GENERATING AEROSOLS FOR LASER VELOCIMETER SEEDING

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INTRODUCTION

The laser velocimeter (LV) is a unique tool for fluid flow measurements. In such measurements, even though the fluid velocity is of primary interest, the LV signal originates from seed particles present in the fluid and the LV actually measures the velocity of these particles. Thus it is important that a sufficient number of seed particles be present in the fluid and they scatter sufficient light to produce LV signals. Also, the seed particles should follow the fluid with nigh fidelity.

Aerodynamic diameter is the true measure of a particle's ability to follow the flow. The aerodynamic diameter of a particle is defined as the diameter of a unit density sphere with same settling velocity as the particle in question. It is affected by geometric diameter, density and shape of the particle. For LV seeding, particles with smaller aerodynamic diameter are desirable because they follow the flow more readily. On the other hand, in general, the particle's ability to scatter light increases with its geometric diameter and its refractive index.

Monodispersity is a measure of the uniformity in particle size. It is represented by geometric standard deviation, σ_g. The σ_g of an aerosol could be calculated by using the equation:

$$\sigma_g = \frac{d_m}{d_1} = \frac{d_2}{d_m} = \sqrt{\frac{d_2}{d_1}} \tag{1}$$

where d_m is the mean diameter of the particles. The d_1 and d_2 are defined so that 15.87 percent of the aerosol particles have a diameter smaller than d_1 and 87.13 percent of the aerosol particles have a diameter smaller than d_2. The σ_g of a perfectly monodisperse aerosol (all particles have identical size) is 1.0.

For a given LV application, monodisperse aerosol containing particles of a particular optimum size is desirable. The particles of optimum size must be large enough to scatter sufficient light, but small enough to follow the flow. Once this optimum size is established, particles that are either smaller or larger than this size are undesirable. Smaller particles do not produce a useful LV signal, but they do scatter light which adds to the noise. The large particles produce signals which are not representative of fluid velocity.

In the past, very little attention has been paid to selecting the right particles for a given application. This is partly because not very many seeders were available, and partly because LV users had not realized the importance of seed particles and were not paying reasonable attention to the seed particles. This has often led to expensive trial and error of the various seeds in the actual facility. The cost of particle generation should be reviewed with respect to the total cost of the project. A reliable, well-characterized particle generator capable of producing large numbers of monodisperse particles of optimum size may actually save thousands, even tens of thousands of dollars in facility running cost. In some applications, a good particle generator may enable one to use a less expensive laser or signal processor, thereby reducing the total cost of the LV system.

Today it is possible to design the right seed particle for a given
application. The first step would be to decide what aerodynamic diameter
particle will follow the flow with sufficient fidelity. The next step would be
to decide on a seed particle material considering its refractive index, toxicity
and errosion properties. Then the optical system should be designed which is
capable of giving measurable LV signal from the seed particles (refs. 1, 2).
Finally, a seeder that will give monodisperse particle of the selected size in
right number should be developed. The point is that now tools are available to
evaluate and control parameters independently and one does not have to depend on
trying various seeders in the facility and seeing what works. A detailed
description of the various seeders available from TSI is given in reference 3.

AERODYNAMIC PARTICLE SIZER

The first instrument that we found very useful in characterizing seed particles is the Aerodynamic Particle Sizer (TSI Model APS 33, ref. 4).

In this instrument the velocity of the particles accelerating from a thin plate orifice is measured using laser velocimetry.

The accelerating orifice assembly consists of a 0.8-mm inner nozzle and a 1.0-mm outer orifice. The inner nozzles receive 20% of the sampled flow, while the remaining 80% passes through a filter and flowmeter and is reintroduced as sheath air. This confines the sampled aerosol particles to the center portion of the accelerating jet.

