes

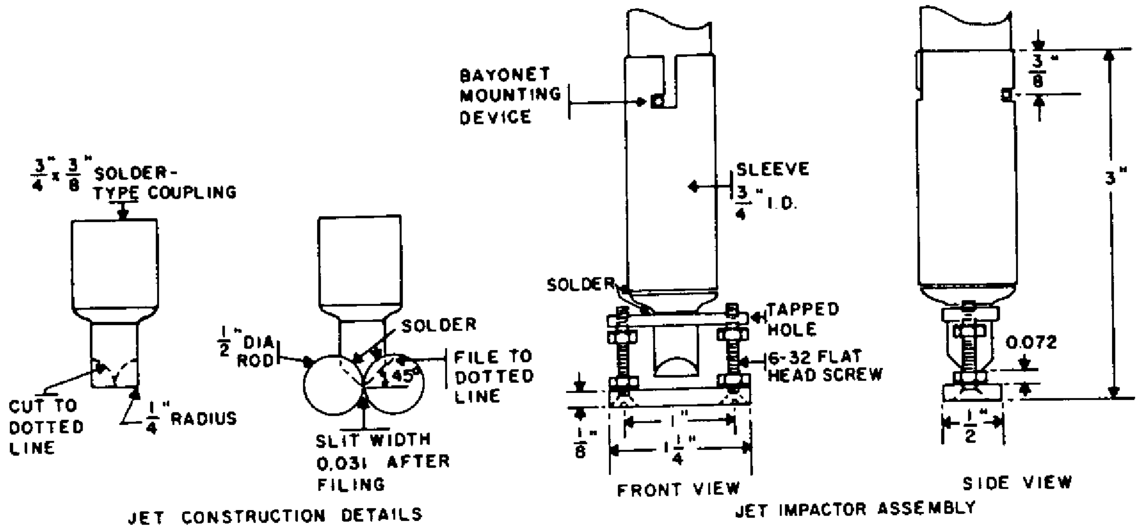


Fig. 6 - Jet impactor (detail sketches)

50 percent of all particles of a certain size, identified by the characteristic diameter of the jet impactor. The light-scattering photometer enables one to measure the light scattering intensity of the aerosol before and after it passes through any given impactor. Therefore a cumulative size distribution of the polydisperse liquid aerosol in terms of percent scattered-light intensity may be obtained. A logarithmic probability plot of size against percent less-than-stated-size light-scattering intensity gives one a measure of the size distribution of a polydispersion. Because the universe of particles is finite in size range and thus only Gaussianlike in character, as is always the case in practice, many plots of size distribution on the logarithmic probability graph tend to be nonlinear in character at the extremities of the curve, particularly toward the larger particle sizes. The best straight line fit between 10 and 90 percent on the plot is considered to be the best characterization of particle-size distribution. From the logarithmic probability plot the average size in terms of light scattering (LSGMD) and σ_g (geometric mean standard deviation) may be obtained. The LSGMD is read off the plot at the 50-percent size. σ_g is the ratio of the 84.13-percent size to the 50.0-percent size (5). In order to determine particle-size distribution experimentally, the dispersion produced by any of the various aerosol generator was diluted with air at a constant rate and passed through a duct in which thorough mixing occurred. The aerosol was then sampled downstream. In the case of the Model II aerosol generator, particle-size distribution was measured by placing the generator in a fume hood and sampling an adequate distance downstream in the hood duct. For the Model III aerosol generator, a motor blower with a smaller duct was employed for making size measurements. In either case the purpose was to dilute the aerosol generated so that the light-scattering power of the aerosol stayed within the range of the light-scattering photometer employed. The NRL E-3 Light-Scattering Meter (6) was used for light-scattering measurements. With this particular light-scattering meter, 100 percent corresponds to 80 micrograms per liter of a 0.3 μ (DOP) monodispersion.

Mass concentration was determined by drawing samples of the aerosol through glass fiber filter paper having 99.99 percent efficiency for an aerosol of DOP of 0.3 μ average size.

