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EVALUATION OF PROPOSED TEST METHODS FOR AIR CLEANERS

SEYMOUR CALVERT
THOMAS E. SLYKHOUSE
DONALD M. ARVESON
J. LOUIS YORK

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INTRODUCTION

This report covers one aspect of an engineering investigation of the performance of induction air cleaners and their principles of performance. The objectives of the overall investigation were stated in the contract between the Detroit Arsenal and the Engineering Research Institute as follows:

(a) Determine the basic principles involved in the mechanism of operation of existing air cleaners and measuring the limits and quantitative effect of these principles on performance, with first emphasis upon the oil-bath units now employed extensively.

(b) Organize these principles and quantitative measurements to furnish a basis for evaluating new design, developing improvements in existing cleaners, and developing new designs.

(c) Furnish technical background for preparation of revised specifications for air cleaners.

After several months of study it became apparent that the biggest deterrent to rapid progress in the experimental testing and evaluation of air cleaners was the lack of a satisfactory dust collection efficiency test. The method widely used by air-cleaner manufacturers and the Detroit Arsenal consists of dispersing A. C. test dust in air, feeding the resulting suspension to an air cleaner, and filtering the entire effluent stream through Canton flannel. The collection efficiency is determined from the weight loss of the dust feeder and the weight gain of the "absolute" filter. There are several drawbacks to this method.

First, the dust feeders employed do not completely de-agglomerate the test dust. As a result, the dust dispersion product has a larger mean particle size than the size analysis of the A. C. dust indicates and the efficiency of the air cleaner is higher than it would be for a true dispersion of the test dust. This is indicated by the fact that a precleaner attached to an oil-bath air cleaner causes the combined efficiency to be lower than

that for the oil-bath cleaner alone. Also, passing the dust-laden air from a "stoker" type dust feeder through an air jet ejector causes the collection efficiency of an oil-bath air cleaner to drop from around 98 percent to the range of from 60 to 80 percent. Since the effect of both the precleaner and the ejector is to break up agglomerates (little or no primary grinding occurs), it is obvious that the original test dispersion contained an appreciable quantity of agglomerates of small particles.

Second, the absolute filters are quite troublesome to use since they must be large (because of their pressure drop and efficiency limitations) and will absorb moisture. Considerable time is expended in running a test long enough to collect a weighable quantity of dust on the filter, dismantling and drying the filter cloth, and in weighing the cloth and filter holder. Because the filter is so large, an abnormally large analytical balance must be used in order to accurately determine its weight.

Third, the range of efficiency obtained with the incompletely dispersed A. C. test dust is so high that variations in air-cleaner performance are reflected by changes in efficiency of about one percent and are consequently hard to detect. Another disadvantage of the high efficiency range is that any sort of filtering or sampling process performed on the effluent air must be carried out for a long time in order to collect enough dust to weigh.

The situation may be summarized by stating the requirement which a good test method would fulfill. These requirements are as follows:

1. The test dust should be completely dispersed and agglomerate-free so that its actual particle-size distribution in suspension is known.

2. The particle-size distribution of the test dust should be such (i.e., small enough) that the efficiency of a standard air cleaner will be approximately 50 percent and changes in air-cleaner design and performance will cause appreciable variations in collection efficiency.

3. The method for determining the dust concentration in the inlet and outlet air should be accurate and rapid and, if possible, should provide a continuous record of instantaneous readings. The time required for an efficiency test should be no longer than about 10 minutes.

POSSIBLE IMPROVED TEST METHODS

Quite a few methods can be conceived, many of which have been reported in the literature, which offer promise for meeting the requirements for a good collection efficiency method. The basic points of these methods may be classed as methods of dispersal, methods of sampling, and methods of aerosol analysis without sampling. Among the methods of dispersal are the redispersal of a powder in air, the spray drying of a solution containing a dissolved solid, the condensation of a vapor to form liquid droplets, and the formation of liquid droplets by atomization. While the employment of liquid drops has some advantages, it was considered more appropriate to employ solid particles for the testing of oil-bath cleaners since their retention in the cleaner is partially dependent on their being wetted by the oil. Some sampling methods suitable for this application are wet collection (preferably of a soluble dust), electrostatic precipitation, thermal precipitation, and filtration with a millipore filter. All of these methods would be applied to the separation of dust from a small sample of the total air stream. To insure that the sample be representative it would have to be taken under isokinetic conditions; that is, the velocity into the sample tube must match the local velocity of the main air stream. While the last three methods listed are capable of very high collection efficiency, they all require the disassembly of apparatus and the removal of the captured sample for weighing. The first method listed is not quite as efficient as the others, but it possesses the attractive feature of being capable of continuously dissolving the dust in a solution whose properties can be measured.

The principle methods of analysis without sampling involve the application of light-scattering measurements or the use of radioactive tracers as test dust. Both methods have the advantage that they can continuously monitor a flowing stream without having to collect the suspended material.

THE EVALUATION OF PROPOSED TEST METHODS

While there was not sufficient time available under the present contract to fully explore and develop the possibilities for improved collection efficiency test methods, it was considered worth-while to briefly study and evaluate the most promising. The processes chosen for study were methods of redispersing powders in air, the spray drying of a salt solution, the analysis of a salt-dust suspension by means of a wet-collection device, the application of light-scattering techniques to aerosol analysis, and the use of radioactive test dust. The investigation of powder dispersal is still in progress and will be reported later. The evaluations of the remaining processes are presented in this report and may be summarized as follows:

1. Spray drying is a feasible process for the preparation of a suspension of salt particles suitable for air-cleaner testing. An experimental investigation of the characteristics of the dust produced by drying an air-atomizing spray indicated that a suitable quantity of dust ranging in size from 0 to 10 microns can be produced with simple apparatus. The maximum size of the particles can be controlled as desired by the proper design and operation of the apparatus.

2. The continuous analysis of a salt-dust suspension can be accomplished by the combined use of a wet-collection device and apparatus for measuring the electrical conductivity of the collecting liquid. Several collection devices were tested, and it was shown that both wet impingers and fiber-packed scrubbers are suitable. This type of device could be applied to the analysis of either a sample of the air stream or the entire stream.

3. Light-scattering techniques offer considerable promise as a rapid analytical method. The properties of a light-attentuation system were predicted by means of computations based on light-scattering theory as applied to a representative test dust (silica). It is shown that the method is capable of about 1/2- to 1- percent accuracy in collection efficiency determination and that it is most sensitive to the smaller particles. The measurement of forward scattering is another possibility along this line and could result in an even more sensitive method.

4. The use of a radioactive tracer as a test dust or as an additive to test dust would be feasible and would offer no great problem in protection from radiation. The most suitable tracers would be phosphorous 32 and sulfur 35, which are both beta emitters. The employment of Geiger counters as monitors on the inlet and outlet streams from an air-cleaner would permit the determination of collection efficiency to about 2- to 5- percent accuracy. Since the tracers have short half-lives, the disposal of sludge, etc., would be safe after a retention period of a few weeks.

A comparative evaluation of these methods leads to the recommendation that light-scattering techniques be the first choice for development as a routine analytical method. The second choice would be the use of a spray-dried salt dust and the wet-collection plus conductivity measurement analytical system. The use of radioactive tracers is not recommended as a routine test method because of the complexities of scheduling and the safety precautions required.

CHAPTER I

A SALT-DUST GENERATOR FOR TESTING DUST COLLECTION EQUIPMENT

(AN EVALUATION)

INTRODUCTION

The following report is a summary of the work carried on to determine the feasibility of using a salt-dust generator as an aerosol source for testing dust collecting equipment. The principle of this technique is to generate a dust of about 0- to 5-micron or 0- to 10-micron salt particles which are injected into a stream of air and passed through the equipment being tested. The effluent stream containing the salt-dust is sampled and the salt is collected in water. Conductivity of the solution is then used to measure the quantity of salt collected from the gas. Analyses of the inlet and outlet streams can thus be obtained for the calculation of collection efficiencies of the equipment being tested. The particle size range given above is a desirable one for testing engine air cleaners since it covers the region in which collection efficiency decreases rapidly with particle size.

Experimental dust generators were built and some data taken to permit the design of a unit suitable for incorporation into the test apparatus. This data and a description of the experimental dust generators are included in the report. A dust generator has been designed to illustrate the use of the information obtained from the experimental equipment, and a discussion of advantages and limitations of this equipment is included in the "Evaluation" section of the report.

SUMMARY

Experimental work on an air-brine spray-drying system for generating

salt dust showed that a device can be constructed which will produce a dust of small salt particles suspended in air. The size range of the particles in the dust can be varied by changing the operating conditions and the geometry of a settling chamber used for size classification. This dust generator will operate continuously for about a half hour with only occasional adjustment, and the rate of atomization will remain uniform throughout the period of operation.

Exploratory work was done on the CO_2 brine system, where CO_2 was to dissolve in the liquid at from 600 to 900 psig and help to atomize the liquid when sprayed, but the method showed no signs of providing any substantial increase in atomization efficiency and it was discarded.

An impinger and a water-washed packed bed were evaluated for collecting the salt-dust particles. The impinger was successfully used in conjunction with a conductivity cell and an a-c conductivity bridge and a rate of particle collection determined in this manner. In an impinger considerable evaporation and atomization occur, which makes conductivity measurement somewhat inaccurate if small volumes of liquid are used, and large volumes decrease the sensitivity of the measurements. In a water-washed packed bed, the recirculation of liquid requires a pump in the system, which not only may add to the time lag of conductivity measurement but may also cause an error by increasing the conductivity of the liquid if any soluble metals are used in the pump. On the other hand, the water-washed packed bed can be made as efficient as the impinger, and does not atomize the liquid in the process of collecting salt-dust particles. It evaporates a quantity of water, which can be calculated from water content of inlet and exit air.

The design of a dust generator is illustrated in this report and suggestions for the selection of other components of the complete test setup are included.

EVALUATION

DUST GENERATOR

The dust generator proposed is a simple and convenient piece of equipment capable of continuous operation over a period of at least 10 minutes; only the tendency of the air orifice to clog would prevent unattended continuous operation for longer periods. It is quite possible that this difficulty can be eliminated by using a liquid-pressure-operated fog nozzle, rather than an air atomizer. Particle size of the exit dust can be controlled

either by changing the nozzle orifice or by adding more air to the separator through a second entrance. A one-nozzle unit as specified would yield about 0.0254 gm/min of sodium chloride suspended in 0.65 cubic feet per minute of 80 percent saturated air (or 0.039 gm/cu ft).

For air-cleaner testing, one would most likely run at a lower dust concentration than this by diluting the aerosol with clean air. That is, the aerosol generator might provide 10 percent of the total air flowing through a cleaner and the dust concentration would then be 0.0039 gm/cu ft. The concentration of 0.039 gm/cu ft is set by the amount of water which can be evaporated by the air, and this indicates the approximate maximum concentration which can be obtained with this technique.

Data on the size of particles generated (Figure 9) shows that a dust composed of 0- to 5-micron particles can be obtained. Theoretically, the particle size can be controlled by changing the geometry and operating conditions of the separator so that larger or smaller particles are elutriated and dried. This has not, however, been borne out by experiment, but should be attained if the generator is to have its maximum flexibility.

Neither nozzle size nor liquid recycle rate seemed to affect the rate of atomization in the range evaluated. There was considerable error in each series of data, but it shows the trends indicated in Figures 7 and 8. These trends indicated that a uniform atomization rate could be maintained in the presence of a fluctuating air rate and liquid recycle rate, if the range of operation is chosen properly. This characteristic of the generator permits it to be operated unattended and with only on-off control of the fluid flow rates, with very little variation in atomizing rate over long periods.

Clogging of the atomizing air orifice prevents extended operation. This might be remedied by using a sharp-edged orifice plate or by coating it with a nonadherent material. ("Krylon" resin spray helps to reduce clogging.)

Materials and utilities for operating the generator are easily obtained. Ninety psig air expanded to atmospheric pressure can be used as the drying air, and low-pressure air bubbled through water or contracted with a spray could be used as elutriating air. Saturated brine is obtained by recycling the liquid being atomized through a bed of sodium chloride.

This generator is similar to units mentioned in the literature except that the variables are more easily controlled, and more uniform atomization can be obtained in this unit. One of the units described in the literature[1] consists of a "sonic" air orifice directed downward into a brine solution in a container. Liquid is splashed onto the orifice tube and is

atomized as it runs down past the orifice. Large drops are collected in the liquid and the finer ones are carried upward and dried, forming the salt dust. In the unit described in this report, liquid flows past the orifice at a constant rate and will atomize more continuously than in the "splash feed" system. Also, the proposed design would provide better control of particle size by separately controlling the operation of the separator and dryer portions of the generator, and by varying the nozzle-diffuser diameter to remove more or less of the larger particles in the diffuser scrubbing action.

The high-pressure CO_2 - brine system showed little promise for dust generating purposes because it was necessary to operate intermittently, and about the same portion of sprayed brine was atomized as in the case of the air-brine system. Modifications of the apparatus shown in Figure 1, such as a recycle pump or an impingement atomizer, might give better results, in which case this system would be valuable.

COLLECTORS

The impinger was the only collector which worked satisfactorily from an operational standpoint. Collection efficiency data is available and was plotted in Figure 13. The one difficulty is that water evaporates rapidly and is atomized by the high-velocity air stream, and therefore any data on conductivity of the solution will not give an exact measure of the amount of material collected unless makeup water is added and a correction made for the small salt loss due to atomization. Outside of that, the impinger is effective for collection of salt dust down to about 0.4-microns diameter, and can be readily adapted to measuring the conductivity of the collecting water.

The water-washed pack-bed collector would be satisfactory in terms of collection efficiency, although the efficiency of an individual element of the packing may be very low, requiring a large amount of packing to be efficient. Usually less air pressure drop occurs across the packing than is needed to obtain sonic flow in the impinger and thus higher sampling rates can be used with the same ejector. A pump is required to circulate the liquid in a packed-bed collector because of the high pressure drop across the packing while an airlift is sufficient for circulating the liquid in the impinger because there is negligible pressure drop in the path of the circulating liquid.

OTHER ANALYTICAL METHODS

Flame photometry was suggested as a method for analyzing the quantity of salt in a given stream of air. This technique has previously been applied to the testing of filters[3] and in that case it involved the visual comparison of sodium lines from two hydrogen flames, one burning in the unfiltered sodium chloride smoke, and the other in the filtered effluent. An analysis of this method was not carried out, but it is probable that it could be used if the salt crystals did not settle out when being conducted through tubes. It would be desirable to use a method involving direct measurement of flame intensity with a photoelectric cell, rather than a comparative method.

Colorimetry was also suggested as an analytical method. The procedure would be to use a dust of some material which, when collected, forms a colored solution. The color versus concentration curve for this material then would tell the quantity of material collected at any time. Colorimetry suffers from the same sampling and collection difficulties as the conductivity measurements, but might be less troublesome since non-electrolytes may be employed either as dust or solvent. However, the flame photometer method does not require the salt to be collected and it offers the possibility of more direct measurement with less time lag, providing the instrument can be calibrated and used for gas samples.

OUTLINE OF THE EXPERIMENTAL PROGRAM

At the present time, there are several methods of sampling dust-laden air such as by filtering the air stream and measuring a gain in weight of the filter, or by drawing the air through an impinger, evaporating the collecting liquid, and weighing the residue. Many other methods are available, but these are among the most widely used. None of the known methods permit rapid and continuous measurement of dust concentration in air with a small amount of equipment.

It was reported in the literature[1] that a salt dust could be generated by atomizing a salt solution and evaporating the liquid from the drops, leaving small crystals of salt in the air. This technique was proposed for use in testing dust-collecting equipment. It showed promise of rapid and continuous analysis either by conductivity, colorimetry, or other measurement on a solution of the sampled dust, or by flame photometry or other measurements on the dust-laden air.

In order to provide a more complete basis for the evaluation of this type of system, a brief exploratory experimental study was made and the work progressed as follows:

1. Development of an atomization system.

   A. Investigation of a salt water - carbon dioxide (900 psi) system for producing salt dust. Qualitative tests indicated the use of 90-psi air in place of CO_2 as a more convenient atomizing fluid having slightly less effectiveness of atomization.

   B. Construction of a salt water - 90-psi air atomizing system, and preliminary evaluation of:

      (1) sizes of particles and their measurements
      (2) effect of geometry changes
      (3) effect of changing flow rates.

2. Development of an analytical system.

   A. Construction of a dust collector for sampling the dust stream generated, and evaluation of collection efficiency for:

      (1) packed column collectors (water-washed)
      (2) impinger

   B. Development of a method for determining the conductivity of a solution for sample NaCl dust.

   C. Construction of an ejector for evacuating the impinger.

EXPERIMENTAL DUST GENERATORS

BRINE - CARBON DIOXIDE ATOMIZATION

Carbon dioxide atomization of salt water was attempted by dissolving CO_2 in a saturated NaCl solution under 600 to 900 psi, and then spraying the solution into the atmosphere through a suitable nozzle. Figure 1 shows the system used for these tests. The system shown in Figure 1 permitted both

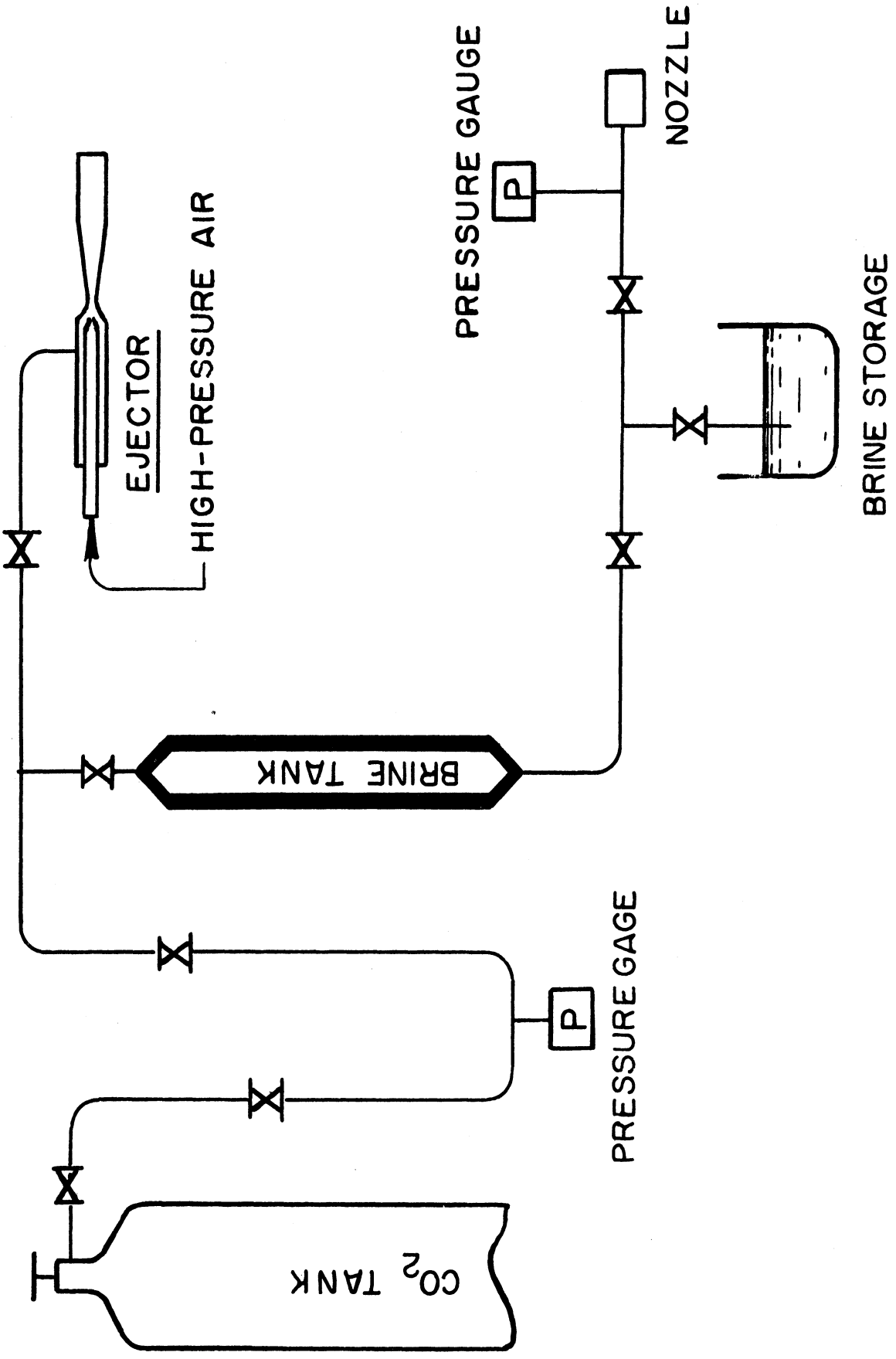

Figure 1. Brine - CO_2 atomization system.

pressurizing of the brine tank with CO_2 to spray the liquid, and evacuation of the brine tank by means of the ejector to draw fresh liquid into the tank from the solution-storage tank. Spraying pressures ranged between 600 to 900 psi with the salt water at room temperature. A simple orifice-type nozzle with a hole about 0.01-inch diameter was used as shown in Figure 2.