The beam from a 2-mW He-Ne laser is split by a calcite plate, producing two beams. These beams are then focused to produce two parallel beams with rectangular cross sections just downstream of the accelerating orifice. The light scattered by the particles passing through the beams is collected and focused onto a photomultiplier tube. A particle passing through the two beams produces a pair of pulses. The particle velocity is determined by measuring the time between the two pulses. A microcomputer system converts the velocity data to size distributions and displays the data.
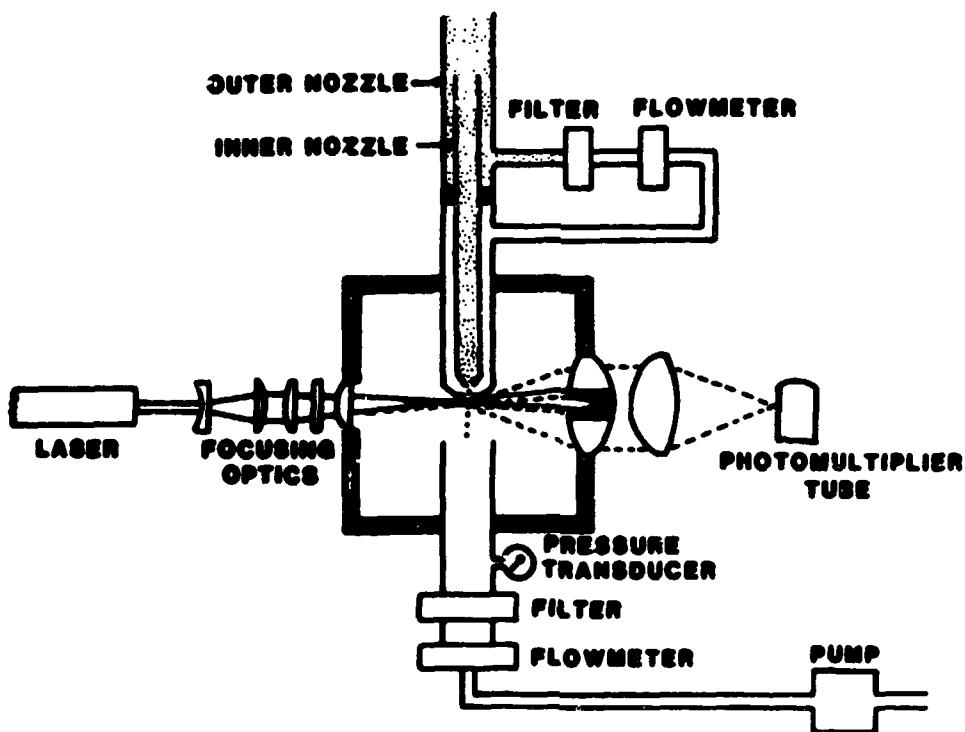

SCHEMATIC OF SENSOR

DIFFERENTIAL MOBILITY ANALYZER

The Differential Mobility Particle Sizer (DMPS, TSI Model 3932, ref. 5) is a unique submicrometer particle instrumentation that offers the fastest, easiest method of obtaining high resolution particle data in the 0.01-1.0 micrometer range. Electrical mobility, which is inversely proportional to particle diameter, is a measurement of how rapidly an electrically charged particle responds to an electric field. Aerosols entering the Electrostatic Classifier acquire a known charge level by passing through a Kr-85 neutralizer. The particles are then passed on to a Differential Mobility Analyzer that consists of two concentric cylindrical electrodes. A high voltage supply controlled by the computer maintains the center electrode at a precise negative potential. The outer electrode is at ground potential.

Inside the DMA is a core of particle-free sheath air surrounded by an annular ring of aerosol. The sheath air and aerosol both flow laminarly downward between the electrodes with no mixing of the two air streams. Particles with positive charges are attracted toward the negative-charged center electrode. The trajectory of the particle is a function of flowrate, analyzer geometry, electric field, particle diameter and the number of charges on the particle. Only those particles within a narrow, predictable mobility range pass through a slit near the bottom of the center electrode. The number concentration of these particles is measured with a Condensation Nucleus Counter. A microcomputer takes the data and presents the particle size distribution.