Experimental Results

The principle of operation is the same for all four of the aerosol generators although Models II, III-A, and IV-A do not contain jet impactors. The rate of aerosol production by the generators is dependent upon the design of the nozzle and the jet impactor as well as the airflow through them. Particle-size distribution is mainly dependent on the design of the jet impactor and the airflow velocity through it. With a given atomizer nozzle, differences in size distribution and aerosol concentration may be achieved by altering the dimensions of the jet impactor or varying the rate of airflow. In either case the characteristic diameter of the jet impactor is changed, which therefore alters the size range of the aerosol emerging from the generator. In all of the aerosol generators, the average size of the dispersed phase decreases as the airflow rate through the nozzle is increased. The effect is augmented by the use of jet impactors as the characteristic diameter is decreased with an increasing airflow.

Model I

The first portable air-operated aerosol generator (1) was developed for the purpose of quality testing an item which came under the Laboratory's cognizance. Initially, it was used at an air pressure of 5 psig. When the Model I aerosol generator is operated at this pressure, the aerosol which emerges from the surge tank has had most of the larger airborne particles (>3 microns) removed by inertial impaction. At an air pressure of 5 psig on the nozzle and a resulting airflow of approximately 32 liters per minute (lpm), measured at atmospheric pressure, the Model I generates an aerosol which has a mass concentration of approximately 0.50 milligram of DOP per liter and a particle-size distribution as shown by the histogram in Fig. 7.

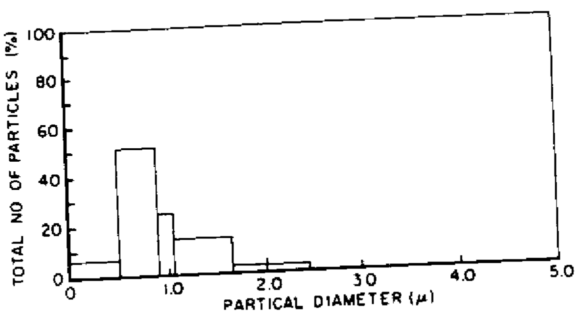


Fig. 7 - Particle-size distribution, Model I generator at 5 psig

Mass concentration and flow rates for the Model I aerosol generator have been determined at other air pressures on the nozzle. At 25 psig, for instance, it will produce 84 lpm of aerosol having a mass concentration of 1.26 mg/l with an average light-scattering diameter of 0.70 μ. Values for mass concentration, LSGMD, σ_g, and flow rate as a function of pressure for the Model I aerosol generator are included in Appendix A.

Model II

The Model II aerosol generator has been designed to generate profuse quantities of aerosol. For field and laboratory studies where high-capacity systems require copious quantities of aerosol, this particular generator has proved useful. It has been valuable in determining the efficiency of high-capacity electrostatic precipitators (7) and among other applications, in-place evaluation of high-efficiency, high-capacity filter systems (8).

At a nozzle pressure of 25 psig, the Model II aerosol generator produces 516 lpm of aerosol (DOP) having a mass concentration of about 4.95 mg/l.

The LSGMD of the dispersed phase in the aerosol system produced by the Model II at 25 psig is approximately 0.85 μ. In terms of scattered-light intensity, 92 percent of the DOP particles emerging from the generator (at 25 psig) are less than 1.88 μ in diameter and 22 percent are less than 0.59 μ. The results (flow rate, mass concentration, LSGMD, and σ_g) for the Model III are shown in Appendix A.

Model III

The Model III aerosol generator is the same general type of generator as the Models I and II. One of the principle modifications is the increase in size of the liquid feed holes of the atomizer nozzle. It has been experimentally determined that particle-number production is, within limits, a function of the diameter of the liquid feed holes. The size of the liquid feed holes in the nozzle has thus been doubled in diameter from 0.040 to 0.080 inch. Figure 8 graphically represents the results obtained showing the effect, in terms of scattered-light intensity, of increasing the diameter of the liquid feed holes from 0.040 to 0.060 to 0.080 inch. Comparison of the three curves indicates the increased particle-number production realized by limited enlargement of these holes. Liquid feed hole size of 0.080-inch diameter was chosen on the basis of (a) the light-scattering power of the aerosol (Fig. 8), (b) the mass concentration increase (Fig. 9), and (c) the increased abundance of smaller particles over that produced by the Model I aerosol generator. From the results it may be concluded that, up to a limit, liquid feed hole enlargement above 0.040-inch diameter leads to an increased number of particles of each size in the total population.