Enough runs were made with this equipment to show that any dissolved CO_2 had no visible effect on the atomization characteristics. The atomization was like that of any other liquid being sprayed from a small orifice at high pressure. It was noted, however, that a very fine mist of salt was produced by this nozzle when only a trace of solution was pushed through the orifice at the same time that CO_2 was being exhausted. This suggested the use of an air atomizing system.

The failure of the CO_2 system to operate as proposed (by having CO_2 dissolve at high pressure, and evolve at low pressure) was probably due to two major factors:

1. insufficient time allowed for CO_2 to dissolve in water, and

2. slow nucleation and growth of bubbles.

The solubility of CO_2 in H_2O is given[2] in terms of its partial pressure and mole fraction as:

Henry's Law Constant = $H = \frac{P}{x}$ P = partial pressure of CO_2, mm Hg

x = mole fraction of CO_2 in liquid phase

TABLE 1

SOLUBILITY OF CO_2 IN H_2O AS A FUNCTION OF TEMPERATURE (900 PSIG)

Temp, °C	$H \times 10^{-7}$	$x_{900\ psi}$	(volume CO_2/volume liquid$_{STP}$
0	0.0555	0.0837	103.5
10	0.0788	0.0590	73.2
20	0.108	0.0431	53.5
30	0.139	0.0334	41.4
40	0.173	0.0269	33.4
50	0.217	0.0214	26.6

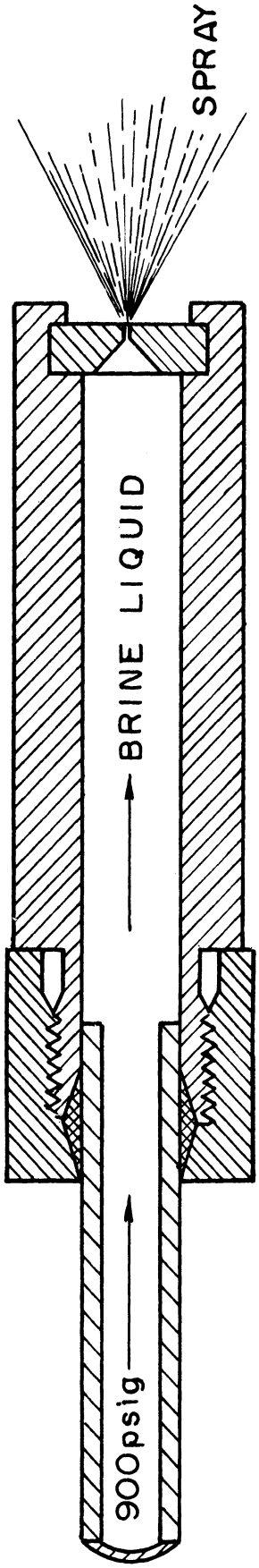

Figure 2. Orifice-type nozzle used for brine - CO_2.

From Table 1 it is evident that, when operating properly, the system should have displayed considerable evolution of gas. Lack of gas evolution indicated either incomplete solution of CO_2 in the salt water or else the solubility was reduced markedly by the presence of NaCl in solution.

BRINE - AIR ATOMIZATION

Figure 3 is a diagram of the apparatus used to atomize salt water with high-pressure air and to finally produce a dust of 0- to 5-micron salt particles suspended in air. The generator as shown operates by aspirating liquid from the brine reservoir through the nozzle and atomizing it in the diffuser throat. Excess liquid is carried through the diffuser throat with the air stream and all but the smallest particles impinge on the sides of the separator and run back to the brine reservoir. The smaller particles are carried out the top of the separator and evaporate, leaving a cloud of cubical salt crystals suspended in air.

The original design shown in Figure 3 was replaced by the apparatus shown in Figure 4. In this unit a nozzle with interchangeable orifices and diffuser sections was used to permit flexibility of operation and determination of the optimum geometry. The nozzle is shown in Figure 5.

Venturi meters were used to measure air rates. They were made from glass and calibrated with a wet-test meter in the low range and a rotameter (originally calibrated with a critical flow orifice) in the high range. A Venturi meter for liquid flow was also made, but has not been calibrated. The liquid rate was measured with a rotameter.

The graduated saturator (see Figure 4) for collecting the salt water being recycled serves several purposes. First, the solution must pass through the salt crystals before going to the nozzle and therefore remains saturated at all times. Second, it serves as a calibrated storage tank for measuring the volume of liquid in the system. It also allows a longer time for air bubbles in the brine to rise so that they cannot affect the pressure drop in the flow meter. Lastly, the glass wool filters out salt crystals which would interfere with flow in the lines and plug the nozzle. Excess air is added to the system through a tee attached to the top of the separator in order to dilute the spray and dry it more rapidly and completely.

The data obtained on this apparatus contains only a small amount of material on each topic, but in most cases it is sufficient to indicate a trend and is used as the basis for the evaluation. The size of the orifice used in the nozzle is of primary importance. Three different sized air orifices were used: D_o = 1/32 in., 1/64 in., 0.010 in. (see Figure 5). The

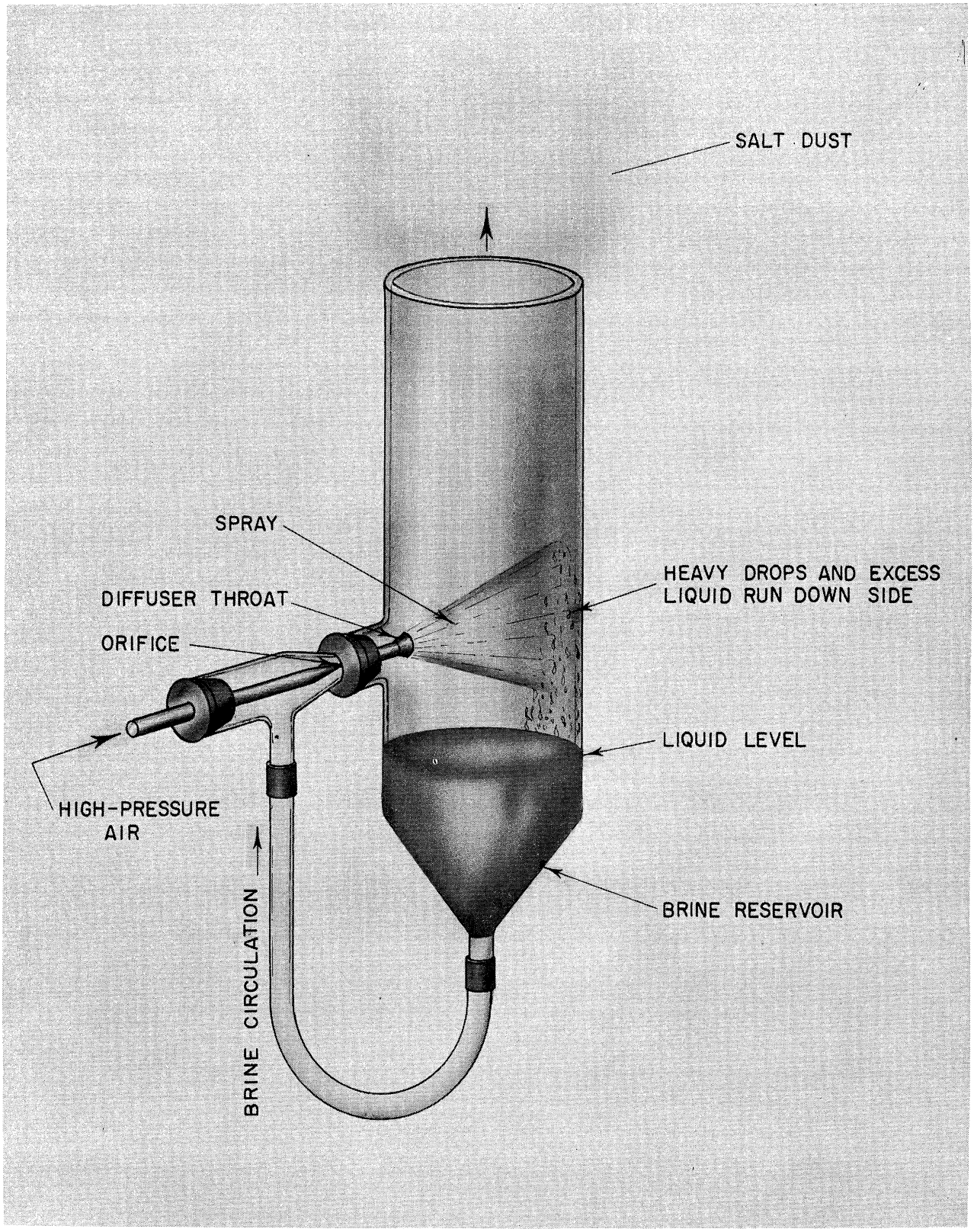

Figure 3. System for air-brine atomization.

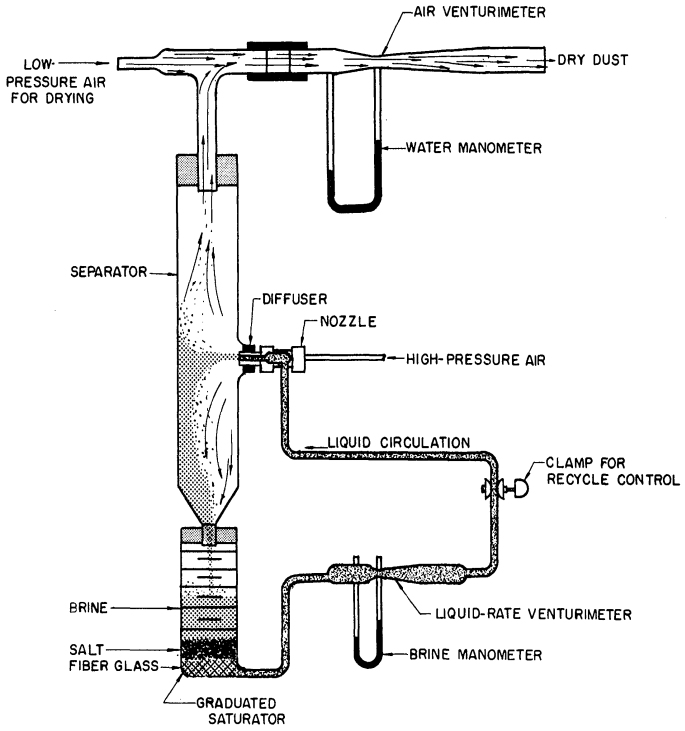

Figure 4. Experimental salt-dust generator.

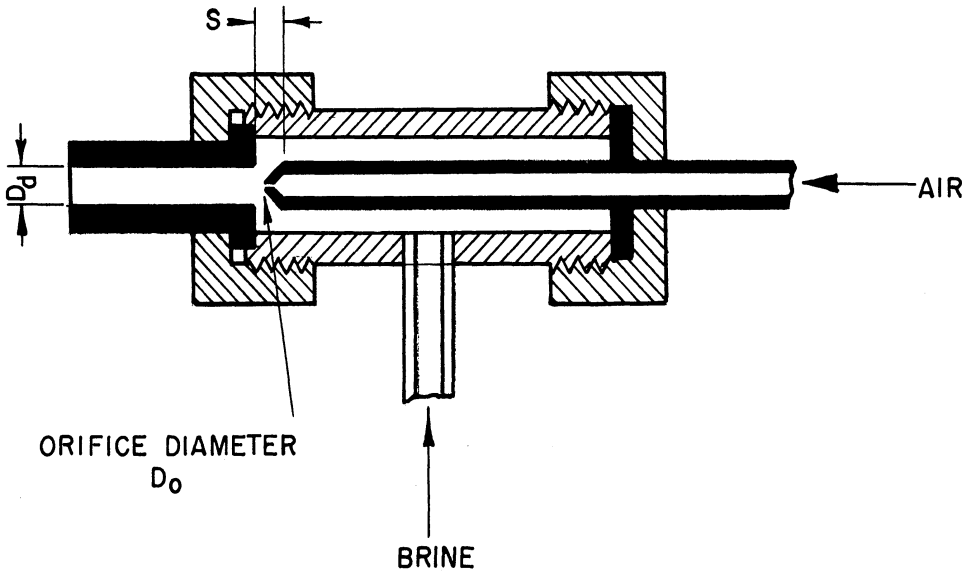

Figure 5. Nozzle used for air atomization.

dust generator was allowed to run for about 20 minutes and the quantity of brine evaporated was determined by measuring the loss in volume (or weight) of liquid in the graduated saturator from the beginning to the end of each run, using the apparatus shown in Figure 6. Table 2 lists the data obtained and Figure 7 shows the effect of orifice size on quantity of brine atomized per unit of atomizing air. These runs were carried out on a single diffuser size (D_d = 0.172 in.) and orifice spacing (S = 0).

This data includes both the weight loss due to evaporation and that due to atomization. In order to determine the magnitude of the evaporation loss, the spray leaving the generator was dried and the dry salt collected in a tube filled with fine glass wool. The rate of atomization of dry salt was then determined from the weight gain of the tube.

The atomization rate determined in two runs with 0.38 scfm of atomizing air were 0.0282 gm salt/min and 0.0207 gm salt/min with an average of 0.0245 gm salt/min. This is approximately 40 percent of the minimum rate shown in Figure 7 and indicates that the weight loss due to evaporization is a major factor. Consequently, the data given on atomization rate in Tables 2 and 3 and in Figures 7 and 8 do not give the true atomization rate, but are included in this report since they do illustrate the general trend of the effects of atomization variables. Such comparisons seem to be valid, since a large portion of the water evaporated will come from drops and will thus be related to the degree of atomization.

TABLE 2

EFFECT OF ORIFICE SIZE ON ATOMIZATION RATE
(AT CONSTANT ORIFICE PRESSURE)

Nozzle Diam. (in.) D_o	Volume Atomized (Cm^3) ΔV_L	Weight Atomized (gm) ΔW_L*	Time Change (min) Δt	Atomization Rate (gm/min) $R = \Delta W_L/\Delta t$	Air Rate (scfm)** W_A	Ratio $\frac{gm}{scf}$ R/W_A
0.0312	2.5	3.0	14	0.215	1.08	0.199
.0312	-	3.0	12.5	.240	.37	.649
.0312	-	1.9	7	.272	.37	.734
.0156	4.5	5.4	16	.337	.37	.91
.0156	-	2.1	5.5	.382	.38	1.00
.0156	-	2.0	9	.222	.36	.615
.0156	-	1.5	7	.214	.36	.595
.010	3.75	4.5	20	.226	.132	1.71
.010	-	1.1	7	.157	.174	.902

*ΔW_L is not corrected for evaporation losses.
**Standard cubic feet per minute.

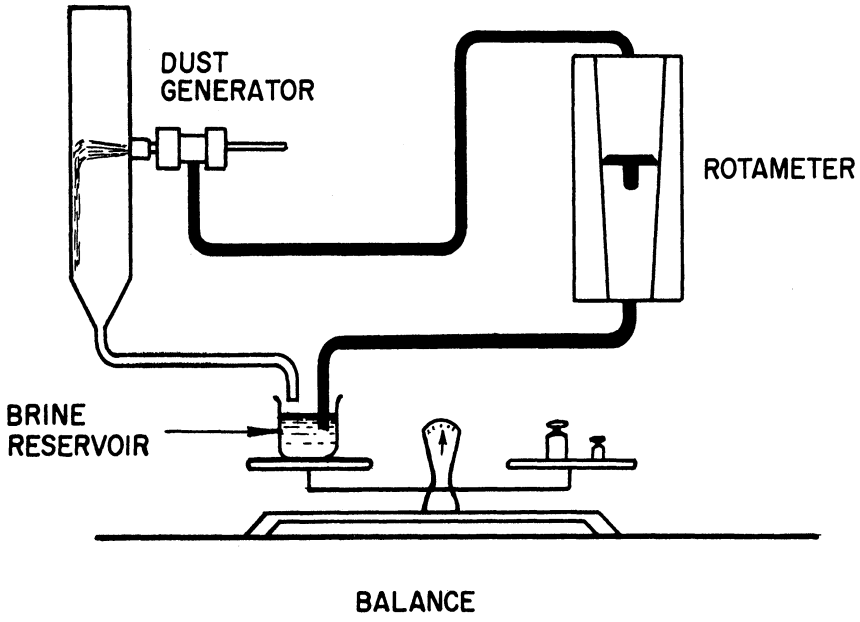

Figure 6. System for determining the effect of flow rate of liquid upon atomization.

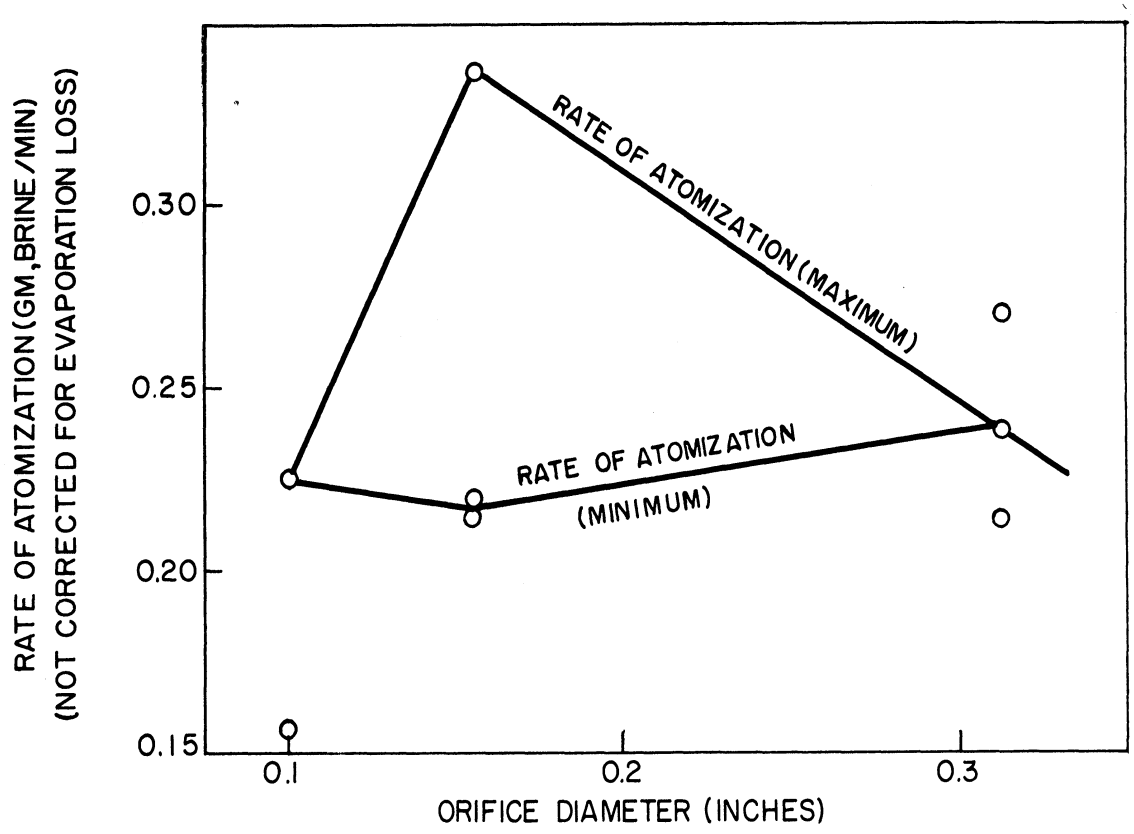

Figure 7. Rate of atomization vs orifice diameter. Constant size generator and full air rate (sonic) at 90 psig.