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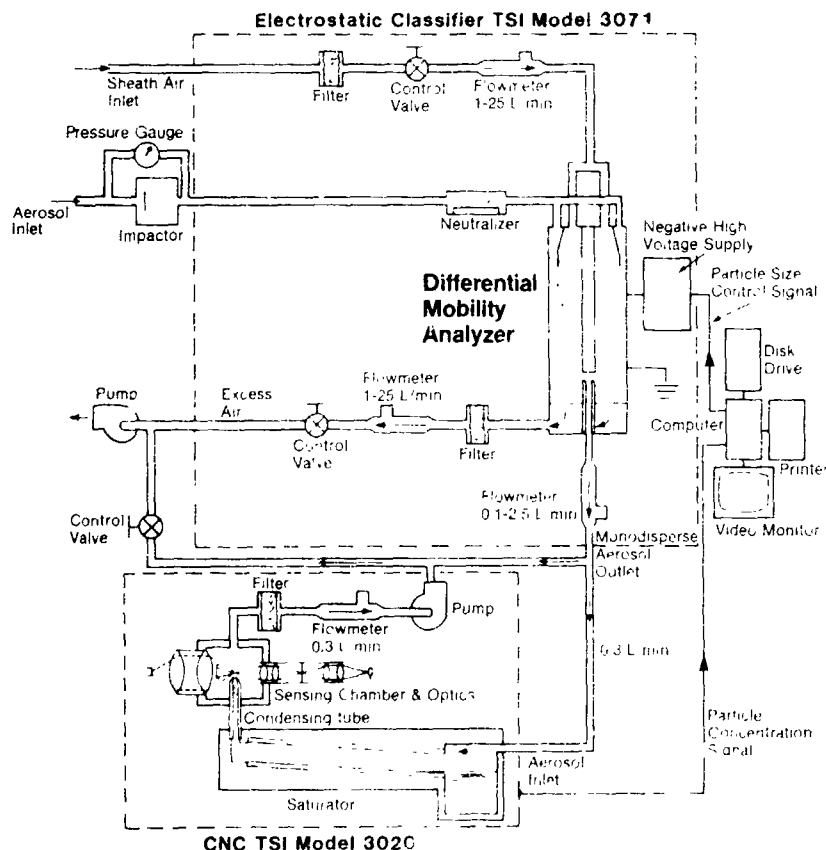
ELECTROSTATIC SAMPLER

Another instrument that is quite useful in evaluating seed particles is the Electrostatic Aerosol Sampler (TSI Model 3100, ref. 6). It consists of a charging section and a collecting section. A vacuum pump draws the aerosol through the system at a constant rate. As the aerosol passes through the charging section, the particles are subjected to alternating pulses of positive ions generated by a corona discharge from a fine wire. The positively charged particles then flow through the collecting section. A positive voltage periodically applied to the upper plate drives the particles to the lower surface. After sufficient time to deposit all charged particles, the voltage on the upper plate is shut off. The continuous aerosol flow through the chamber again fills it with charged particles. The unique separation of the charging section and the collecting section, together with the pulsed precipitating voltage, produces a uniform, representative sample, which may be evaluated without bias due to particle characteristics

The instrument allows precise determination of the sampled aerosol quantity because this volume is completely independent of the flow rate through the instrument. Volume depends only on the number of precipitating pulses or cycles and the volume directly above the sample surface. This instrument is used to collect samples of seed particles on a microscope slide. The microscope slide is then examined under an electron or optical microscope. The geometric size of the seed particles can be obtained by visual examination of the collected sample. Also, the number concentration of the seed particles can be calculated by counting the number of particles per unit area of the microscope slide.
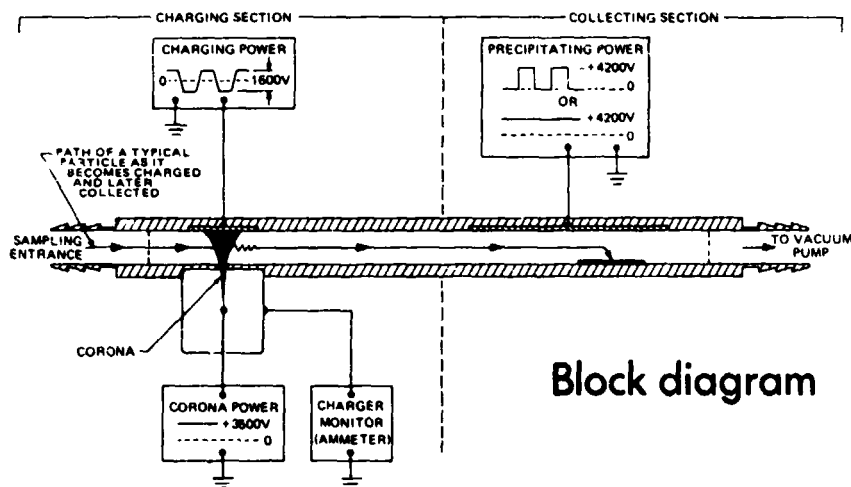