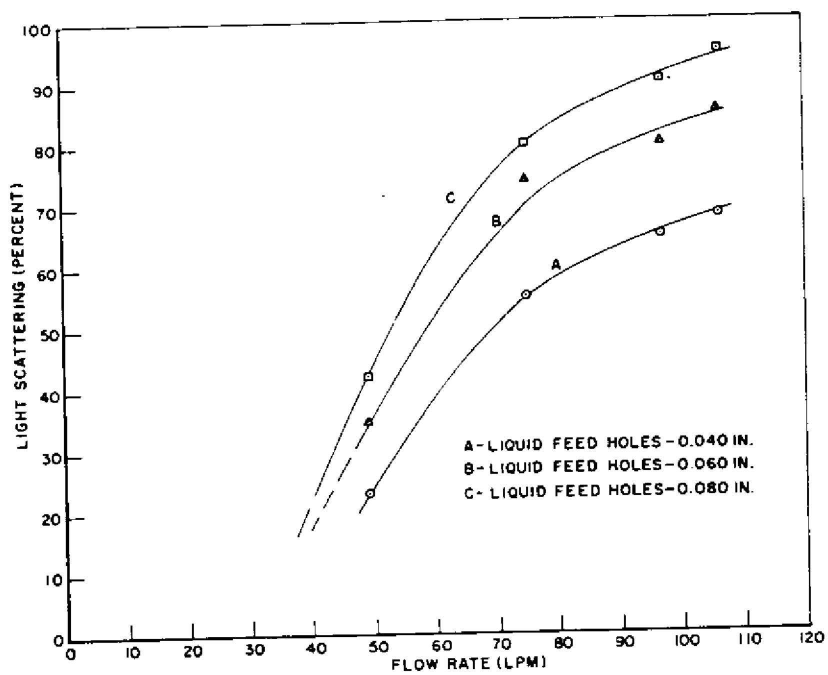


Fig. 8 - Effect of increasing diameter of liquid feed holes of nozzle

The second important modification incorporated into Model III is the change in the jet impactor dimensions. The width of the jet impactor has been narrowed to 0.031 inch and the length reduced to 0.364 inch. Jet plate distance also was decreased to 0.072 inch. Thus, the experimental cutoff point for particles in the upper size-range is approximately

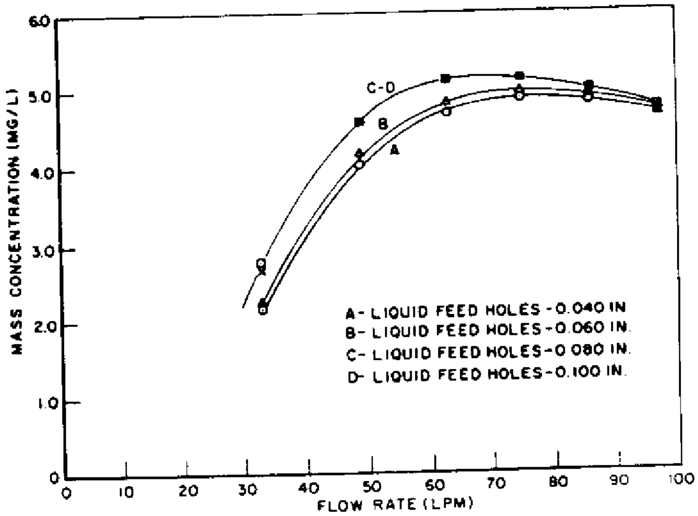


Fig. 9 - Mass concentration as a function of flow rate and liquid feed hole size, Model III-A

1.3 microns at a flow rate of 86 lpm through the jet impactor. With an air pressure of 25 psig on the nozzle, the average size of the dispersed phase in the aerosol system produced by the Model III aerosol generator as determined from the results of light-scattering measurements is 0.69 μ. The values obtained for the Model III at 5-30 psig are shown in Appendix A.

The effect of the jet impactor on the polydispersion as the aerosol is passed through it at increasing flow rates is shown in Fig. 10. (Slight differences in nozzle performance at increasing flows are occurring.) As is shown in Fig. 10, the LSGMD decreases from 0.82 μ at a flow rate of 33 lpm to 0.69 μ at a flow rate of 97 lpm.