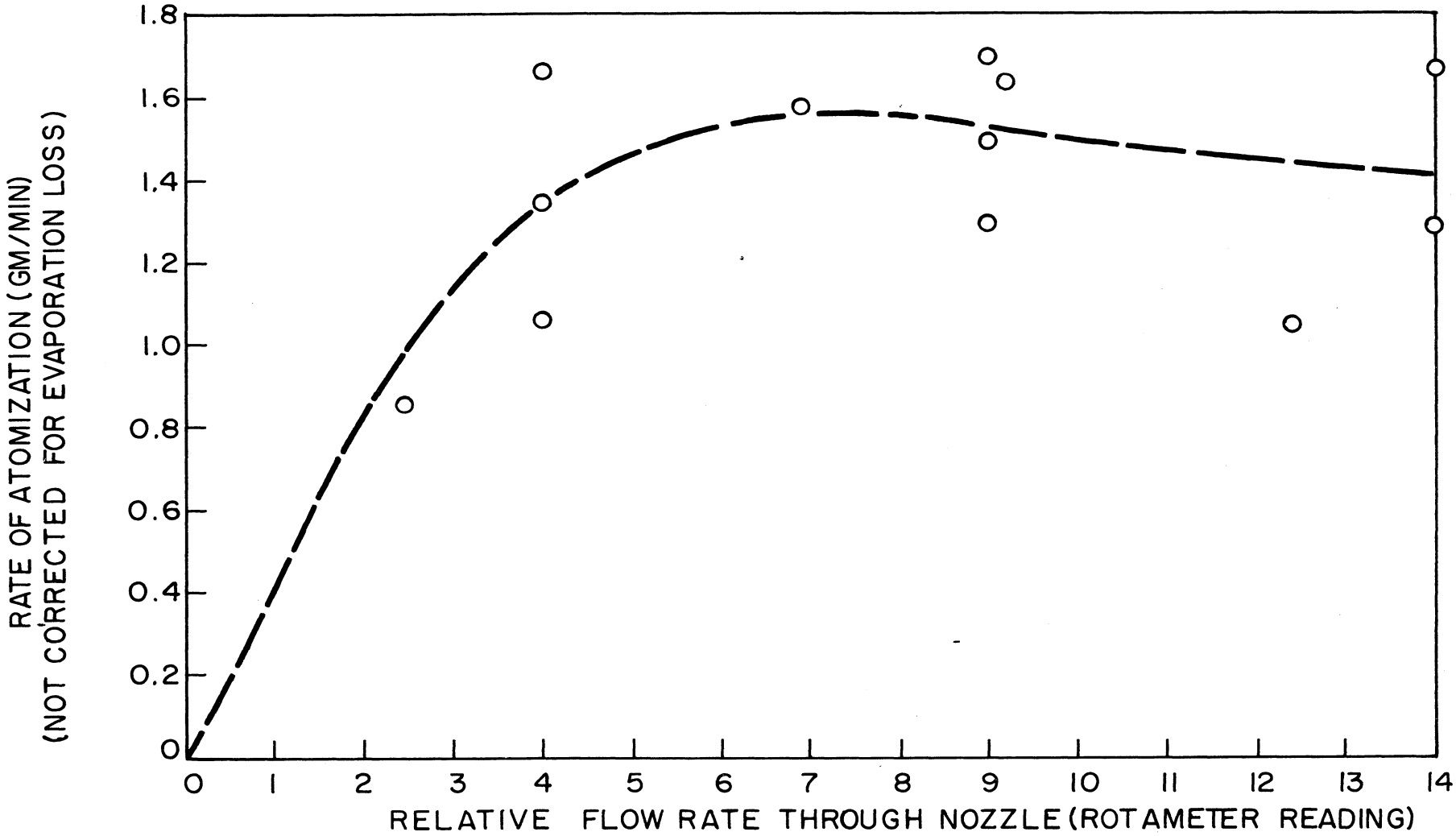

Figure 8. Rate of atomization vs relative flow rate through nozzle. Constant air rate, constant dimensions.

Changing the liquid recycle rate seemed likely to affect the generator operation and a system was devised for testing it. A rotameter measured the liquid rate, and the brine was collected in a beaker. The change in weight of the beaker and solution during each period of operation was used as a measure of the atomization rate. Figure 6 illustrates the apparatus used for this procedure. The air rate and nozzle dimensions were kept constant throughout these runs. Table 3 lists the data obtained under these conditions and atomization rate versus liquid circulation rate is plotted in Figure 8.

Another factor to be considered in evaluating the dust generator is particle size. Two samples of the particles generated were collected and analyzed by microscopic counting of slides, which resulted in the data given in Table 4 and Figure 9. In Figure 9, the total number of particles counted within a given size range is plotted against the average diameter in that range for the two slides taken.

TABLE 3

EFFECT OF LIQUID RECYCLE RATE ON ATOMIZATION RATE

Rotameter Reading (not calibrated) Y	Weight Atomized (gm) ΔW_L	Time Change (min) Δt	Atomization Rate (gm/min) $R = \Delta W_L/\Delta t$
21.4	5.8	7.0	0.83
14.0	4.5	3.5	1.29
14.0	5.0	3.0	1.67
12.4	6.4	6.0	1.06
9.2	6.8	4.2	1.62
9.0	6.5	5.0	1.30
9.0	3.4	2.0	1.70
9.0	7.5	5.0	1.59
4.0	6.2	3.7	1.67
4.0	5.0	4.3	1.16
4.0	5.0	3.7	1.35
2.45	9.9	11.5	0.86

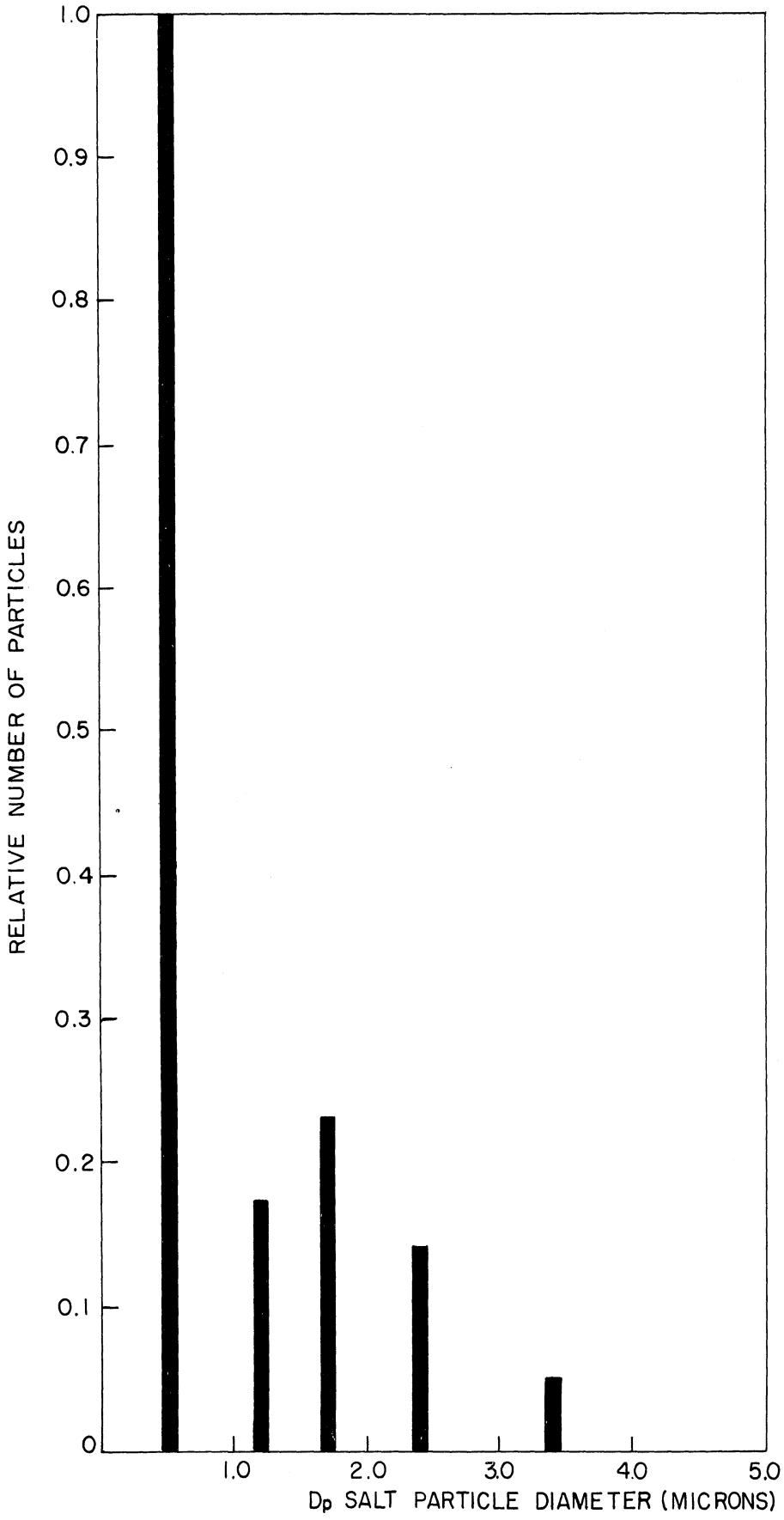

Figure 9. Particle-size distribution for average of two slides taken of sodium chloride dust.

TABLE 4

SIZE ANALYSIS OF A TYPICAL SALT DUST

Range of Particle Diameters (microns)	No. of Particles	Fraction of Total	Average Size (microns)
0 - 1.0	100	0.63	0.5
1.0 - 1.4	17	.107	1.2
1.4 - 2.0	23	.149	1.7
2.0 - 2.8	14	.088	2.4
2.8 - 4.0	5	.0314	3.4
4.0 and larger	0	.000	-

DUST SAMPLING EQUIPMENT

Three methods of dust-sampling equipment to be used in determining the characteristics of the salt dust generator were examined.

1. Air sedimentation was used to prepare slide samples for determination of particle size with a microscope. Dust-laden air was allowed to blow into a sampling cylinder (4 in. in length and 2 in. in diameter and with one end closed) for about 1 second at an air rate of 1 scfm. The sampling cylinder was then placed upside down over a cleaned microscope slide. The cylinder was left undistrubed until the finest particle required to be completely analyzed could settle the length of the cylinder. Settling time is obtained from Figure 10, which gives settling velocities for particles of NaCl in the 0.1- to 10-micron range.

With dust collected on the slide in this manner, a cover glass is coated with a very thin layer of Canada balsam in xylene and placed on the dust-covered slide to preserve the crystals for analysis. Figure 9 shows the microscopic analysis for a typical sample of dust from the generator.

2. The water-washed packed bed is another effective device for continuous removal of dust from air streams, and it was examined quite closely. Figure 11 illustrates a typical unit of this type.

The collectors tested used a high-pressure jet pump to circulate liquid through the tubing as illustrated, but the major objection to this type of unit is the added pressure drop due to the air required to circulate the liquid. Some qualitative data were obtained, however, on pressure drop and efficiency of collection. Values on collection efficiency for this unit

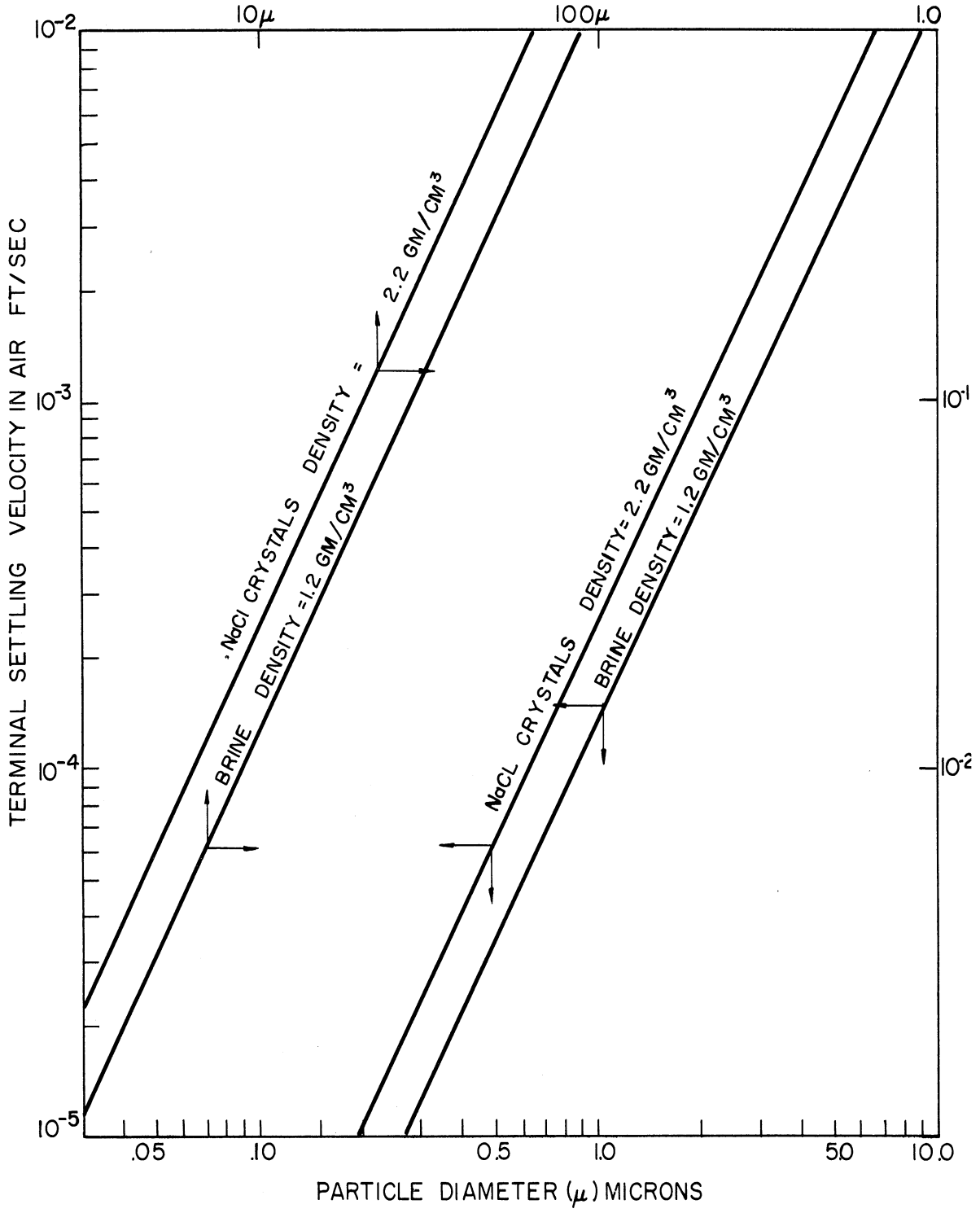

Figure 10. Settling velocity vs particle size (spherical particles).

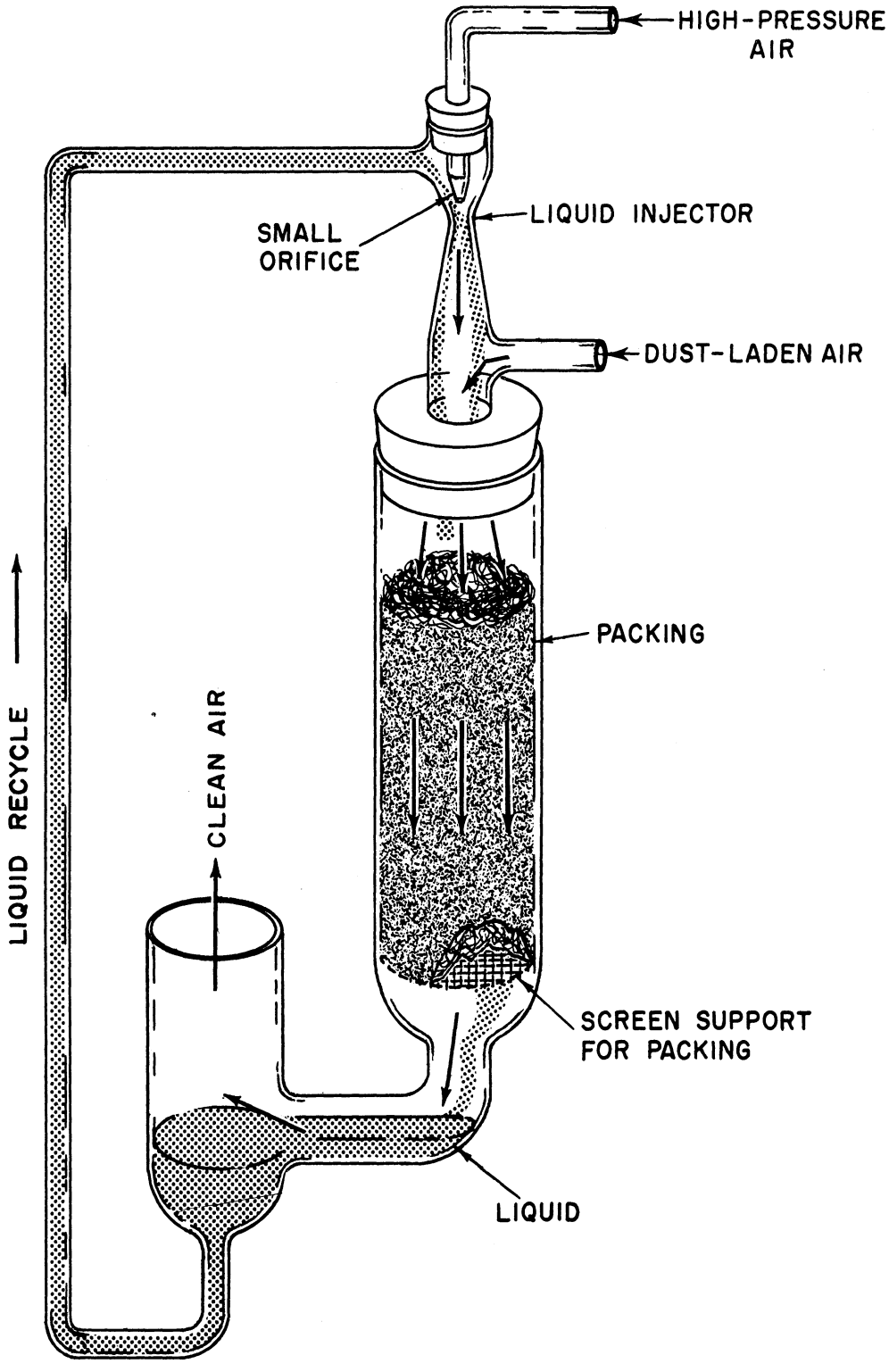

Figure 11. Typical water-washed packed column dust sampler.

were not obtained because the conductivity system for analysis had not been developed at the time these runs were made. For estimating the efficiency, a positive pressure was applied to the dust stream by connecting the collector directly to the dust generator and eliminating the need for a vacuum pump; the cleaned air leaving the collector could be observed in a strong light with a black background. The air stream could be plainly seen with all the dust present, and a visible decrease in brightness of the stream indicated a decrease in dust concentration with a constant air rate. Several packings were tried and the results are listed in Table 5. The data are mostly self-explanatory except that it might be noted that moisture had little effect on the efficiency of a packing, but density and length of the bed affected both pressure drop and efficiency markedly.