MODEL 3100—ELECTROSTATIC AEROSOL SAMPLER

ATOMIZATION

Atomization is the most commonly used method to generate seed particles. Atomization is a process in which a high velocity air jet produces a fine spray of droplets by shearing off a liquid film. This process is simple and reliable. The most wide-spread use of atomizers is in medicine for inhalation therapy. Atomizers of various kinds are also used for lubrication in machining operations, dust suppression, and aerosol generation for filter testing. An atomizer can be used to produce seed particles in one of three ways:

1) Generate liquid droplets - In LV seeding, atomizers are often used to produce an aerosol from liquids such as DOP (dioctyl phthalate) or silicon oil. The particle size and number concentration depend on the surface tension and viscosity of the liquids as well as the design of the atomizer.

2) Generate solid particles from a solute - Solid particles of material such as salt can be generated by first atomizing a solution of the material in water and then drying the droplets. After the evaporation of the solvent, an aerosol of solute is obtained. The size of the particles can be varied by varying the concentration of the solute.

3) Generate monodisperse PSL particles - A monodisperse aerosol can be generated by atomizing a dispersion of uniform particles (such as Dow Diagnostic's polystyrene latex (PSL) particles) in a liquid. When the atomized droplets are dried, the size is reduced to that of the original solid particles. However, it is important that the concentration of solid particles in the dispersion be low enough so that the probability of having more than one particle per droplet is low (ref. 5). Normally, 5 drops of dispersion (10% solid) per liter of distilled water give the right dilution for LV seeding applications.

1. Atomizer Jet

2. Liquid Tube

3. Pressurized Air In

4. Spherical Impactor

5. Dilution Air In

6. Aerosol Outlet Tube

7. Drain

8. Atomizer Liquid
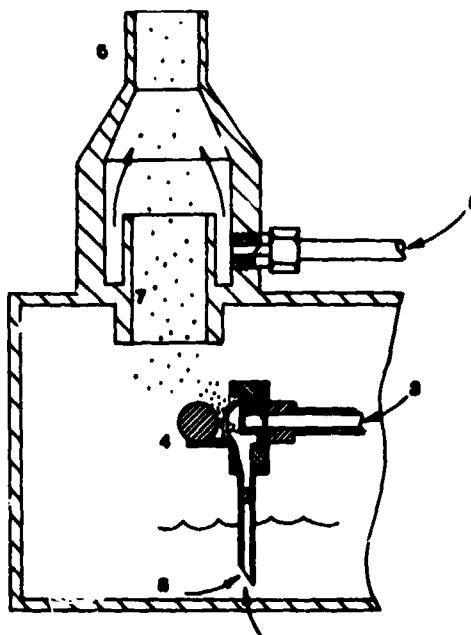
SEEDERS BASED ON ATOMIZATION PRINCIPLE

1.   Model 9302

The Model 9302 atomizer was specifically designed as a set-up tool for LV systems. The aerosol exits through a 1.0 mm black Delrin nozzle in the form of an aerosol stream. The aerosol stream can be easily directed toward the LV measuring volume by positioning the flexible steel aerosol outlet tube. When the black Delrin nozzle is moved in or out, a bypass slit is partially covered or uncovered, thereby increasing or decreasing the velocity of the aerosol stream.
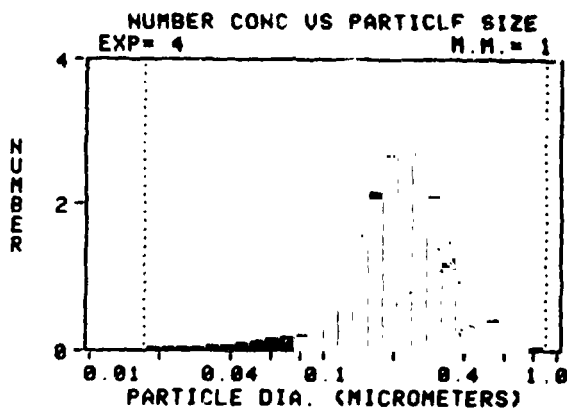
2.   Model 9306