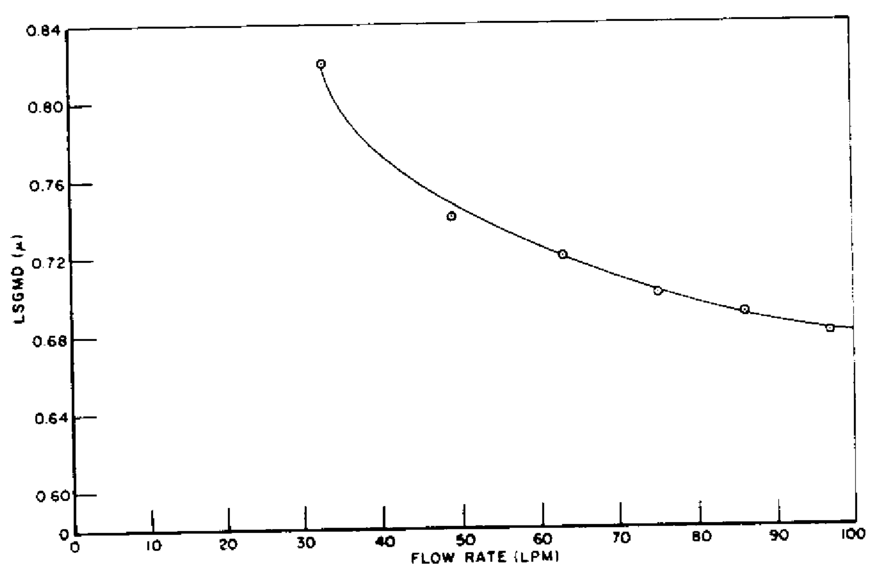


Fig. 10 - Light-scattering geometric mean diameter vs flow rate, Model III

There is the question of an optimum pressure at which to operate the Model III aerosol generator. When a number of generators have to be operated simultaneously by means of a manifold, compressed air capacity may be limiting. From the standpoint of increased aerosol production and the lowest average mean particle diameter attainable, an upper range nozzle pressure is more desirable. Since no increase occurs in aerosol generation efficiency in terms of mass per unit volume above 25 psig and, in addition, the average size shows no significant decrease above this pressure, 25 psig was chosen as the standard operating pressure.

The mass concentration of the aerosol produced by the Model III generator, as a function of airflow was also determined. These data are in Appendix A. Mass concentration shows an increase from 0.63 mg/l (at 5 psig) to a maximum of 1.65 mg/l (at 25 psig). If it is considered that the rectangular orifice of the jet impactor slit of the Model III is about 72 percent of the area of the similar opening in the Model I jet impactor, yet at 25 psig nozzle pressurization the Model III aerosol generator's dispersed phase production is 30 percent greater in terms of weight per unit volume than that of the Model I at the same air pressure, the efficacy of liquid feed hole enlargement is apparent.

The Model III aerosol generator is thus designed to obtain a minimum size range of small particles (submicron to 1.3 μ at 25 psig and 86 lpm flowrate) and a maximum efficiency of aerosol production.

Model III-A

A variation on the Model III, the Model III-A aerosol generator, is simply the Model III with the jet impactor removed. The can which contained the impactor is left intact to serve as a collector for grossly sized particles which are occasionally thrown over from the generator can. Since the larger particles are not removed nearly as efficiently with the impactorless arrangement, a wider spectrum of particle size with increased aerosol output is the end result. In Fig. 9 is shown the mass concentration of the aerosol produced by the Model III-A as a function of flow and liquid feed hole size. Curves A, B, C, and D in Fig. 9 are the results with respective liquid feed hole diameters of 0.040, 0.060, 0.080, and 0.100 inch.

Without the jet impactor there is up to a threefold increase in mass concentration over that of the Model III aerosol generator with a jet impactor. Above 20 to 25 psig on the nozzle, and corresponding flow rates of 75 to 86 lpm, the mass concentration does not increase for the Model III-A aerosol generator. Therefore, from the standpoint of mass concentration and compressed air supply limitation, a nozzle pressure of 20 to 25 psig may be considered optimum. The retrograde character of the curves in Fig. 10 is thought to be due to a number of factors. Aerosol production is not proportional to the flow rate, for above a certain flow rate, dilution effects of the airflow through the nozzle become dominant. Wall loss probably increases at the higher flowrates, but this should not be appreciable for the particle size ranges considered here.

In terms of milligrams per minute, rather than milligrams per liter, an increase occurs above 25 psig on the nozzle. In effect, a greater mass of liquid DOP is atomized above 20 to 25 psig. This is shown in Fig. 11.