TABLE 5

TESTS ON WATER-WASHED PACKED-BED COLLECTORS
(7/8 in. diameter bed, air rate of 0.72 scfm)

Packing Material	Condition	Length of Packing in.	Pressure Drop mm Hg	Visually Est. Amt. of Dust Removal percent
.03 in. glass beads	dry	1-5/8	18.0	50 - 75
.03 in. glass beads	wet	1-5/8	18.0	60 - 80
120-micron glass beads	dry	7/16	109	95
7-micron diam glass wool	dry - loose	2-1/2	7	5 - 10
7-micron diam glass wool	wet (water packed)	1-1/2	36	95
7-micron diam glass wool	dry (hand packed)	1	51	95
7-micron diam glass wool	wet (hand packed)	1	65	95

3. The other sampling device used was the impinger, similar to the commercially available units. Figure 12 is a sketch of the impinger element and the assembled unit.

The impinger element was constructed of a piece of glass tubing drawn down until an 0.05 in. orifice remained. Three glass support rods were fused to the side of the impinger tube and a circular, flat glass plate fastened to the support rods so that the distance from the orifice to the

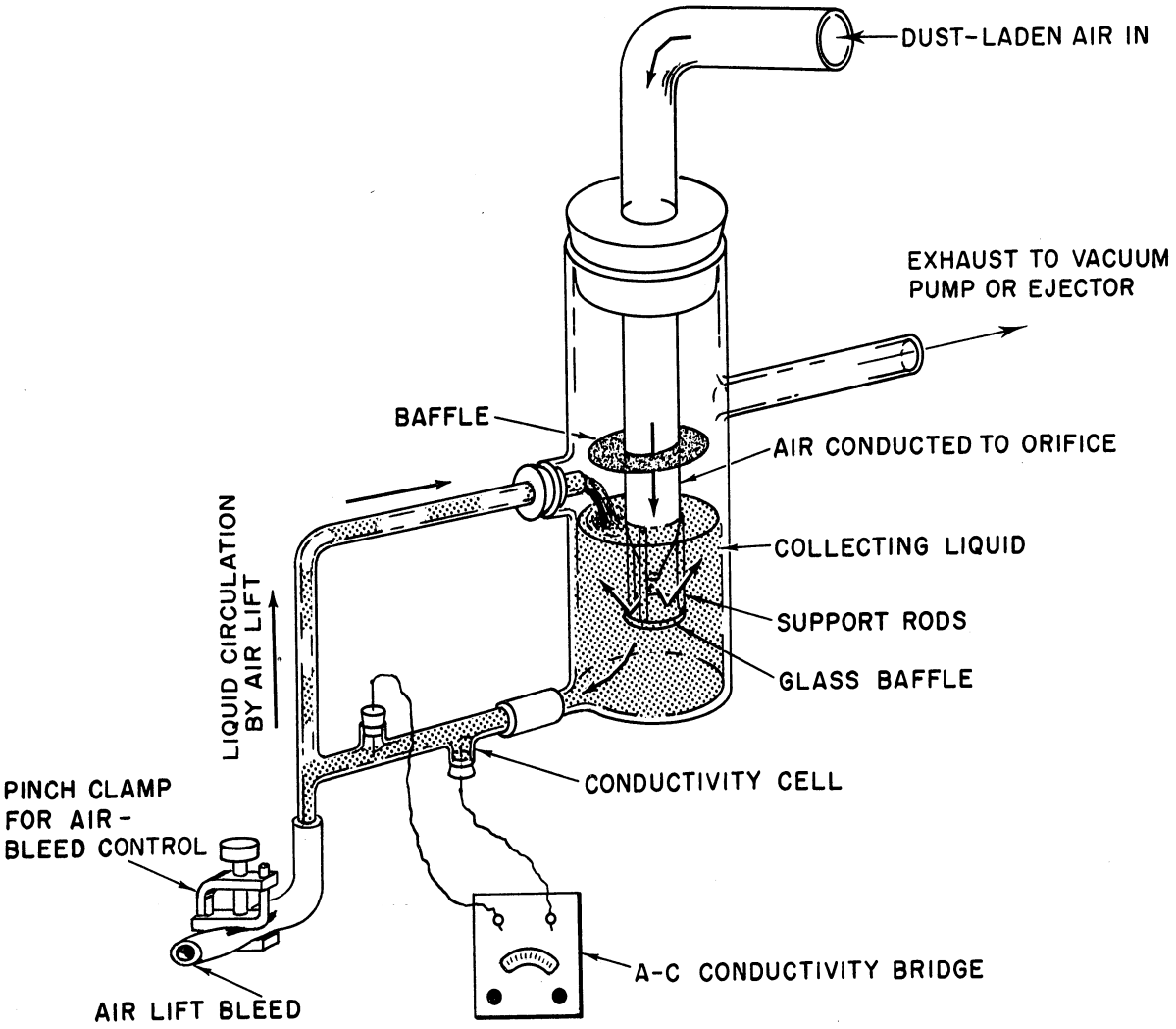

Figure 12. Impinger apparatus for dust collection.

plate is about 5 mm. This element is sealed into a large test tube which has a side arm connected to a vacuum pump. The impingement plate is immersed in liquid, and baffles are placed about halfway between the orifice and the side arm to prevent carry-over of the liquid. A vacuum of greater than 1/2 atmosphere is pulled into the system so that sonic velocity through the orifice is obtained and the air stream is sampled at a constant rate. No attempt was made to attain isokinetic conditions of sampling, because tests were run only to evaluate the impingement effect in connection with conductivity measurements as described in the next section.

The impinger was considered as a possible collecting unit because of its simplicity of operation and because efficiency of impaction can be calculated from data in the literature(7), which enabled the plotting of efficiency versus particle size for NaCl, given any particular velocity in the orifice. Figure 13 gives these results.

A glass ejector, using 90 psi air from a 1/16 in. orifice as the driving fluid was used to evacuate the impinger. The ejector consists of 5-mm-diameter glass tubing reduced to 2-mm diameter at the throat and with a 1-inch-long diffuser section. Air to be ejected enters a side arm connected to the 5-mm tubing about 1 inch upstream of the nozzle. This ejector would produce a vacuum of about 45 cm Hg with no air flow and about 40 cm Hg when drawing air through the above-described impinger.

4. Conductivity measurements were used to measure the concentration of salt collected from the air drawn through the impinger. A conductivity cell and a-c conductivity bridge were attached as shown in Figure 12. A vacuum air lift was provided to circulate liquid through the cell continuously (the amount of air added in this was negligible compared to the sampled air).

Platinized platinum electrodes were used to increase the sharpness of measurement on the a-c bridge. A cell constant in the range of 5 is required to obtain the proper sensitivity in highly conductive solutions such as concentrated NaCl and yet be capable of measuring the conductibility of doubly-distilled water.

The body of the conductivity cell was constructed of glass blown to the proper shape with inlet and outlet for flow and two electrode openings. A small copper plate soldered to a copper lead wire was used as the electrode. Electrical conduction was limited to the unsoldered surface of the electrode by coating all other exposed surfaces with "3M" adhesive and accelerator mixed in proportions of about 15 to 1 by volume. This left a single exposed surface and prevented corrosion of the solder joint. The lead wires were pushed through corks and the corks sealed tightly into place with "3M" adhesive. After the adhesive hardened, the electrodes were platinized and were ready for use.

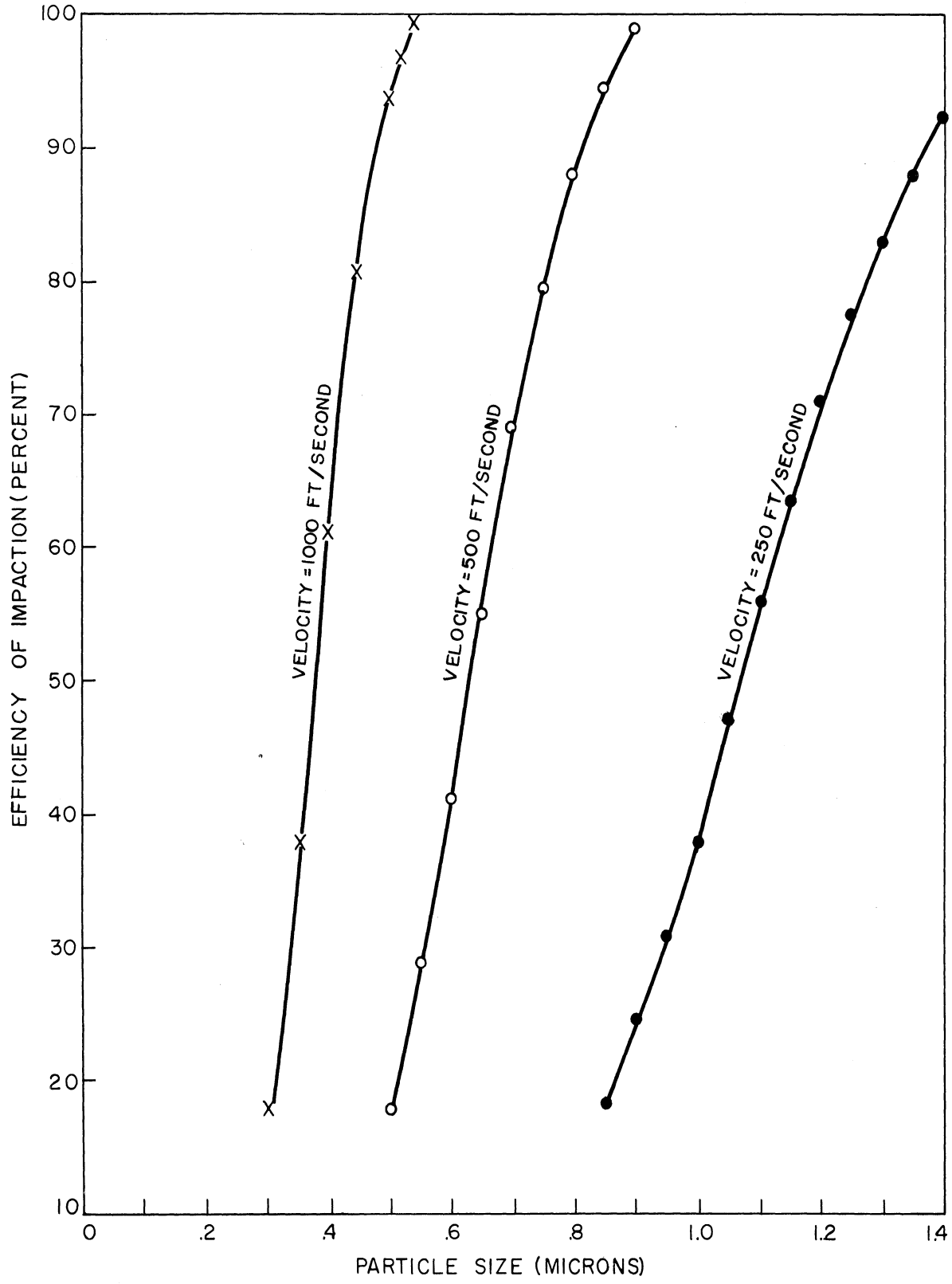

Figure 13. Efficiency of impaction vs particle size for sodium chloride cubes.

The conductivity cell was tested with the system in Figure 12. Fifty ml of singly-distilled water were placed in the impinger and air containing salt dust was sampled continuously through the impinger. Table 6 lists the data and Figure 14 shows how the concentration of salt in the

TABLE 6

SALT CONCENTRATION AS A FUNCTION OF TIME
FOR A 50-ml IMPINGER SOLUTION
SAMPLING THE TOTAL SALT GENERATOR OUTPUT

Time (min) t	Temp (°F) T	Conductivity Correction Θ=K Temp (T) K 18° C	Resistance of Solution (ohms) R_s	Specific Conductance mhos/cm^3 $K_s \times 10^4$	Specific Conductance at 18°C $K_s/\Theta \times 10^4$	Salt Concentration grams/liter
0	67	1.03	10,150	5.04	4.89	0.27
1	65.5	1.012	8,400	6.095	6.02	.33
2	65	1.005	7,700	6.65	6.62	.365
3	64	.994	7,150	7.16	7.21	.396
4	63.5	.987	6,600	7.76	7.87	.435
5	63	.982	6,050	8.46	8.61	.480
6	62.5	.975	5,800	8.83	9.06	.503
7	62	.968	5,400	9.48	9.80	.54
8	62	.968	5,150	9.94	10.27	.565
9	62	.968	4,900	10.5	10.85	.625
10	61.5	.962	4,670	11.0	11.44	.665
11	61	.955	4,450	11.5	12.04	.705
12	61	.955	4,300	11.9	12.46	.730
13	60.5	.950	4,120	12.4	13.07	.760

Cell constant (K) = 5.12.

singly distilled water varied with time as the dust was sampled. Concentration was determined from values in Figures 15, 16 and 17. The values of conductivity were obtained from the literature[5] and represent the net contribution of NaCl to the specific conductivity of the solution. The equation used for correcting for the conductivity of water is:

$$\text{Conductance of the solution} = k' = k_s + k_w$$

where k_s is the value of specific conductivity of salt obtained from the graphs of Figures 16 and 17, and k_w is the specific conductivity of the water

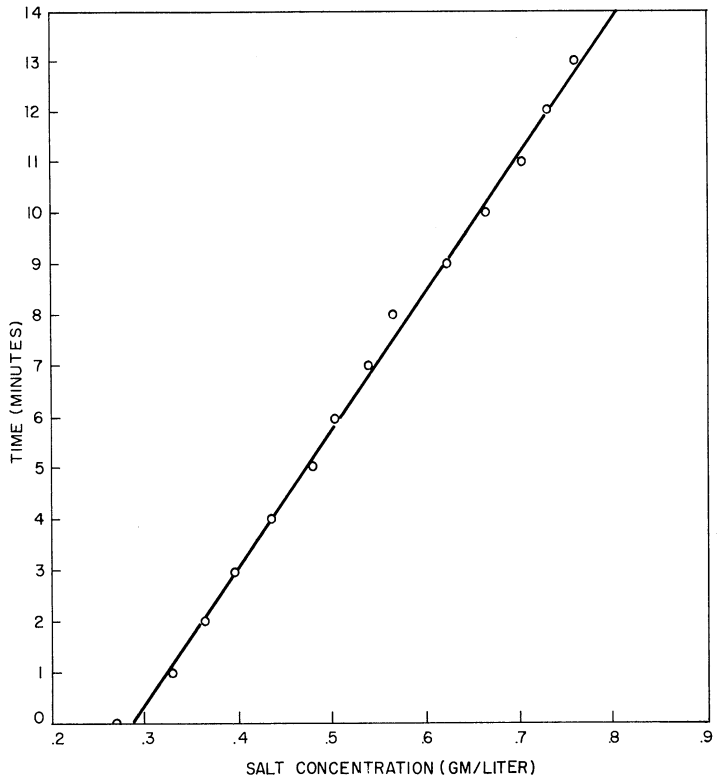

Figure 14. Concentration of salt solution in impinger vs time of sampling. For solution in the impinger-collector (50 ml) while collecting dust from the salt-dust generator at a constant rate.

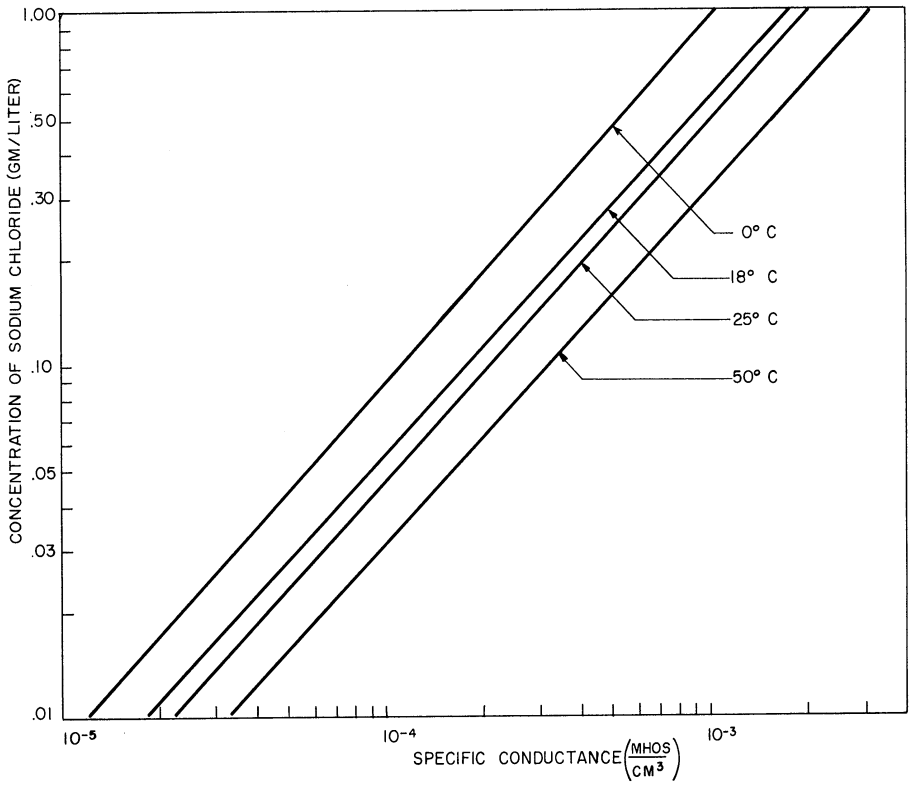

Figure 15. Specific conductance of sodium chloride vs concentration (aqeous). From international critical tables. Low range of conductivity.

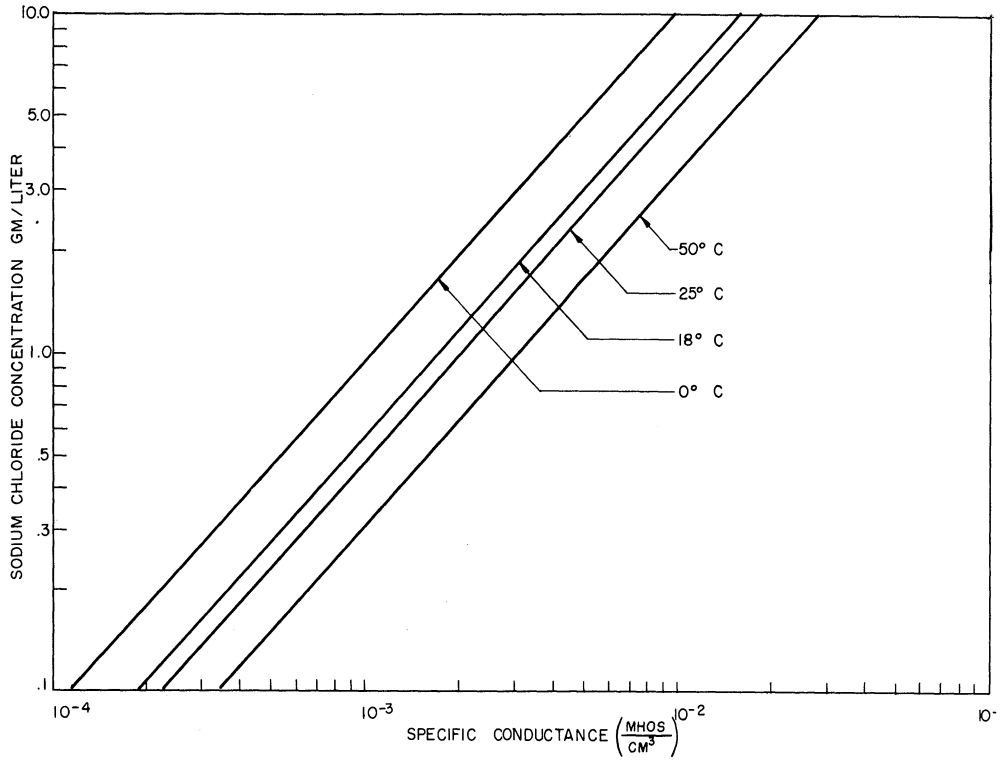

Figure 16. Specific conductance vs concentration (high range) for aqeous sodium chloride. From international critical tables.