The Model 9306 atomizer has six atomizer jets. The atomizer is designed to introduce aerosol into a system under pressure (up to 400 kPa or 60 psi). Since any number of jets (1 through 6) can be selected, it provides the flexibility of changing the particle number concentration. The built-in dilution air system makes this atomizer ideal for generating dry monodisperse PSL aerosol as well as salt aerosol.
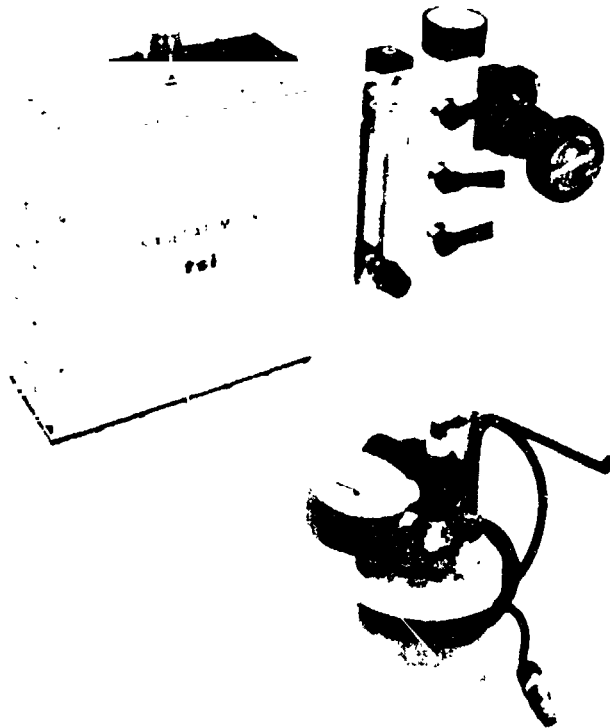
PARTICLE SIZE DISTRIBUTION OF SEEDS GFNER⚹ ⊃ BY 9302/9306 ATOMIZER