Particle-size distribution data for the Model III-A are shown in Appendix A. At 25 psig on the nozzle and consequent flow rate of 86 lpm, the experimental LSGMD obtained is 0.83 μ. The average size obtained is identical to that value (0.83 μ) for the Model II aerosol generator, which also has no impactor. In contrast the Model III aerosol generator has for the same flow rate (at 25 psi) of 86 lpm a LSGMD of 0.69.

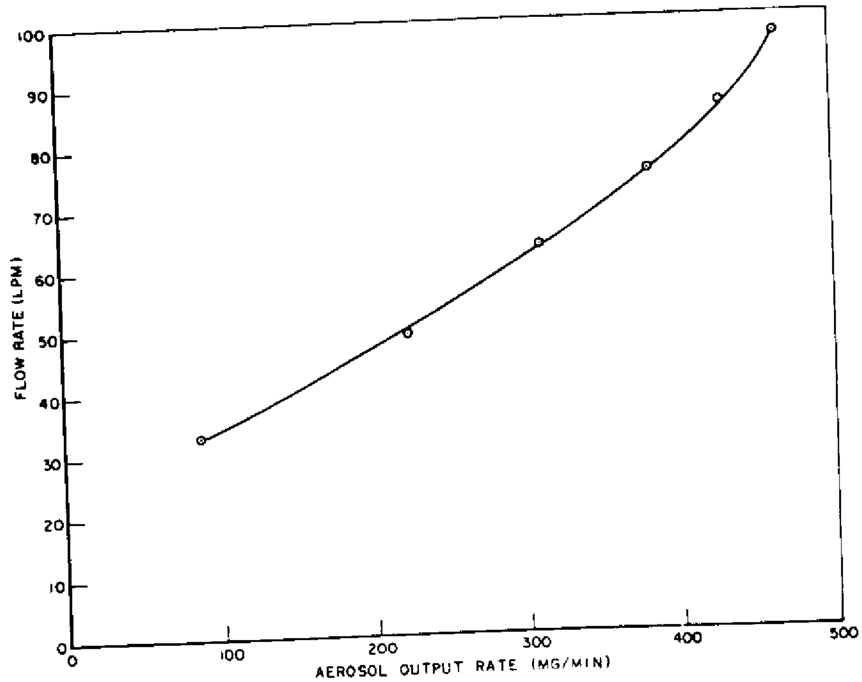


Fig. 11 - Flow rate in mg/min vs flow rate in lpm

In Fig. 12 the airflow rate in lpm through the atomizer nozzle used in Models I, II, III, and III-A is plotted as a function of air pressure applied to the nozzle. Since the nozzle is the flow controller in any of the generator systems, this curve is valid on a per nozzle basis excluding the Model IV and its counterpart, Model IV-A. The flow rate versus pressure curve in Fig. 12 is obtained from averages for approximately a dozen Model III aerosol generators. Since differences occurred among the Model III generators of as much as 9 percent deviation from the average at 5 psig to 3 percent at 30 psig, the average flow rate is given as representative of all the Model III generators. Since only one Model I aerosol generator was available, the flow rate obtained is shown. These values are within the flow rate ranges obtained for the Model III.

Models IV and IV-A

The Model IV aerosol generator represents recent efforts to reduce compressed air requirements for aerosol generation. Attempts to reduce this requirement involved experimental studies with various air-hole sizes and the subsequent effects on the airflow rate, mass concentration, and particle-size distribution. From these experiments it was concluded that an air-hole diameter considerably smaller than 0.040 inch would be more effective. Optimum hole size was found to be approximately 0.015 inch for DOP aerosol generation at pressures of 30 to 40 psig on the nozzles. However, the large number of air holes of this diameter necessary to produce an amount of dispersed DOP equivalent to that produced by the Model III-A aerosol generator made a nozzle of this type impracticable. The most favorable comparison indicates it would be necessary to have at least 4-1/2 nozzles (each with four 0.015-inch-diameter holes) to produce the quantity of aerosol equivalent to that of the Model III-A.