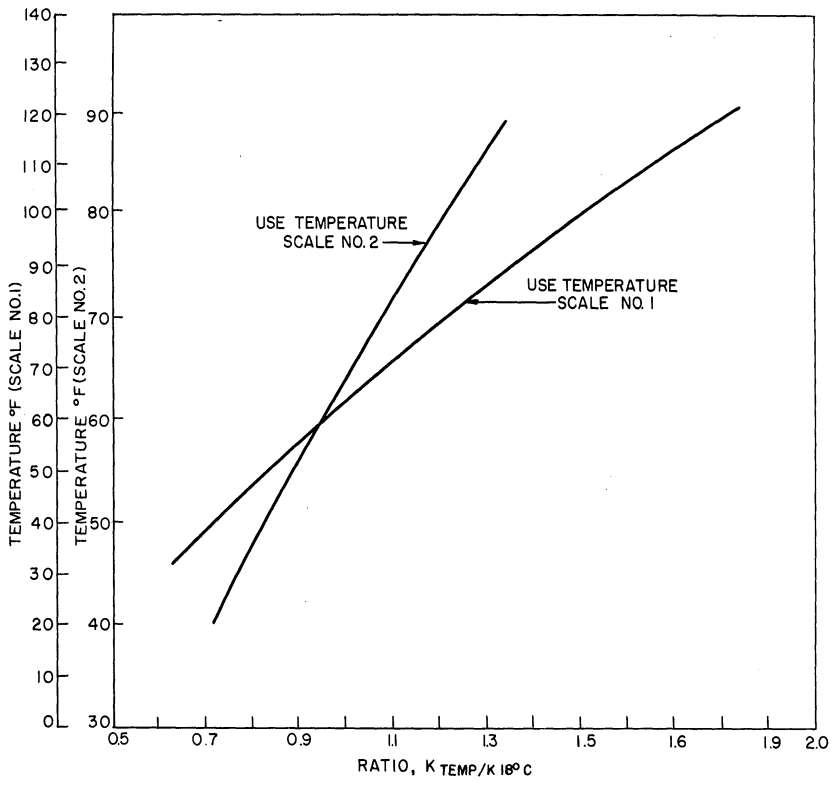

Figure 17. Variation of specific conductance with temperature for aqeous sodium chloride.

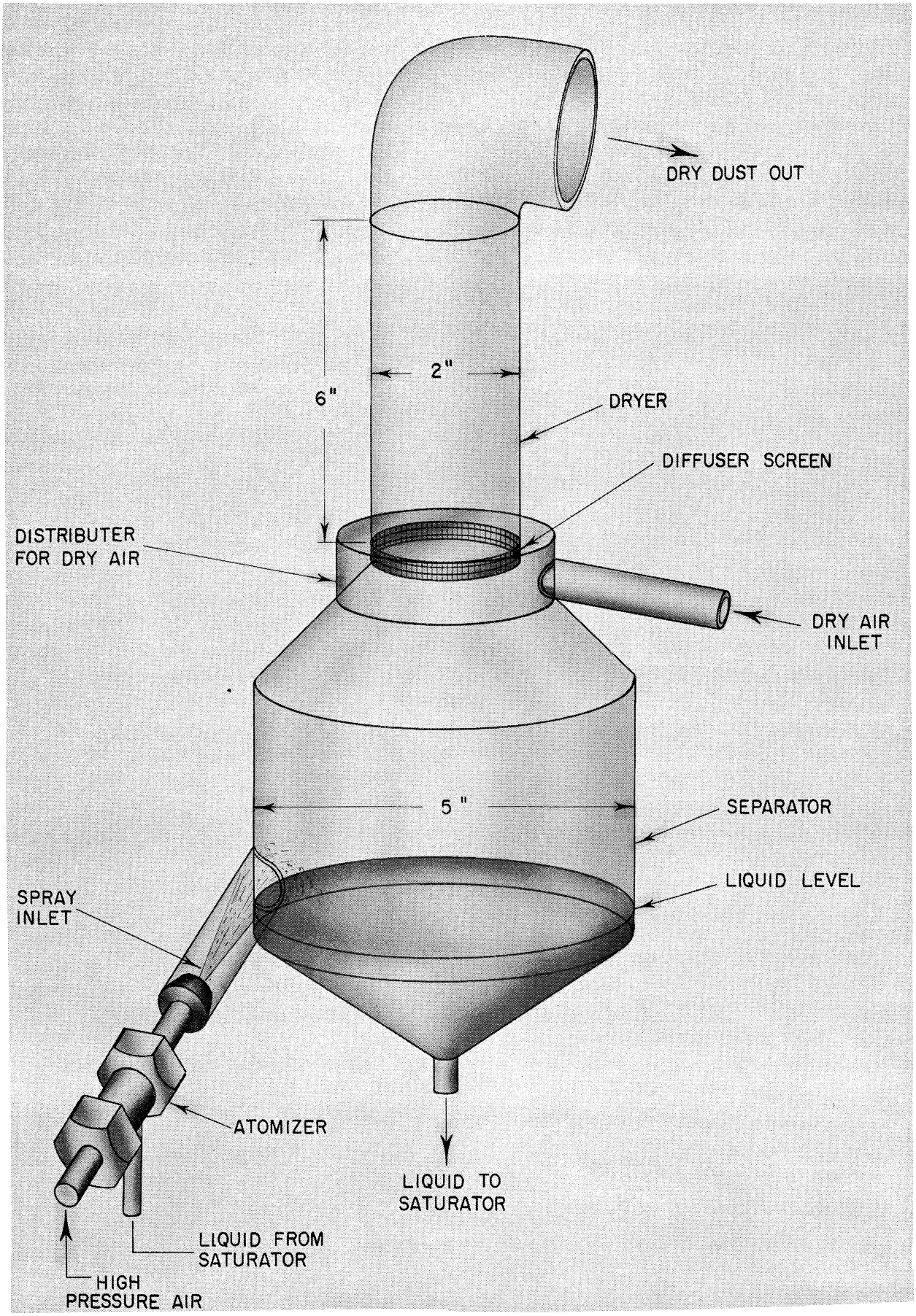

Figure 18. Proposed salt-spray generator design.

used in making up a given solution. Calculation of the specific conductance was by means of the equation $k = \frac{K}{R}$.
Where

K = cell constant ($1/cm^3$)
R = resistance of solution (ohms)
k = specific conductivity ($1/ohms/cm^3$)

SAMPLE CALCULATIONS TO ILLUSTRATE THE DESIGN OF A DUST GENERATOR

Specifications for a salt-dust generator are determined by the particle size required for test purposes. The diameter and length of the separator are fixed by particle size as shown in the following calculation procedure.

Assume, as an example, that a dust with a zero- to five-micron size range is to be produced. From Table 7 below, it is noted that a saturated brine solution at near room temperature will have a salt concentration of about 0.264 grams of sodium chloride per gram of brine solution. The performance data indicate an atomization rate of approximately 0.093 grams of brine per minute (containing 0.0245 gm salt) can be expected with a 1/64 in. nozzle and an atomizing air rate of 0.38 scfm. These values will be used for the design proposed.

TABLE 7

SOLUBILITY DATA FOR AQUEOUS NaCl[6]

Temp °F	Temp °C	Solubility: Gm NaCl / Gm H_2O	Solubility: Gm NaCl / Gm Solution
32	0	0.357	0.263
50	10	.358	.263
67	20	.360	.264
85	30	.363	.266
104	40	.366	.268

In order to obtain only five-micron and smaller particles in the salt dust, all particles of brine larger than the size which evaporate to a five-micron particle must fall into the liquid reservoir (see Figure 4). The

relationship between sizes of brine and dry salt particles is determined from the proportion:

$$\frac{V_2}{V_1} = \frac{d_2^3}{d_1^3}$$

or

$$d_1 = d_2 \sqrt[3]{\frac{V_1}{V_2}}$$

where d is the particle diameter and V the particle volume, with subscripts 1 and 2 referring to the brine particle and to the salt particle left after evaporation of the water. Then, if d_2 = 5 microns,

$$V_1 = \frac{W_1}{\rho 1}, \quad V_2 = \frac{W_2}{\rho 2}$$

(W = weight of the particle and ρ = density of the material in the particle of weight W) or, for W_1 = 1 gram of solution and therefore W_2 = 0.264 grams of salt [ρ1 = 1.2 gm/cu. cm., ρ2 = 2.2 gm/cu. cm.] we then obtain

$$\left(\frac{V_1}{V_2}\right) = \left(\frac{1}{0.264}\right)\left(\frac{2.2}{1.2}\right) = 6.94 \quad .$$

Then $d_1 = 5\sqrt[3]{6.94} = 5(1.91) = \underline{9.57 \text{ microns}}$.

Now that the diameter of the largest brine particle to produce a 5-micron spray is known, the settling velocity is found from Figure 10 as 0.012 ft/sec for the 9.57-micron particle, which must be the upward velocity in the separator. Thirty-eight hundredths (0.38) standard cubic foot per minute are required for atomization from which the diameter of the settler is:

$$D_s = \sqrt{\frac{4(0.38)}{\pi(V_s)(60)}} = \sqrt{\frac{(4)\ (0.38)}{\pi(60)(0.012)}} = \sqrt{0.672}$$

$$D_s = .819 \text{ ft} = 9.8 \text{ in.}$$

In the same manner, if the maximum size of particle is to be 10 microns (dry), then:

$$d_2 = 1.91 \times 10 = 19.1 \text{ microns}$$

and $V_s = 0.048$ ft/sec

then

$$D_s = 9.8\sqrt{\frac{.012}{.048}} = \frac{9.8}{2} = 4.9 \text{ in.}$$

In this way, a curve could be drawn of D_s versus d when a given rate of atomizing air is used to elutriate the particles.

After the particles have been separated, the brine particles must be thoroughly dried so that they can be conducted through tubes to the experimental setup without collecting on the walls of the tubes.

For particles being dried, the rate of drying is given[6] by the following relation:

$$-\frac{dm}{dt} = kg\ 4\pi R^2\ (y_i - y) \qquad (1)$$

kg = mass transfer coefficient $\frac{\text{lb mole}}{\text{hr sq ft mole fraction}}$

R = particle radius in feet

y_i = mole fraction of the evaporating liquid at the gas interface

y = mole fraction of evaporating liquid in the bulk stream (gas)

m = mole of liquid in the particle

t = time (hours)

kg was given as a function of Reynolds number of Schmidt[8] number by the equation

$$Kg\ \frac{RTd}{DP} = 2\left[1 + 0.276\left(\frac{dV\rho}{\mu}\right)^{1/2}\left(\frac{\mu}{\rho D}\right)^{1/3}\right] . \qquad (2)$$

Using proper values in this equation and letting the velocity equal the settling velocity of the particle, we found that kg RTd/DP was approximately 2.0 for particles of from 5 to 10 microns or smaller settling in air.

Solving the relation

$$kg = \frac{2DP}{RTd} \qquad (3)$$

where

D = diffusivity (ft^2/hr)

P = pressure (psia)

R = gas constant $\frac{\text{psia - cu ft}}{^{o}R \text{ lb mole}}$

T = temp (^{o}R)

d = particle diameter (ft)

we find that for all the particles we will consider and at atmospheric pressure and temperature,

$$kg = \left(\frac{.00524}{d}\right) \text{ , (d in feet).} \tag{4}$$

Substituting equation 4 into equation 1 and substituting

$$\left(\frac{\rho 4\pi R}{M} \frac{dR}{dt}\right) \text{for} \left(\frac{dm}{dt}\right)$$

we get a relationship describing the rate of change of radius with time, as a drop evaporates:

$$\frac{-\rho}{M} \frac{dR}{dt} = \frac{.00524}{d} (y_i - y) \tag{5}$$

M = molecular weight

ρ = density of the evaporating material.

From which comes:

$$\int_{R_o}^{R} -RdR = \int_{o}^{t} .00262 \left(\frac{M}{\rho}\right) (y_i - y)\, dt \tag{6}$$

or

$$R^2 = R_o^2 - (.00524) \frac{18}{62.4} (y_i - y)\ t \ .$$

Knowing that y_i is the mole fraction of liquid in air at saturation for the given temperature, and letting $y = y_f y_i$, where y_f is the fractional saturation attained in the bulk stream (assumed constant for integration), we can substitute these values for a temperature of 520°R (70°F):

$$y_i = .363/14.7 = \frac{p_w}{p_{total}}$$

and

$$R^2 = R_o^2 - \left(\frac{.00524 \times 18}{62.4}\right)\left(\frac{.363}{14.7}\right)(1 - y_f)\ t$$

or

$$R^2 = R_o^2 - 3.74 \times 10^{-5}\ (1 - y_f)\ t \qquad (7)$$

In equation 7, R is in feet and t is in hours. If the units are changed to R in microns and t in seconds, we will have

$$R^2 = R_o^2 - 3.74 \times 10^{-5}\ \frac{(10^4 \times 2.54 \times 12)^2}{3600}\ t\ (1 - y_f)$$

$$R^2 = R_o^2 - 964\ (t)\ (1 - y_f) \qquad (8)$$

Since the largest particles will determine the length of chamber, we can solve this for time t_f at $R = R_f$

$$R_o^2 = R_f^2 \left(\frac{V_o}{V_f}\right)^{2/3} = (1.91)^2\ R_f^2 = 3.65\ R_f^2$$

and $t_f = \frac{2.65\ R_f^2}{964(1-y_f)}$ = time to evaporate the particle from its initial to its final size (R_f).

For a ten-micron maximum dried particle we have

$$t_f = \frac{.00275\ (5)^2}{(1-f_y)}\ ,$$

and for an air stream humidity of 80 percent,

$$t_f = \frac{(.00275)\ (25)}{(1 - .8)} = .344 \text{ seconds}\ .$$

With an upward velocity large enough that all particles below 10 microns which have been elutriated are carried along rapidly (for example 1 ft/second), then we need only .344 ft (4-1/8 inches) to dry all particles.

If a 20-micron spray were generated and a 1 ft/second drying velocity used, we would need only 1.376 feet for the drying operation. Since the calculation of length was based upon an air saturation of 80 percent, it is necessary to add excess air. The total quantity of air required if it is completely saturated with water is given by:

$$q = 0.38 + \frac{(1 - .264)\ (.1)}{.543} = 0.52 \text{ cu ft saturated air at } 70°F/\text{min}$$

$(1 - .264)$ = gm H_2O per gram of solution

$(.1)$ = gm solution atomized per minute

$(.543)$ = gm H_2O per cu ft of air at saturation

The minimum to evaporate all of the atomized particles is q = 0.52 cubic feet of air, or, in other words,

q = 0.38 (cu ft for atomization) - 0.14 (cu ft for drying).

Since it is assumed that only 80-percent saturation is reached, then

$$q = \frac{0.52}{0.8} = 0.65 \ \frac{\text{cu ft}}{\text{min}} \text{ of air in drying apparatus and}$$

q added = 0.65 - 0.38 (atomization) = <u>0.27 scfm</u> .

For a velocity of 1 ft/second at 0.65 scfm, a dryer diameter of

$$D_d = \sqrt{\frac{4}{\pi}\ \frac{(0.65)}{(60)\ (1.0)}} = .118 \text{ ft} = 1.42 \text{ inches} .$$

A design of this salt spray generator is shown in Figure 18 where

D_s = 5.0 in. (4.9 required)

D_d = 2.0 in. (1.42 required)

L_d = 6.0 in. (4.13 required)

Atomizer nozzle diameter = 1/54 in.

Atomizing air = 0.38 scfm

Excess air = 0.14 scfm

The saturator is made from a large test tube with a tubing connection on the bottom. A Fibreglass mat is placed in the bottom of the test tube and a layer of sodium chloride crystals dumped on top of the Fibreglass. Recycled liquid from the separator to the nozzle is allowed to pass through the layer of sodium chloride and then through the Fibreglass filter to saturate the liquid and remove any suspended particles.

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CHAPTER II

DUST-CONCENTRATION MEASUREMENT BY LIGHT-SCATTERING TECHNIQUES

INTRODUCTION

The possibilities for utilizing light-scattering techniques for the determination of dust concentration in air were explored and are discussed in this report. Such techniques have the attractive feature that measurements can be made on a flowing air stream with the dust in suspension. It is not necessary to sample the air stream and/or to separate the dust from the air. The principle on which the techniques are based is that particles in the path of a light beam will scatter the light striking them, so that the intensity of light in the direction of the beam decreases while the intensity in other directions increases.

It is possible to determine the effect of the particles either by measuring the decrease of intensity or by measuring the intensity of scattered light. Both approaches have been used by many investigators and the theory is well established for spherical particles, although it is not established for irregular shapes because of the complexity of the problem. There are, however, experimental data on irregular shapes which indicate that the theory for spheres is an adequate approximation.

The feature of the light-scattering phenomenon which makes it difficult to interpret is that the relationship between particle size and the amount of light scattered becomes quite complex when the particle size is in the region of from 1 to 10 times the wave length of light (ordinary daylight has a wave length of approximately 0.5 micron). This region of about 0.5 to 5.0 microns is also that in which engine air-cleaner efficiency drops off abruptly so it is not possible to judge the applicability of the method from the superficial examination above. Consequently, it was necessary to calculate the light-scattering characteristics for a material which could be used as a test dust.

SUMMARY

There are two major methods of utilizing light scattering for the determination of particle concentration in a suspension. These are the measurement of the decrease in intensity (the attenuation) of a parallel beam of light passing through a suspension and the measurement of the light scattered in a small forward angle cone.

Both methods are applicable to the problem of determining dust collection efficiency of air cleaners. Calculations for the attenuation method applied to a representative test dust indicate an expected accuracy on the order of from $\pm 1/2$ percent to ± 1 percent in collection efficiency on a weight basis. The forward angle scattering method should be as good or better.

The basic elements of the necessary apparatus have been developed and used successfully so that an extensive development program would not be required. Some work would have to be done on the design of light cells and accessories related to such things as the elimination of dust deposition on the cell windows.

LIGHT SCATTERING THEORY

The basic idea in the application of light-scattering techniques to the analysis of suspensions is that the particles in suspension will decrease the forward intensity of a beam of light passing through by reflection, refraction, and absorption. The simplest case is that in which the particles are large in comparison to the wave length of light, and the degree of extinction of light can be predicted from the size of the particles and, thus, the size of their shadows. The Lambert-Beer law describes this type of situation and it is derived as follows:

Let I_x be the intensity of a parallel beam of light after traveling a distance x through the suspension. Then, the fractional decrease in the light intensity, which results when the beam traverses an additional distance dx through the suspension, will be equal to the product of the scattering cross section per particle times the number of particles contained in an element of volume one unit square and dx units in depth. If the particles are not all the same size, the scattering cross sections for each size must be summed in order to get the total cross section, thus,

$$\frac{-dI_x}{I_x} = dx \sum_{D=0}^{D=D_{max}} S_D \, n_D \quad . \tag{1}$$

Where n_D is the number of particles of diameter D, S_D is the scattering cross section of particles with diameter D, and D_{max} is the maximum particle diameter in the suspension. Integration of equation 1 yields the following:

$$\ln \frac{I_o}{I} = l \sum_{D=0}^{D_{max}} S_D \, n_D \quad , \tag{2}$$

where I_o is the intensity of the original light beam and I is the intensity of the parallel beam after traversing a distance l through the suspension.