The particle size distribution of the corn oil aerosol generated by the MOdel 9302 or 9306 is shown below. This size distribution was measured by the Differential Mobility Analyzer. The operating parameters for the atomizer are compressed air pressure (input) = 35 psi. Aerosol flow rate = 3 LPM per jet.

```
TSI DIFFERENTIAL MOBILITY PARTICLE SIZER
      RFTI  CORN OIL PARTICLE SIZING
         AEROSCL FLOW RATE:  .3 LPM        MEAS. MODE: 1
      MAXIMUM DIA. MEASURED:  .884 UM      START: 00:00:00
      MINIMUM DIA. MEASURED:  .017 UM      END: 00:08:00
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NUMBER CONC VS PARTICLF SIZE
EXP= 4   M.M.= 1

PARTICLE DIA. (MICROMETERS)

This is the process of evaporating an oil and allowing the vapor to recondense on ultra-fine nuclei particles under controlled conditions. Once the condensation process begins, the particles grow until all the oil vapor is consumed. Thus, if the condensation on the nuclei can be controlled to begin at the same time, all the particles will grow to the same size. This technique is widely used for filter testing (the particle generators are generally called hot DOP generators). Even though the principle is simple and well proven, the need for precise control of vapor feed rate, nuclei feed rate. and other parameters introduces several practical problems. This method is also limited to oil droplets. The advantage of this technique is that the generated aerosol is very monodisperse ($\sigma_g \approx 1.2$).

TSI markets a system based on this principle which consists of TSI Models 3074, 3075, and 3072. The Model 3074 is an air supply system consisting of a pressure regulator, air dryer, and high efficiency air filter. The Model 3075 is a non-recirculating type constant output atomizer using a syringe pump feed. The atomizer is used to generate DOP aerosol from a DOP and alcohol solution The DOP aerosol then passes through the Model 3072 aerosol conditioner. It consists of a heated evaporation section where the DOP is vaporized. After the evaporation of DOP, a large number of ultra-fine residue particles made of nonvolatile impurities contained in the DOP are left behind, which subsequently act as condensation nuclei. The air then passes through the cold section where the DOP vapor condenses on the residue particles.