Consequently a different approach was attempted, that of using a slit-type nozzle. In order to reduce air volume requirements, the open area of the slit had to be less than that of four air holes (0.040-inch diameter) with an open area of approximately 5.03×10^{-3}

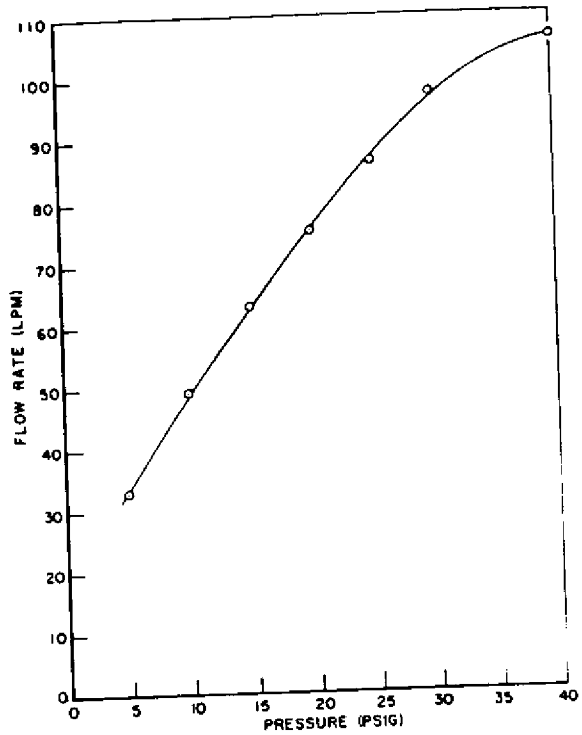


Fig. 12 - Flow rate vs pressure on nozzle - Models I, II, III, and III-A

sq. in. Thus it was decided to establish the parameters for a nozzle of approximately 1.5 mil slit size by 1.964 inches diameter which would have an open area of approximately 2.93×10^{-3} sq in.

Because of the uncertainty involved in establishing a proper width, the prototype slit nozzle was designed so that its open area could be adjusted. The piston and chamber were threaded with micrometer-sized threads so the width of the slit could be set at any desired setting and locked into position by means of a lock washer and nut.

The average width of the first setting, measured with a 30-power microscope, was approximately 1 mil. Initial mass concentration and particle size distribution data indicated the performance of this type nozzle was excellent. At 40 psig air pressure on this nozzle (and without an impactor) 57.5 liters of aerosol per minute was generated having a LSGMD of approximately 0.85μ and a mass concentration of 6.42 mg/l. This indicated approximately 20 to 25 percent less total air input was required at 40 psig to achieve the same total dispersed phase production as compared to the Model III-A at 25 psig.

A 1.5-mil slit opening was also studied. (A measured slit opening of 1.8 mils was found to result in flow rates that were too high.) The open area for the 1.5-mil slit was 2.95×10^{-3} sq in. as compared to 1.96×10^{-3} sq in. for the 1.0-mil opening. Flow rates through this larger opening at nozzle pressures of 5 through 40 psig were approximately 50 percent greater than for those with the smaller slit. Mass concentrations were comparable at the same nozzle pressures, except at lower pressures the larger opening resulted in higher mass concentration (1.99 mg/l for 1.5-mil opening compared to 0.99 mg/l for 1.0-mil slit, both at 5 psig).

Based on the preliminary results with the adjustable-slit nozzle, the decision was made to fabricate a fixed-slit nozzle with an opening of approximately 1.0 mil and a length of 1.964 inches. Since the main purpose was reduction in compressed air input, the smaller opening was chosen. Design and construction of the fixed-slit nozzle has been previously described (Fig. 5).

As measured with the "Shadowgraph," the width of the prototype fixed-slit nozzle was 1.1 mil. The variables – flow rate, mass concentration, and particle-size distribution – with and without a jet impactor (Model IV and Model IV-A, respectively) were determined. A jet impactor of the same dimensions as that used in the Model III aerosol generator was used in the Model IV. Performance data for the Model IV and Model IV-A are included in Appendix A.