For the case of large particles this reduces to the following:

$$\ln \frac{I_o}{I} = l \sum_{D=0}^{D_{max}} \frac{\pi D^2}{4} n_D \tag{3}$$

Equation 3 is the Lambert-Beer law and it is usually valid for particles down to around 30 to 50 microns in diameter. Below this particle size, two factors become important enough to cause large deviations between the observed case and that predicted by equation 3. One is that the scattering cross section is not equal to the geometric cross sectional area of the particle. In fact, it varies from less than the geometric cross section to four times larger, and for large particles it has a constant value of twice the geometric cross section.

This leads us to the seeming contradiction that a large particle blocks off twice as much light as strikes it, and yet experimental observations indicate that this is not so. The justification lies in the fact that a large particle does scatter twice as much light as would strike its cross sectional area, but practically half of the scattered light is beamed within the cone of a small forward angle. If the angle of reception of the light meter is equal to or larger than this angle, all of the forward scattered light will be detected. Thus, the second factor which causes deviations from the Lambert-Beer law is the angle of reception of the light meter.

When the particles are smaller than about ten times the wave length of light, however, the angle of reception becomes less important since a change gradually takes place in the mode of scattering. The proportion of

light scattered in a forward angle decreases with decreasing particle size and, consequently, less and less of the scattered light will be detected within the cone of the light meter.

The general relationship for spheres between scattering cross section, particle size, wave length of light, and relative index of refraction of the particles is shown in Figure 19. The symbols used in the figure are defined as follows:

K_t = Total scattering coefficient (ration of effective scattering cross section to geometric cross sectional area)

$\alpha = \pi D/\lambda$ = ratio of particle diameter to the wave length of light

m = index of refraction of the particle relative to the suspending medium.

The relationships which define the light scattering phenomenon and on which Figure 19 is based are described in reference 2. Because of their complexity, solutions of these relationships had to be carried out on a high-speed electronic computer and the results have been published in tabular form[2]. It is sufficient for this discussion to consider only the final results.

As mentioned above, the total scattering cross section is not necessarily that which will determine the intensity of light which is measured. Rather, the cross section representing the quantity of light which is not seen by a light meter with a particular angle of vision is the one of interest. This corrected cross section, which is valid for a particular system, is represented by RK_t, where R is a correction factor dependent on α and θ (the half angle of the cone of vision of the light detector). The relationship between R and $\alpha\theta$ is presented in reference 2 but is too complex to go into thoroughly here. Values for R for spheres as a function of the product $\alpha\theta$ are presented in Figure 20.

Scattering cross section coefficients were computed for the special case of quartz particles suspended in air. The values of the variables chosen for this illustrative case are as follows:

m = 1.544 (refractive index relative to air)

λ = 4,700 Å = 0.47 microns (blue light)

$\theta = 0.92°$ (half angle of cone of vision).

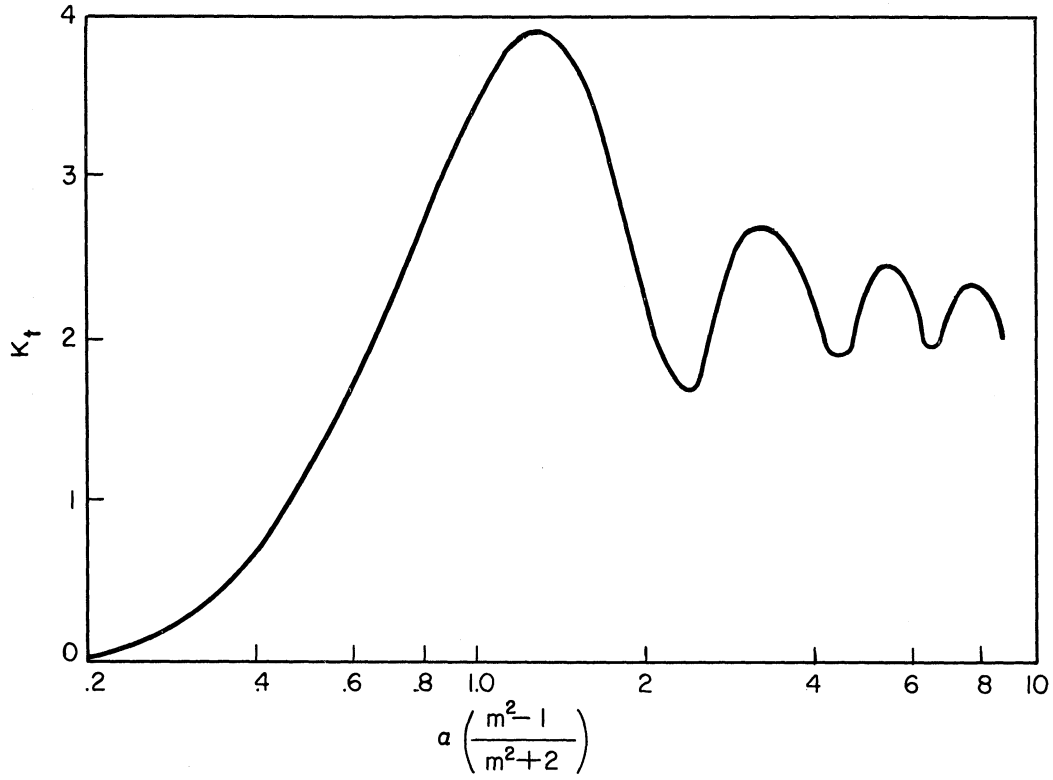

Figure 19. Total scattering cross section vs scattering parameter.

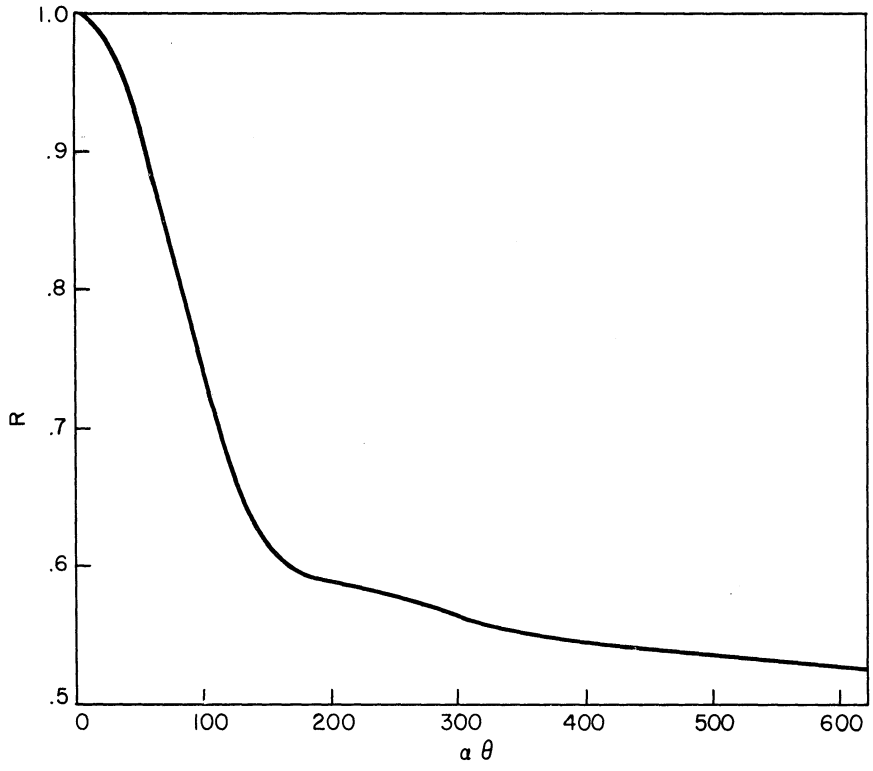

Figure 20. Plot of R vs $\alpha\theta$. Reference

The results of these computations are plotted in Figure 21, which shows the values for both K_t and RK_t versus particle diameter.

It can be seen there there is considerable variation in both K_t and RK_t in the region of from 0.5- to 5.0-micron diameter. Since this is just the region of greatest interest so far as engine air-cleaner performance is concerned, it is important that we evaluate the final effect of these fluctuations.

When the scattering coefficients are multiplied by the cross sectional area per unit weight of particles we obtain the relationship illustrated in Figure 22, a plot of cross sectional area in cm^2/gm versus particle diameter. It can be seen that the variation of cross sectional area per unit weight with diameter is sufficiently great to somewhat mask the fluctuations of scattering coefficient.

The next step is to apply the information on scattering cross section to a dust with a size distribution such as one might employ as a test dust. A dust which has been used by us for test purposes is a ground silica manufactured by the Vapor Blast Company and provided in several size grades. Figure 23 shows the size distribution by weight for a sample of 5,000 mesh Novaculite as weight percent per micron versus particle size in microns.

The light-scattering cross section for this material was computed by multiplying the distribution function by the scattering cross section per unit weight (from Figure 22) and plotting the results as a function of particle size in Figure 24. The area under the solid curve between any two diameters on Figure 24 is equal to the total scattering cross section present in that size range in 5,000 mesh Novaculite. Graphical integration of the solid curve yielded the answer that the total scattering cross section is 1834 cm^2/gm. The dashed line on Figure 24 represents the cumulative fraction of the total scattering cross section as a function of particle size.

It is interesting to note that while the particles smaller than 2.5 microns represent 4.5 percent of the total weight of dust, they represent approximately 30 percent of the total scattering cross section.

APPLICATION OF THE TECHNIQUE

Light-scattering techniques have been applied to the determination of particle concentration in suspensions and the data have been checked with

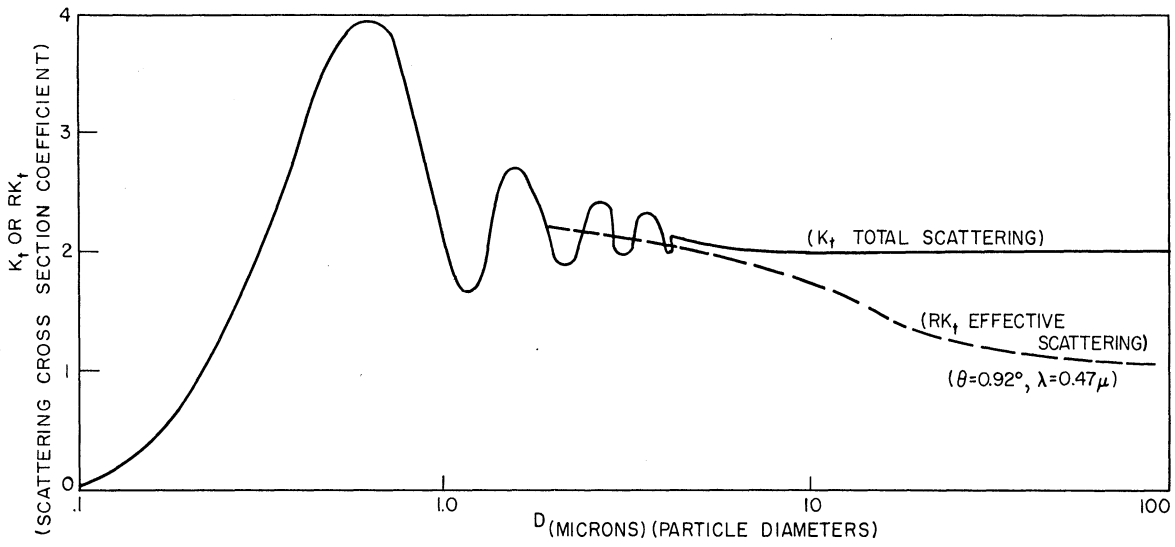

Figure 21. Scattering cross section coefficient vs particle diameter for silica and 0.47-micron light.

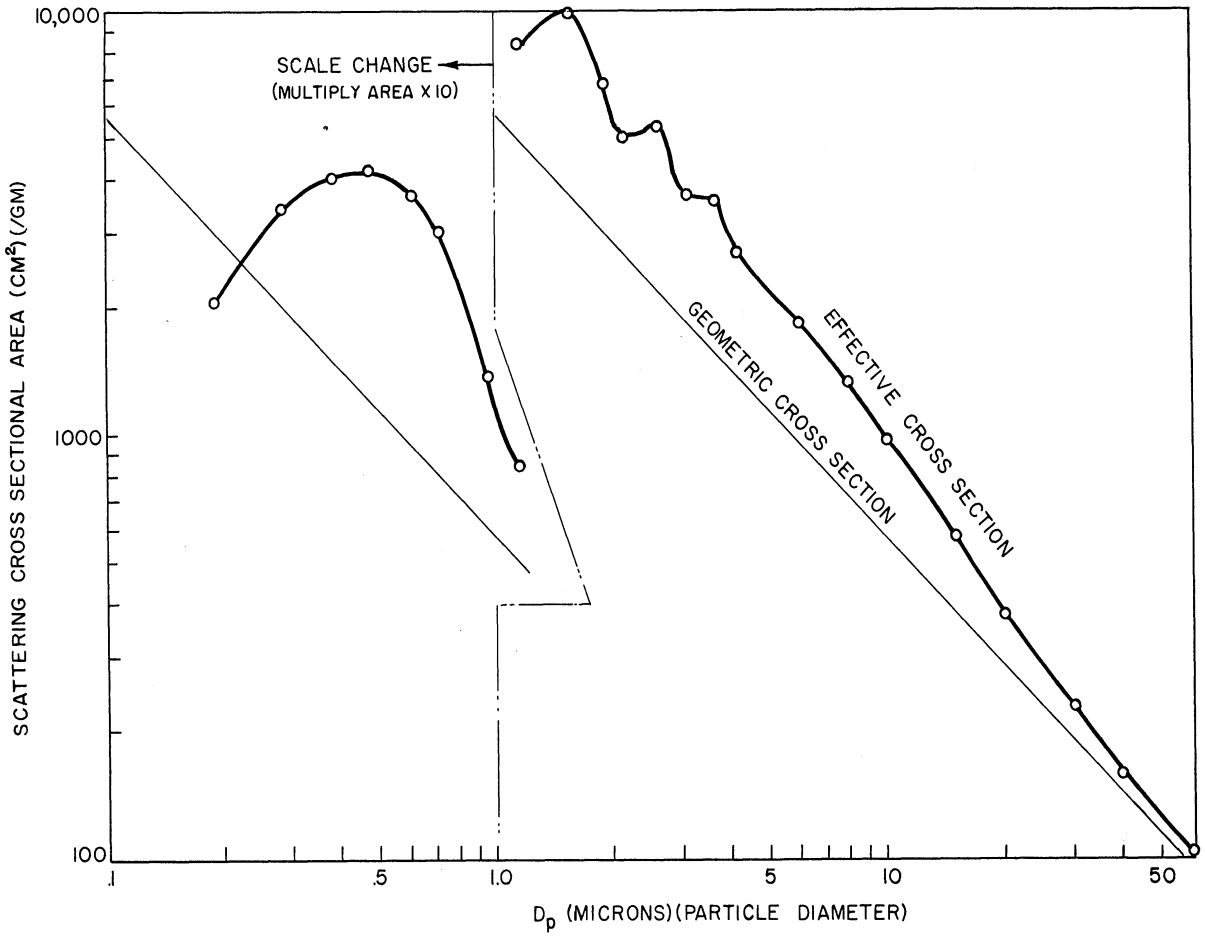

Figure 22. Scattering cross section per gram vs particle diameter for silica, λ = 0.47μ, θ = 0.92°.

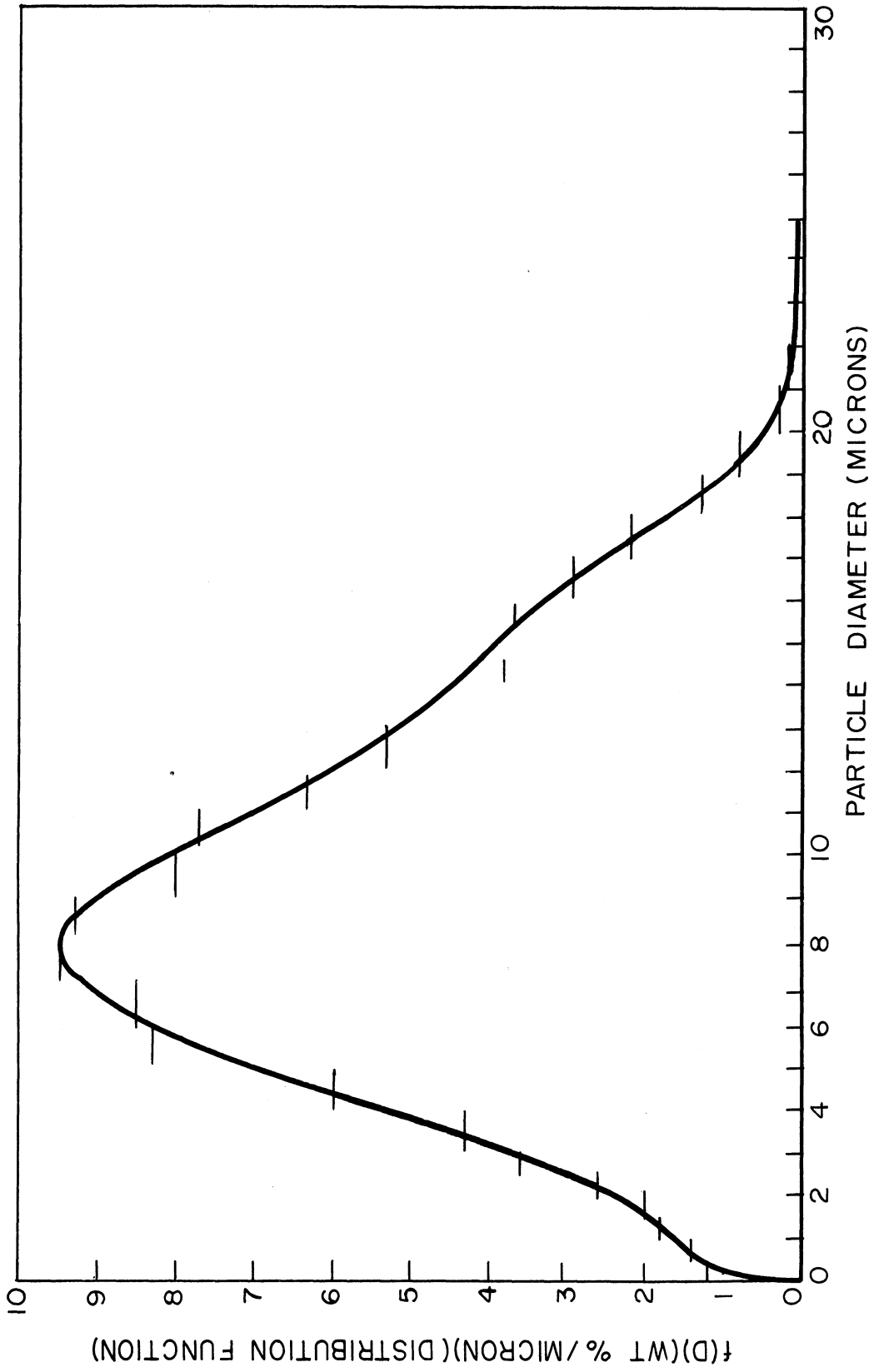

Figure 23. Size-distribution function vs diameter for 5000-mesh Novaculite.