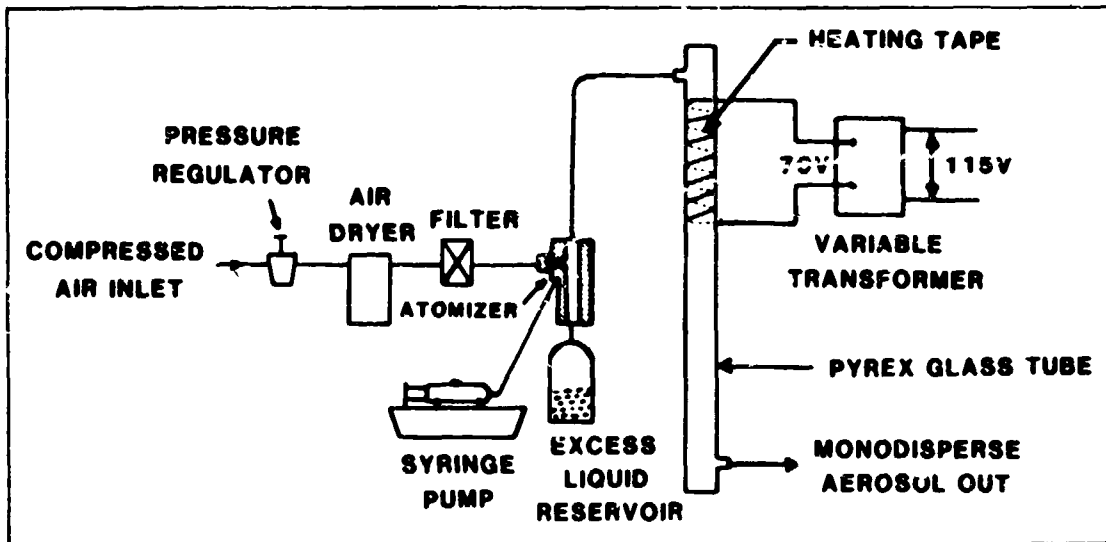
EVAPORATION/CONDENSATION SEEDER USING NaCL NUCLEI

Another type of evaporation/condensation generator is schematically shown below. Even though no standard commercial product is available at this time, such a seeder is available from TSI built on a custom order basis. It consists of an atomizer, a syringe pump, a heating coil and a cooling chamber. NaCl particles generated by the atomizer provide the condensation nuclei, and the DOP introduced by the syringe pump provides the aerosol material. The condensation nuclei and DOP mixture pass through a heating coil, where the DOP is vaporized. The mixture is then cooled in a chamber located immediately after the heating coil. The DOP vapor condenses on the NaCl particles causing the submicron NaCl particles to grow. The particle growth stops when the DOP vapor is consumed. Since the number of nuclei generated by the atomizer is constant, the particle size can be controlled by the DOP feed rate.

The main advantage of such an aerosol generator is that it produces reasonably monodisperse aerosol in large quantity.
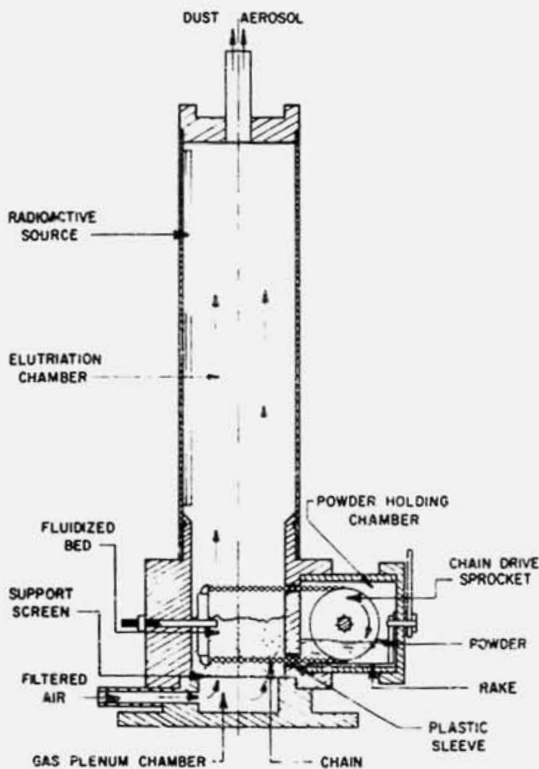

Evaporation/Condensation Seeder
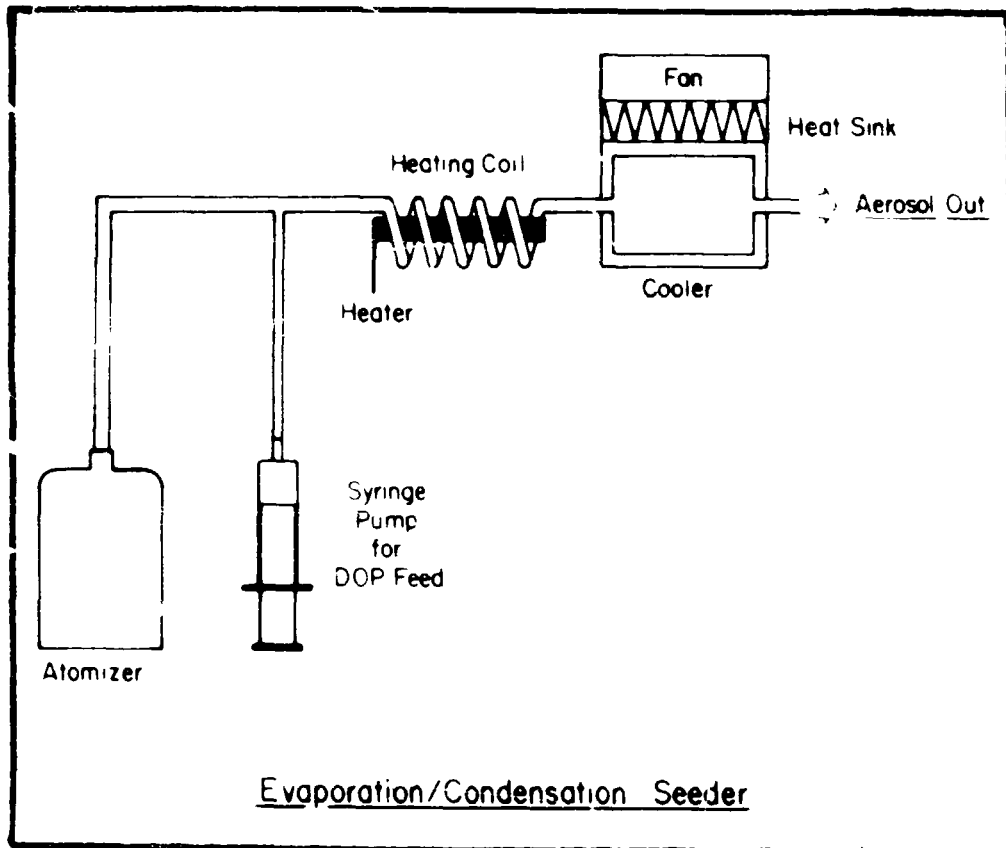
SEEDERS BASED ON THE PRINCIPLE OF DISPERSING SOLID PARTICLES:

MODEL 3400

The Model 3400 fluidized bed aerosol generator shown below is a dust generator designed to disperse any kind of non-sticky powder. The powder to be dispersed is stored in the powder chamber and is constantly fed into a bed of bronze beads by a variable speed bead-chain drive. The powder mixes with the bronze beads and coats them with a single layer of particles. An air stream then strips the particles from the beads and carries the particles with it in the form of an aerosol. By this process, an aerosol consisting of deagglomerated particles is obtained.