A comparison of the data (Appendix A) for the Model III-A and the Model IV-A shows that the particle-size distribution produced at identical nozzle pressures are very similar. LSGMD's are nearly identical. However, as indicated by the σ_g, the aerosol system of Model IV-A shows a slightly greater dispersion at high nozzle pressure. Though the Model III-A produces a greater mass concentration below approximately 20 psig air pressure on the nozzle, the Model IV is superior in this respect above 20 psig. An equivalent flow comparison shows that the Model IV at 35 psig air pressure on the nozzles generates approximately 59 liters of aerosol per minute at a mass concentration of 6.09 mg/l. In contrast the Model III-A aerosol generator produces, at approximately 14 psig, 59 liters of aerosol per minute at a mass concentration of approximately 5.00 mg/l. Mass concentration rarely surpasses 5.10 mg/l for the Model III-A aerosol generator, whereas the Model IV-A exceeds 6 mg/l above 34 to 35 psig on the nozzle and is still increasing at slightly higher pressures. These data show that where compressed air source limitation is a factor to be dealt with, there is a definite advantage in using the Model IV-A.

Mass concentration as a function of pressure (or flow) is not as high for the Model IV as for the Model III at similar pressures. The LSGMD's are lower, which would indicate that the Model IV produces an aerosol having a polydispersity slightly greater than that for the Model III.

It has been found that foreign matter from an unfiltered compressed air supply can contaminate the atomizer nozzle air holes and smaller jet impactor slits. The worst fouling, however, is the debris from the interior of high-pressure hose which sometimes flakes off when the hose is slipped onto the nozzle. Should this happen, it usually severely restricts nozzle flow rate and consequently affects performance and reproducibility. A filtered air supply prevents contamination from the compressed air. To prevent fouling from hose debris, quick-disconnect, metal couplings for the high-pressure-hose connections are used.

CONCLUSIONS

Where polydispersions suffice, the only requirements for generator activation is an adequate, well-regulated and filtered compressed air supply and the proper liquid. These portable air-operated aerosol generators produce known and reproducible mass concentrations as well as known and reproducible particle-size distribution. In many instances these generators may serve as inexpensive and useful substitutes for the rather costly and somewhat less easily managed standard apparatus which produces monodisperse aerosols. They have potential value in many laboratory and field studies in which portability may be a requirement or practicability rules out the use of condensation-type aerosol generators.

An excellent example of the application of the Model III aerosol generator is that of evaluating high-efficiency filter systems. In this evaluation a condition approaching monodispersity and a lower mean particle diameter (i.e., that which approaches a 0.3 μ diameter monodisperse aerosol) is desirable. Because of the composite nature of high-efficiency filter units and the fact that gasket bypass coupled with leakage due to imperfection within the filter units is almost always greater than actual filter penetration, true monodispersions are not necessary for ascertaining installed filter performance.

These aerosol generators have found other applications. They have been used to determine the integrity of gas masks and gas mask components, glove boxes, and air lock systems. They have also been used in ventilation distribution studies and in the study and evaluation of electrostatic precipitators.

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APPENDIX A

AEROSOL GENERATOR PERFORMANCE

Pressure (psig)	Flow (lpm)	Mass Concentration (mg/l)	LSGMD (μ)	(μ)
Model I				
5	32	0.50	0.83	1.57
10	48	1.02	-	-
15	62	1.22	0.76	1.45
20	73	1.27	-	-
25	84	1.26	0.70	1.37
30	95	1.24	-	-
Model II				
5	198	2.07	-	-
10	294	3.78	0.94	1.44
15	378	4.52	-	-
20	450	4.82	-	-
25	516	4.95	0.82	1.40
30	582	4.85	0.80	1.37
Model III				
5	33	0.63	0.82	1.31
10	49	1.28	0.74	1.29
15	63	1.58	0.72	1.26
20	75	1.64	0.70	1.23
25	86	1.64	0.69	1.26
30	97	1.60	0.68	1.26
Model III-A				
5	33	2.63	0.88	1.61
10	49	4.57	-	-
15	63	5.10	0.84	1.51
20	75	5.10	-	-
25	86	5.00	0.83	1.44
30	97	4.80	-	-
Model IV				
5	190	0.36	-	-
10	27	0.62	-	-
15	34	0.73	0.75	1.35
20	40	0.89	-	-
25	47	1.06	0.68	1.36
30	53	1.24	-	-
35	59	1.34	0.63	1.29
38	63	1.44	-	-
Model IV-A				
5	19	1.60	-	-
10	27	2.88	-	-
15	34	4.06	0.92	1.60
20	40	4.84	-	-
25	47	5.24	0.84	1.55
30	53	5.46	-	-
35	59	6.09	0.82	1.51
38	63	6.17	-	-