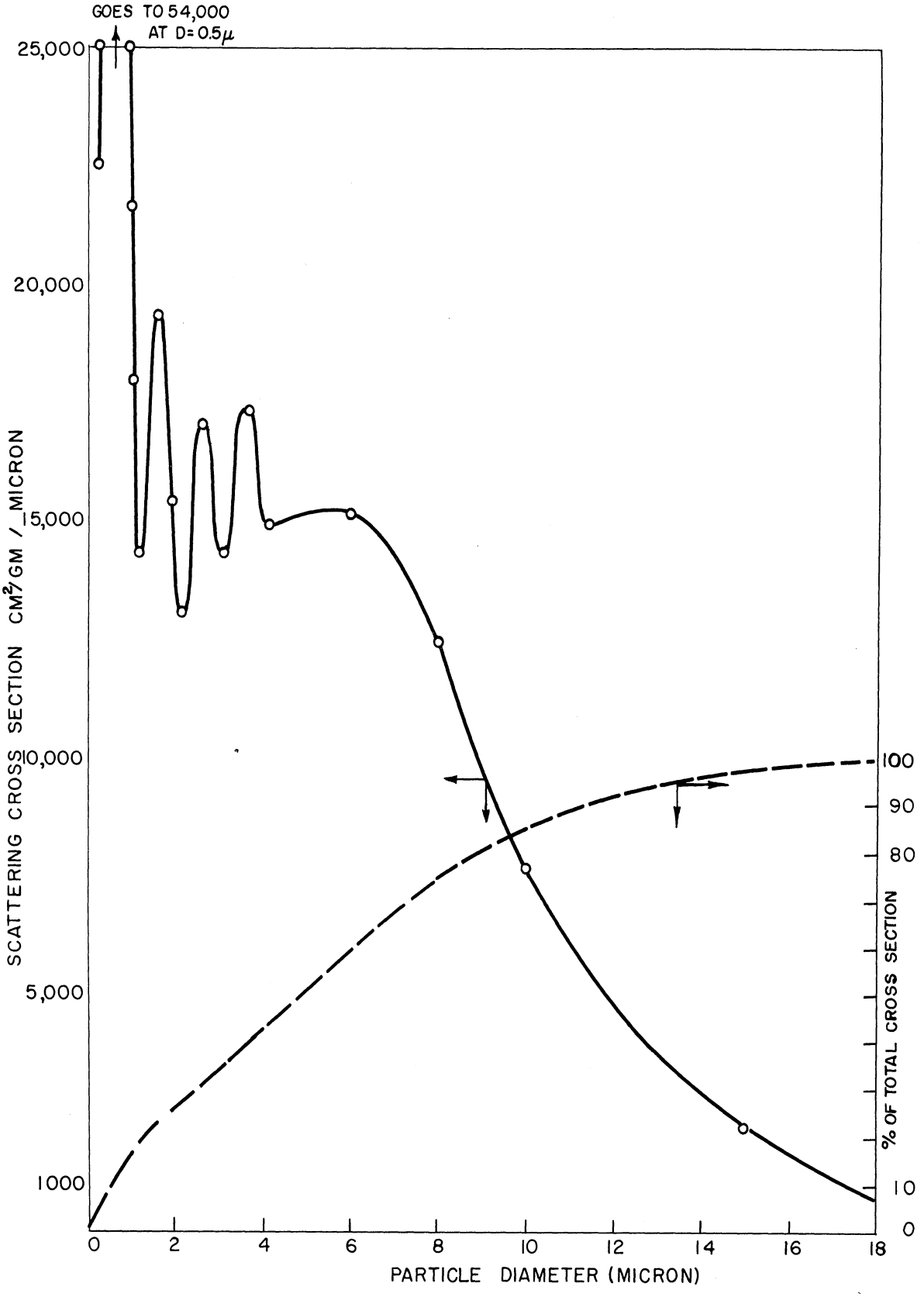

Figure 24. Scattering cross section function vs particle diameter and cumulative percent of total cross section vs particle diameter.

the theory[2, 4]. In the application of photo-extinction measurements (decrease in transmitted light) to the sedimentation analysis of powders, Rose[4] has experimentally determined that the predictions from theory (which is based on spherical particles) are valid for irregularly shaped particles. Thus, it is possible to predict the behavior of a suspension of dust particles fairly well.

In order to get some idea of the apparatus required for measuring the concentrations of dust such as 5,000 mesh Novaculite in air, the values of the ratio of light intensities, I/I_o, have been calculated for a range of variations of operation. The relationship between the intensity ratio and the properties of the system is as follows:

$$\ell n \frac{I_o}{I} = \frac{\pi \ell}{4} \sum_{D=0}^{D=D_{max}} R_D K_{+D} D^2 n_D \qquad (4)$$

This is equivalent to equation 5 below,

$$\ell n \frac{I_o}{I} = \left(\frac{A_E}{W}\right) C l \qquad (5)$$

Where:

$\frac{A_E}{W}$ = effective scattering area per unit weight (cm^2/gm)

C = concentration of particles in suspension (gm/cm^2)

ℓ = length of light path (cm).

This relationship is shown graphically in Figure 25, a plot of I/I_o versus $(A_E/W)Cl$. Several combinations of the variables are given in Table 8, in order to illustrate the effects of each.

It can be seen from the values in Table 8 that it is advantageous to use a high concentration of dust and a long optical path if sizeable variations in light intensity are to be obtained. It would not be unreasonable to use a dust loading of 0.1 gm/cu ft and an optical path 4.0 ft long on the inlet to an air cleaner and 5.0 ft long on the outlet. This represents a dust loading four times as high as is presently being used for testing and sections of pipe for optical cells which are not excessively large.

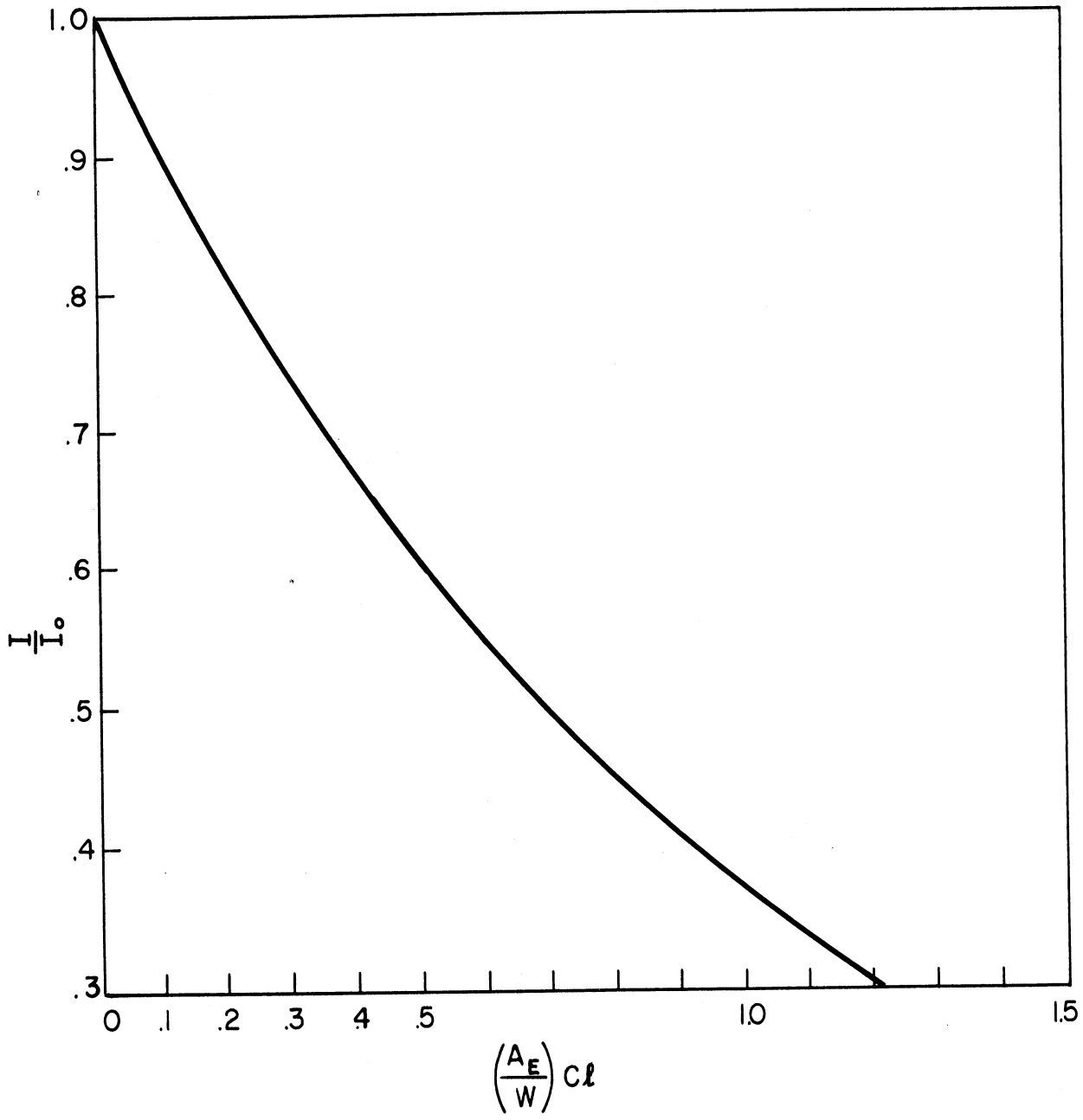

Figure 25. Plot of $\frac{I}{I_o}$ vs $\left(\frac{A_E}{W}\right)C\ell$.

TABLE 8

RELATIONSHIP BETWEEN THE INTENSITY RATIO
AND THE PROPERTIES OF THE SYSTEM

$\frac{A_E}{W}$	C (gm/ft3)	l (ft)	I/I_o (ratio)
1834 cm^2/gm	0.025	1.0	0.95
	.05	1.0	.905
or approximately	.075	1.0	.86
	.10	1.0	.818
2.0 ft^2/gm	.10	4.0	.45
	.01	5.0	.905
	.01	4.0	.92

Obviously, both the dust loading and the path length required will be dictated by the accuracy attainable with the light metering device. The experience of investigators at the University of Michigan has been that ±1 percent accuracy can be obtained with little difficulty with a recording meter, and ±1/2 percent accuracy with a hand-operated potentiometer. This would indicate an error in dust concentration measurement of about ±5 percent, varying from ±1 percent in the lower range of I/I_o to ±10 percent in the high range.

For the system described above, the inlet dust concentration would be measured as 0.1 gm/cu ft ±1.5 percent and, if the efficiency of the cleaner were 90 percent, the outlet concentration would be measured as 0.01 gm/cu ft ±3.5 percent. Thus the collection efficiency would be determined by computation from experimental data as approximately 90 percent ±1/2 percent. It is important to note that while the material penetrating the air cleaner represents only 10 percent of the feed dust by weight, it represents approximately 40 percent of the total scattering cross section.

For the illustration above, it was assumed for simplicity that the material penetrating the air cleaner would be 3.9-micron diameter and smaller, thus accounting for 10 percent of the dust weight. Actually, there would be no sharp cut at one diameter but, rather, a more gradual decrease in collection efficiency with particle size. In order to exactly determine the scattering cross section of the material penetrating the filter, one would have to know the particle size distribution. This could be predicted by means of the method of determining collection efficiency described in Interim Technical Report No. 1 under this contract. That is, one could predict the particle-size distribution of the penetrating dust which would occur for a

given collection efficiency based on weight percent. From the size distribution one can compute the scattering cross section for the penetrating dust and thus have a relationship between scattering cross section and collection efficiency.

A possible arrangement of the light-scattering equipment for measuring dust concentration into and out of a cleaner is shown in Figure 26. The light cells would consist of lengths of tubing equipped with entrance and exit sections, one holding the light source and the other holding the light meter. The windows in front of the light source would be kept free of dust by a clean air purge coming in through an annular slot around each window.

MEASUREMENT OF FORWARD ANGLE SCATTERING

The preceding discussion of the method based on measurement of the attenuation of light points out that a considerable quantity of dust must be seen in order to get an appreciable decrease in light intensity. If one goes at the measurement from the other direction—that is, measures the intensity of only the light which is scattered—a much more sensitive method results. Apparatus which will measure only the light scattered in a small forward angle cone has been designed and used for such things as the determination of the penetration of filters by test smokes(1, 3, 5) and the basic type is illustrated in Figure 27.

The forward angle Tyndallometer shown in Figure 27 consists of a light source, lenses for focussing the light, an opaque disc which blanks out that portion of the beam which would fall directly on the light meter, a light metering system, and a cell for observation of the aerosol stream. If no particles are present in the air stream no light falls on the light meter. If particles are present, the light scattered in a small forward angle cone (usually the light falling between 5° and 30°) will fall on the light meter. Thus the intensity of light seen by the meter will depend on particle concentration and the forward angle scattering cross section of the particles.

All of the references dealing with this type of system describe its use in measuring the concentration of monodisperse aerosols (particle diameter varies by no more than ±10 percent) and it has been satisfactory for that purpose. It would also be suitable for use with polydisperse systems if the particle size distribution were known.

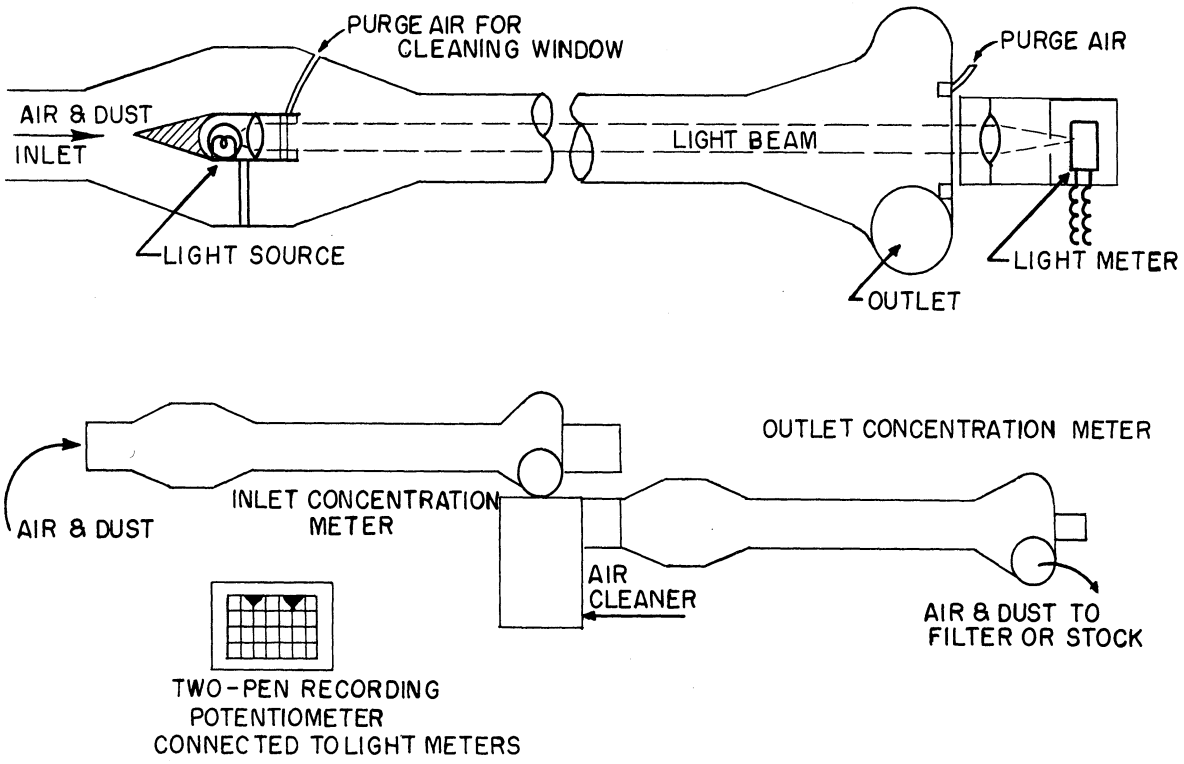

Figure 26. Light-scattering apparatus for measuring dust concentration. Light cell for measuring attenuation.

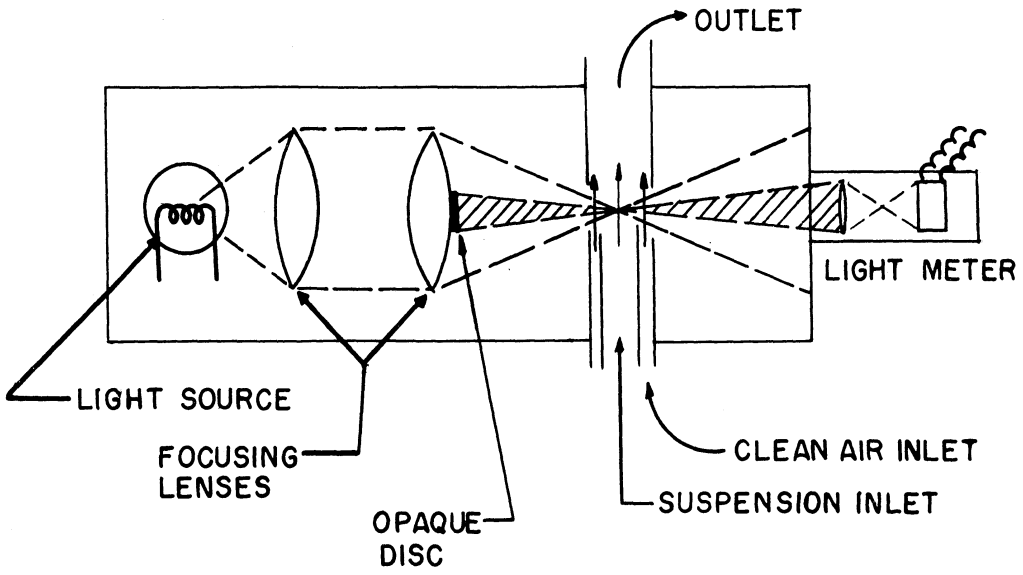

Figure 27. Apparatus for measuring forward angle scattering.

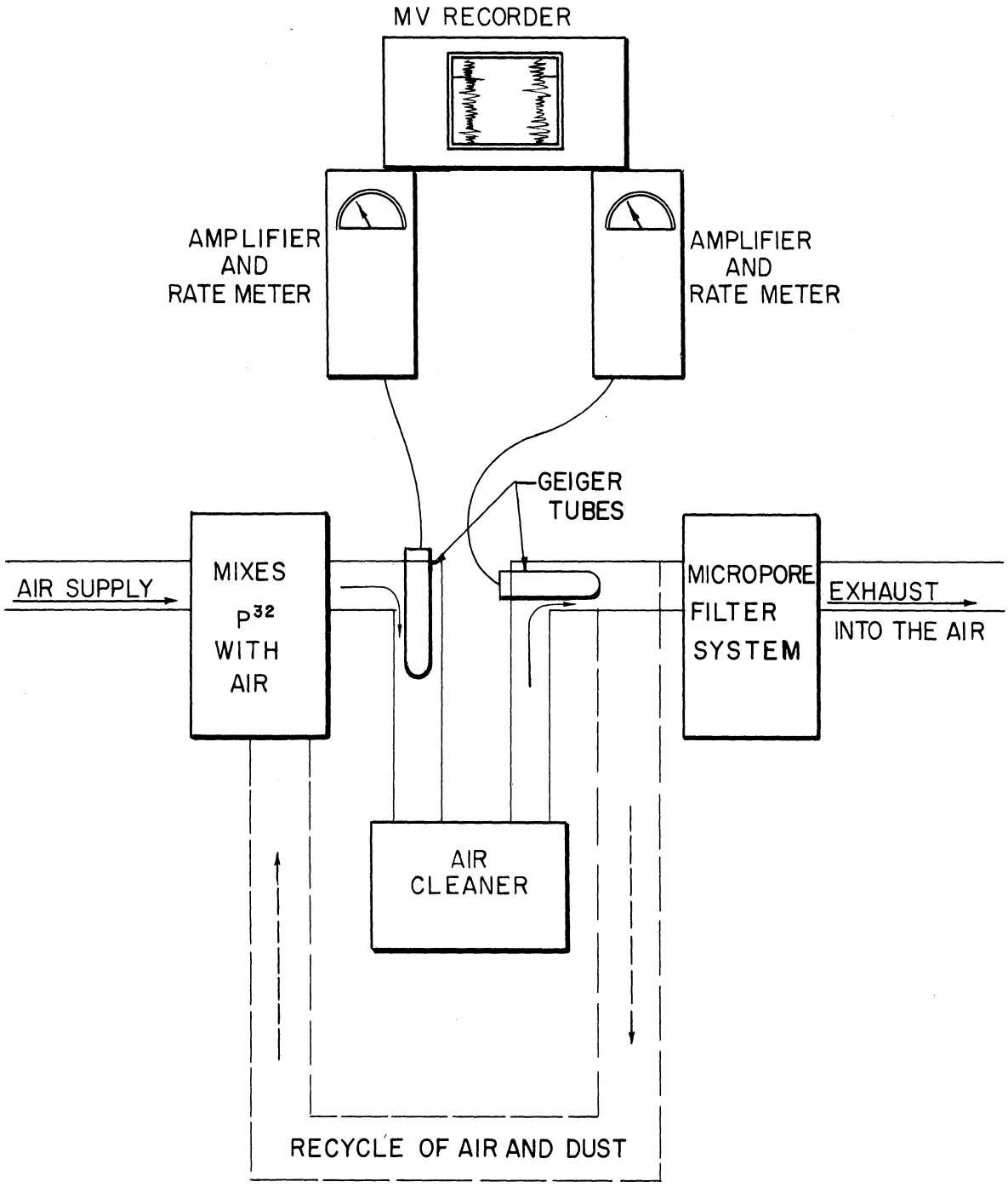

Figure 28. Schematic layout of proposed test system for radioactive tracers.