The adjacent micrograph shows the titanium dioxide particles dispersed by this seeder. The sample was collected by the electrostatic sampler described earlier.
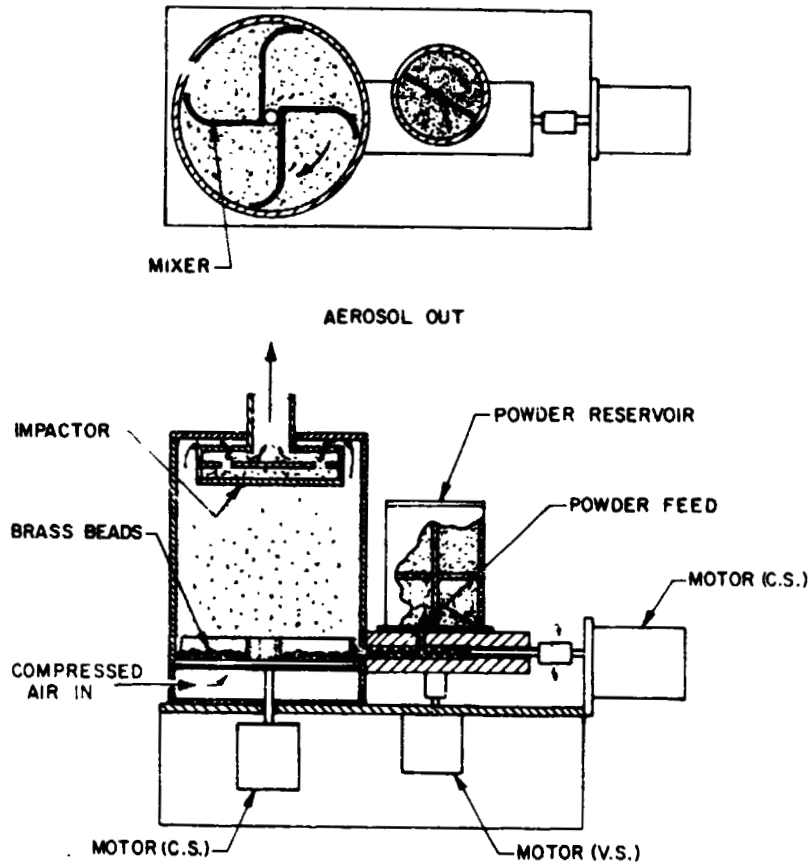
# SEEDERS BASED ON THE PRINCIPLE OF DISPERSING SOLID PARTICLES:
MODEL 9310

This dust generator shown below is similar to the Model 3400, but it was designed to disperse much larger amounts of dust. The powder to be dispersed is stored in a powder chamber. The powder is continuously transported from the powder chamber to the bronze bead bed through a rotating spring. A stream of air strips the powder material from the bronze beads and carries the particles with it. As in the Model 3400, the aerosol output is constant and nearly complete deagglomeration is achieved.

MIXER

AEROSOL OUT

IMPACTOR

POWDER RESERVOIR

POWDER FEED

BRASS BEADS

MOTOR (C.S.)

COMPRESSED
AIR IN

MOTOR (C.S.)

MOTOR (V.S.)

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DRY POWDER DISPERSER: MODEL 3410

The Dry Powder Disperser is a power dispersion system using mechanical abrasion from a bulk of densely packed powder by a rotating brush. The bulk powder is contained in a metallic cylinder and is continuously pushed towards the rotating brush by a piston moving at a specified velocity. Particles are broken out of the top surface of the bulk and are swept away by air passing through the brush. The seeding rate can be varied by varying the piston speed. When the cylinder is empty, it can be conveniently replaced by a filled one and the seeding can be resumed in a few minutes. To fill a cylinder, the powder is poured into the cylinder and compressed manually to give constant bulk density to the powder compound. Any dry and non-sticky powder can be dispersed by the Model 3410.

The adjacent micrograph shows the titanium dioxide particles dispersed by this seeder. The sample was collected by the electrostatic sampler described earlier.
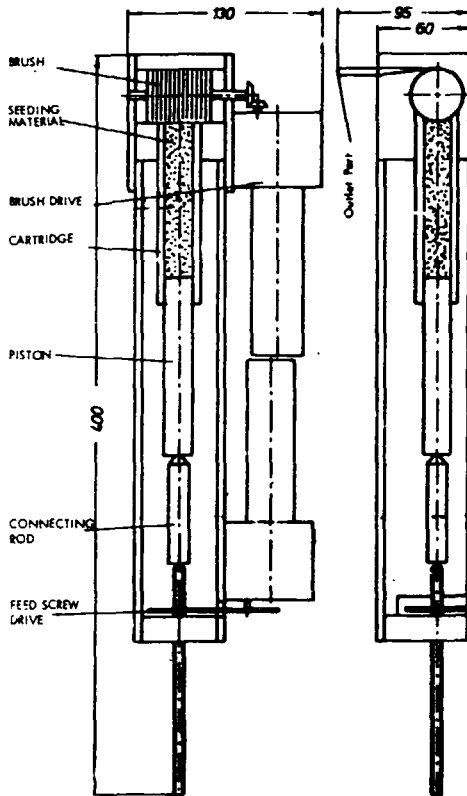
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