EVALUATION OF THE METHOD

Both attenuation and forward angle scattering methods are feasible for the proposed use. Forward angle scattering holds promise for providing a more compact and sensitive apparatus.

The chief advantages of light-scattering techniques are as follows:

1. Measurements are continuous and can be continuously recorded. They provide an instantaneous measurement of collector efficiency. Time required for an efficiency test is reduced to a few minutes.

2. Sampling and/or filtration of the air stream are not necessary. Thus, the additional pressure drop added to a test system is small, and there is no concern over the collection efficiency of an obsolete filter.

3. Both inlet and outlet dust concentrations can be measured, thus eliminating the need for weighing bulky dust feeders and filters.

4. The measurements are more sensitive to small particles than to large ones.

The disadvantages of light-scattering techniques are as follows:

1. More elaborate electronic equipment is required and careful attention must be paid to such things as the maintenance of stable voltage to the light source and the cleanliness of the cell windows.

2. The interpretation of data for polydisperse systems is not simple and requires the services of a technically-trained person.

An important possibility to note is that the use of a monodisperse aerosol as the test dust will greatly simplify the interpretation of the data. If it were possible to make a suspension of, for example, 2-micron dust particles (or an equivalent size of liquid droplet), the light-intensity measurements would be dependent on concentration alone. While it is questionable whether a close enough cut could be made by ellutriating solid particles, there are methods for making monodisperse aerosols of liquids by the condensation of vapor. This aspect is certainly worth consideration if the use of light-scattering techniques is contemplated.

The apparatus required for these methods has been described by Gumprecht[2] and others. The apparatus developed by Gumprecht has been

further refined by later investigators at the University of Michigan in the Department of Chemical and Metallurgical Engineering. Information may be obtained as it is published in the future or by personal communication at present.

REFERENCES FOR CHAPTER 2

1. Gucker, F. T., "Determination of Concentration and Size of Particulate Matter by Light Scattering and Sonic Tenchniques." Proceedings of the First National Air Pollution Symposium, Stanford Research Institute, 1949, p 14.

2. Gumprecht, R. O., "Particle Size Measurements by Light Scattering," Doctoral Thesis, University of Michigan, 1952.

3. LaMer, V. K., "The Preparation, Collection, and Measurement of Aerosols." Proceedings of the First National Air Pollution Symposium, Stanford Research Institute, 1949, p 5.

4. Rose, H. E., The Measurement of Particle Size in Very Fine Powders. Chemical Publishing Co., Inc., New York, 1954.

5. Sinclair, D., "Optical Properties of Aerosols," Atomic Energy Commission Handbook on Aerosols, Atomic Energy Commission, Washington D.C., 1950 p 81.

CHAPTER III

OIL-BATH AIR-CLEANER EFFICIENCY MEASUREMENT BY A RADIOACTIVE TRACER METHOD

INTRODUCTION AND SUMMARY

The purpose of this investigation is to survey the possibilities for and practicality of adopting a radioactive tracer method of measuring the efficiency of an oil-bath air cleaner. The greatest merit of such a system would be its ability to accurately detect very small traces of radioactive dust in the outflow from the cleaner. Several investigators have used radioactive tracers for this purpose, but all of the techniques which were used depended upon first collecting the suspended material on a filter and then counting the emissions from the filter. Since this requires laborious and careful sampling techniques it appeared worth-while to look into methods for counting the material while it is still in suspension in an air stream.

This report covers the following areas of consideration:

1. Nature of radioactive tracers
2. Possible tracers
3. Counting technique
4. System to be used
5. Necessary protection from the activity
6. Cost of operation

The conclusions reached with regard to the optimum system for the purpose of testing air cleaners of the engine-intake type are as follows:

1. The most promising tracer materials are phosphorous 32 and sulfur 35 which are both beta emittors. The phosphorous is available in the form of potassium di-hydrogen phosphate which may be spray-dried from a water solution impregnated on another material, or used as is. The sulfur is available as solid sulfur and could be dispersed as a dust or impregnated on another material (by drying a solution of the tracer on the inert material).

2. The dust contents of the air streams entering and leaving the air cleaner being tested can be determined by monitoring the flowing streams with Geiger counters. The accuracy of the measurement with this type of counter runs between 2 percent and 5 percent and a running time of about 10 minutes is recommended.

3. No radiation shielding other than the walls of the test equipment is necessary for beta emittors, although the equipment must be leak-tight to prevent escape and sbusequent ingestion of the tracer.

4. Disposal of tracer-bearing oil sludge poses no problem if the sludge is retained in storage for a few weeks until the tracer has decayed. The effluent gas stream must be filtered so that it is free of radioactive particles and the filters may also be disposed of after holdup in storage until the tracer has decayed sufficiently.

NATURE OF RADIOACTIVE TRACERS

Radioactive substances are characterized as being unstable and undergoing a decay process that will eventually result in a stable substance. This is sometimes a number of successive stages, one resulting in another radioactive substance which in turn will decay to the stable product. This is particularly true with the naturally radioactive elements like radium and uranium, which undergo successive stages eventually resulting in the stable element of lead. Radioactive decay occurs at a specific rate described by the equation $dN/dt = -\lambda N$, where N is the number of active atoms remaining after a time t and λ is the decay constant (characteristic of the substance). The solution to this differential equation is $N = N_0 e^{-\lambda t}$ and from this it is seen that the decay occurs exponentially.

The usual way to describe the rate of decay is by the half-life of the element (the time required for the activity to fall to one-half of its initial value) and is given by the equation $T_{1/2} = 0.693/\lambda$. The radioactive isotopes made artificially by nuclear reation are the ones this investigation is concerned with. The decay is in a single stage to a stable isotope of the

same element or of an adjacent element on the periodic table. The decay is characterized by changes in the nucleus of the atom brought about by the emmission of particles and electromagnetic radiation.

The use of radioactive tracers as a means of measurement stems from the fact that a radioactive material gives off distinctive particles or radiations in its decay. The most distinctive of these are the alpha particle, the beta particle, and the gamma radiation, each of which have distinctive energies and are given off in a distinctive number from a particular isotope.

The alpha particle is a double-charged helium ion (He^4) with a rest mass of 4.0039 and a charge of +2. Therefore, alpha emission is always accompanied by a decrease of 2 in atomic number and a decrease of 4 in atomic mass. Most of the naturally-occuring alpha particles are emitted with energies of between 4 and 8 Mev. The penetrating power or range of an alpha particle is less than .01 cm for most solids and is about 4 cm in air. This particular characteristic makes shielding from alpha particles a negligible matter but also makes their counting difficult—in our case, impossible. A method of counting alpha emissions is by tracks left on an emulsion-covered plate.

The beta particle is an electron, positive or negative, emitted from the nucleus as distinguished from electrons originating in the extra-nuclear shells. The beta particle has a rest mass of .0005486 and a charge of ± 1, depending on whether it is a positron or an electron. The beta particles are not monoenergetic like the alpha particles, but are emitted with varying velocities and energies. The average range or penetration into a solid by a beta particle is given by the relationship

$$\bar{R} = \frac{0.543\ E_{max} - 0.16}{d}$$

where E_{max} is given in Mev and d is the density. As an example, the beta particles emitted by P^{32} (which is of interest to this investigation) have an average range of 0.28 cm in aluminum. Beta particles are very easy to count and will be the basis for measurements in this study, employing a Geiger Müller counter. The characteristic of the beta particle which makes it measurable is that it produces ionization of air or other gas. It is this ionization which is measured by the counter.

The gamma ray is a penetrating electromagnetic radiation having no mass or charge. It is emitted with the velocity of light and has a specific wavelength (λ) and energy (E) related by the equation

$$\lambda E = 1.238 \times 10^{-10}\ \text{cm} \quad .$$

The energy of a nuclear gamma ray is between 0.05 and 3 Mev. Since the rays

are very penetrating and lose their energy very slowly, the protective shielding required for a gamma emittor would be quite thick.

The usually accepted unit of activity is the curie (3.7×10^{10} disintegrations per second) and is used to describe the disintegration rates of both alpha and beta emittors. Following this, a millicurie (mc) is 10^{-3} curies or 3.7×10^{7} disintegrations per second and a microcurie (μc) is 10^{-6} curie of 3.7×10^{4} disintegrations per second. We will be interested in the millicurie as this is the unit by which the activity is sold. For example, a microcurie of P^{32} which is beta active (decays only by beta emission) would emit 3.7×10^{4} particles per second, while Mn^{52} decays by beta emission for only 35 percent of the transition and would emit $.35 \times 3.7 \times 10^{4}$ beta particles per second. Thus it is obvious that the emission of a given particle depends on the disintegration scheme of the isotope.

POSSIBLE TRACERS

Our problem rests in introducing a tracer with the dust in the air stream and using the activity count as a measure of the efficiency of the cleaner. A suitable tracer must be used that will give adequate particle size and will not be soluble in the oil of the air cleaner.

A very promising tracer would be the active isotope of phosphorous (P^{32}). This isotope emits beta particles and no gamma rays which would make it a safe tracer to use. Additionally it would reduce shielding problems. The half-life of P^{32} is 14.3 days. This is a convenient decay rate as one can isolate the system after tests until the radioactivity has decayed away and then the disposal problem will not be difficult. The isotope is beta-active with a radiation energy of 1.69 Mev, which is quite high. These features make its measurement quite easy. P^{32} is produced by bombarding the stable isotope of phosphorous with deuterons (heavy hydrogen nuclei). Active materials can be obtained from the Oak Ridge National Laboratory. The only solid form of P^{32} available is in the form of an irradiated unit of KH_2PO_4, which is water soluble and could be spray dried to yield a dust or could be impregnated on particles of another material. This unit would contain 31 grams with an activity of 215 mc, which is a concentration of 31 mc/g. Each unit would cost $33. The unit also contains K^{42} which is a gamma emittor which has a very short half-life. A hold over before using of 5 days would remove this radiation. This unit is called the P^{32}-I irradiated unit.

Another possible tracer would be sulfur (S^{35}) which has a half-life of 87.1 days and is also a beta emittor, but at the lower energy of .17 Mev.

This is also a non gamma emittor. This isotope is available in solid form as elemental sulfur. The irradiated unit S-35-I contains 25 grams with an activity of 7.5 mc, which is a concentration of .3 mc/g. This unit also costs $33, but for less activity. The longer half-life could be advantageous if the tests spanned a long period of time, but the cooling-off period would be much greater also.

The particle size and other information about irradiated units can be obtained by writing to:

Mr. J. H. Gillett
Supt. Radio Isotope Control
Oak Ridge National Laboratory
Oak Ridge, Tennessee

If the desired particle size cannot be obtained, it will be necessary to grind the material.

The concentration of the irradiated units is high and it would be economical to mix or impregnate some inert dust with it, preferably of the same material. This and the grinding would have to be done under a special hood, such as Dr. Meinke has in his nuclear chemistry laboratory.

COUNTING TECHNIQUES

There are several methods of measuring or counting radioactivity. The different emissions give distinct patterns in a Wilson cloud chamber or on a photographic emulsion. They can also be measured by detector elements such as the ionization chamber, proportional counter, Geiger Müller counter, or the scintillation counter in conjunction with an electroscope, a scaling circuit, or a rate meter.

The method which would be most applicable to this type of detection is the Geiger Müller counter multiplicative ion collection method. This method is based on the fact that beta particles cause ionization of a gas. When ionization occurs in air between two electrodes and there is no voltage drop across the electrodes, most of the ions will recombine quickly. If voltage is applied most of the ions will be collected at the electrodes before recombination can occur. At about 10 volts per cm all of the ions are collected. If the voltage is still increased the "avalanche" process, multiplication of ionization by collision, occurs until the ionization multiplication reaches a saturated stage. Here the pulses of ionization, regardless of

initial strength, are multiplied to a constant pulse size. This is called the Geiger Müller region and herein the counter operates.

There is a portion of the Geiger region where the counting rate varies only slightly with a change in voltage. This is called the plateau and is where the instrument should be operated. A stabilized power unit must be used to supply the high voltage (about 1000 volts) and to compensate for changes of line voltage keeping a steady operating voltage. This is usually made up of a transformer, rectifier, and filter. An amplifier amplifies the pulses so that they will operate a scaler or rate meter. The counting rate is proportional to the radioactivity and the proportionality constant is determined by the geometry of the counter and the efficiency of the counter.

The Geiger tube or ionization chamber may be one of several types. One type is the bottom-window type with a metal cylindrical cathode and a coaxial tungsten-wire anode, all of which is enclosed in a glass sheath. The bottom has a thin glass or mica window through which the particles pass. Another type is the tube type where the cathode forms part of the outer shell and window. The coaxial wire anode is supported by insulated plugs. This can or can not have a glass sheath over it.

Since the particles must pass through this wall it must be made very thin. P^{32}, however, has a reasonably high energy particle so a stronger wall can be used. The tube used here would probably be an aluminum window-tube type. The tubes are additionally classified as to the type of gas enclosed in the tube and as to whether or not a quenching agent is included. "Quenching" means neutralizing the ionization so another count can be taken. Either a quenching agent or an exterior quenching circuit must be used. Most of the more recent tubes are self-quenching and can be used in continuous counting.

An electron tube head amplifier amplifies the pulse to a level where they operate the scaler or rate meter. This gives the total counts over a period of operation or the activity level at the instant of the count.

The counter requires that the activity be between one and one one-hundredth of a microcurie. The counters measure to an accuracy of between 2 and 5 percent. This makes it possible to detect extremely small amounts of activity.

SYSTEM TO BE USED

A possible layout for an air-cleaner testing system using a radio-

active tracer is shown in Figure 1. The essential features of the system include a means for introducing the tracer into the air, Geiger counters monitoring the air streams in and out of the air cleaner, amplifiers and recorders collecting data, and a filter for cleaning exhaust air.

By using the recycle as shown, the series of filters required to exhaust into the air would be eliminated and the cost of operation would be cut down as the dust in the exhaust stream would be recirculated and reused. The problem involved would be to keep the air circulating with the required velocity. If, however, it would not be practicable to use the recycle, the air stream could be exhausted into the air after passing through a series of micropore filters. It must be absolutely free of activity before it can be exhausted into the atmosphere.

The Geiger tubes shown are cylindrical tubes with metal cathodes (probably aluminum would be most suitable) forming the envelopes of the tubes. The tubes would be sunk through the pipes and pointed in the direction of flow. The Phoenix project radiation laboratory recommends this type of installation. They do not believe that a pile-up of dust around the tubes would be a serious problem and this type of installation would give the greatest geometric efficiency to the counter. The Victoreen 6306 tube, costing $7.50 each, would probably be the best choice. However, the window-type tube could be used if necessary. John Wighton, a graduate student working under Professor Porter of the Mechanical Engineering Department, is eventually going to run this type of experiment with a water-bath air cleaner and he will be using a Victoreen tube inside the pipe.

The possibility of particle pile-up around the projecting Geiger tube is a problem that would have to be tested experimentally. In the absence of Wighton's results, it could be determined with simple apparatus. A tube could be sunk into the pipe section as it would be in the system, and a very-low-count tracer dust could be run through. A counter could be used to check this pile-up or background count. Another method would be to introduce known concentrations of dust and measure the weight collected on the tube under various operating conditions.

Another possible system is one using a filter system and isokinetic sampling. Samples would be steadily taken from the inlet and outlet and caught on filters. The activity of the filters would then be counted and compared. The sampling unit would have to be operated isokinetically so that an accurate and constant portion is taken from the airstream. The chief advantages of using this system are that a much-lower-activity dust could be used and only one measuring counter would be needed. This would cut the cost of installation considerably and the cost of operation would be greatly reduced.

In either system the runs would have to be made over a moderate length of time. Both Dr. Meinke of the Nuclear Chemistry Department and Dave Weyant of the radiation laboratory suggest that a ten-minute period would be of sufficient length. This would ensure that the system achieves an equilibrium condition which is required because an instantaneous reading would not be a dependable measure.

PROTECTION FROM RADIOACTIVITY

The problem of shielding is not complex for a beta-emittor system. The piping and container walls would be shielding enough. The danger involved here is not external radiation, but rather ingestion. The dust must not be allowed outside the system when it could be taken into a person's lungs or stomach. Therefore, either the system must be completely closed or the filter on the exhaust must be absolute.

Any work with radiation in conjunction with the University must be approved by the Radiation Policy Committee. Dr. Emmons of the School of Public Health is the representative of the committee through whom approval is obtained. The committee must see and approve of the system that will be used before it can be put into operation and they require that the man doing the work must have had experience with that particular isotope. (They might make the exception that he only be available during the runs under certain circumstances.) An air monitor and a Geiger Müller survey instrument must be on hand at all times during operations. The air monitor draws air through a filter and the filter is counted for activity. The survey instrument is used to constantly check for leakage in the system or any accummulation of activity. Personal monitors or film badges are not necessary. To begin operation and procure the isotope the AEC-313 form, "Application for Radioisotope Procurement," must be filled out in duplicate and returned to Dr. Emmons.

The removal and disposal of contaminated equipment or residue that is active would be done by Dr. Emmons' office.

COST OF OPERATION AND EQUIPMENT

The instruments that would be needed both for safety and operation are listed below with their costs.

Victoreen 6306 counter tube (other tubes range from $7.00 to $50.00 per tube)	$ 7.50
Amplifier with rate meter 1615-B	$350
Air monitor	about $100
Survey counter	$280
Twin flush mv recorder	$600

(This would give both readings continuously on a single graph. Any milliavolt recorder, however, could be used and perhaps there are some available within the project that could be used or obtained at a lower cost. A separate single-input recorder could be used on each amplifier.)

The cost of setting up the inflow measurement system would be about $2000, while that for the filtration sampling system would be about $1000. This includes only the equipment listed above.

The cost of operation for the inflow system is calculated as follows:

Using 2 in. pipe and the tube inserted

activity on the output = activity/unit vol x vol seen x geometry factor

$$.01\mu c = A/\text{vol unit} \times 12\ \text{in}^3 \times .4$$

$$A = 3.6\mu c/\text{ft}^3$$

for 10-minute run at 100 cu ft/min. $A = 3.6 \times 10^3 \mu c = 3.6$ mc. If the cleaner is 80 percent efficient, input activity = 18 mc. Cost of P^{32} is about $1.00 per mc., cost of a run = $18.00.

For the filtration system this could be cut to whatever figure desired, as the determining factor is that .01 c is required on the output for a count. A run could be made to cost only a matter of a few cents. The savings shown here for the second system would, however, probably be offset by extra labor and very complex additional shielding and safety equipment.