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February 1, 1950

AEC CONTRACT NO. AT-30-1-GEN-238

CONTRACTOR:

Harvard University
School of Public Health
Department of Industrial Hygiene
Boston 15, Massachusetts

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and Philip Drinker

This contract is between the United States Atomic Energy Commission New York Office of Operations and Harvard University through the above department. It represents a fundamental and applied research project with the following purposes:

- I. Consultation service on problems of dust and fume control and atmospheric pollution related to the operations of the New York Office.
- II. Basic laboratory research on methods of increasing particle size and aggregation by condensation from sprays, Joule-Thomson effect, or other suitable means with particular application to methods of collecting low concentrations of aerosols.
- III. In conjunction with the laboratory project, field studies of the performance of various dust and fume collectors were to be undertaken.
- IV. A literature survey of unclassified domestic and foreign publications on dust and fume collection was also considered a necessary part of this project.

- V. A survey of manufacturers data on dust collecting and air cleaning equipment was also made a part of this project because of its relationship to the applied problem.

Progress to Date

This is a final report of progress on this contract. Delay in submission was due to organization of a new project and a change in personnel.

This study is concerned primarily with only two of the objectives listed above. In a previous report dated July 1, 1949 (1), the results of a survey of manufacturers on dust collecting and air cleaning equipment were shown. In this investigation we present the results of a laboratory research project (I) and data and techniques used for a limited number of field studies (II). The literature survey and consultation services are continuing under the new AEC Contract AT(30-1)841. Further data on the manufacturers survey is being accumulated.

I. Investigation of Aerosol Aggregation and Collection

In our previous report we presented a study of commercially available dust collectors and their performance as specified by manufacturers. Information from this study indicated that there were a number of devices capable of removing particles 10 microns and greater in diameter. Below this size, with the exception of electrostatic precipitators and filters, the performance of wet and dry collectors using other principles is not completely satisfactory. All known principles are applied in some form in commercial and experimental collectors. It was therefore our approach to this problem to study methods to increase the particle size of air borne materials by agglomeration or other forces in order to improve the performance of less efficient types of collectors. In addition to this, it was felt that the possibility of introducing other suspensions as a means of changing characteristics of the aerosol should be investigated for their influence on performance of such collectors.

There are many factors which influence the rate of aggregation of aerosols and these have been discussed in detail by authors such as Whytlaw-Gray and Patterson (2), Gibbs (3), and Drinker and Hatch (4). The properties of particulate matter and aerosols which influence aggregation (as well as performance of dust and fume collectors) are as follows:

Particle Characteristics

- (a) Size
- (b) Shape
- (c) Specific Gravity
- (d) Surface Adsorptive Properties
- (e) Chemical Composition
- (f) Electrostatic Charge

Characteristics of Aerosol

- (a) Concentration (Number and Mass) of Particulate Material (Loading)
- (b) Temperature of Continuous Phase (Gas)
- (c) Pressure of Continuous Phase (Gas)
- (d) Viscosity of Continuous Phase (Gas)

Characteristics of Agglomerating Forces Imposed on Aerosol

- (a) Agitation
 - 1. Mechanical
 - 2. Thermal
 - 3. Sonic
 - 4. Gravitational
- (b) Electrostatic Charge

A discussion of each of these factors in detail may be found in the above (2,3,4) references.

In basic research on air cleaning, a number of these properties may be studied for their utilization in air cleaning. Most of them, based on our literature survey, have been applied with little or only a measure of success.

The properties which appeared particularly worth further study and are discussed in this report are the following:

- (a) Particle size, shape, surface, chemical composition and size distribution
- (b) Dispersoid concentration
- (c) Agitation of aerosols

In respect to agitation, only mechanical and thermal forces appear deserving of further study. Tests on sonic agglomeration were conducted elsewhere (5) and conclusions concerning the value of this method are still in a high state of flux. In this particular study, only the effect of aerosol concentration and mechanical agitation is considered. Investigation of other factors presented above is progressing on the present AEC Contract (AT(30-1)841).

Experimental Considerations

There are many methods of increasing aerosol concentration which have indicated promise for improving collection efficiency. The use of steam and water injection have been reported in the literature and, on an experimental basis, have been shown to be of some value. Radford and Houghton (6) investigated this technique for dissipating natural fogs and many commercial wet collectors utilize water sprays of various types. There are numerous economic considerations (such as cost of high pressure steam, fog nozzle pumps, etc.) which are also important in selection of these aids and for that reason we have attempted to utilize fairly simple, commercially-available equipment for producing increases in loading for studying performance.

The preliminary study was made utilizing water sprays for producing both an increase in loading and mechanical agitation. The effects of thermal agitation and pressure effects (application of Joule-Thompson effect) were observed on a pilot scale but early results were not promising and this was not continued. Further tests are planned and if these show more promise, investigation will be continued. In this report, however, consideration is given only to increase of particle size and mass by water sprays or added solid particulates, and the effect of mechanical agitation on performance.

Experimental Apparatus

Agglomeration Apparatus Number I

The first apparatus built for this study is shown schematically in Figure 1. Room air was drawn through a housing containing five Type 6 C.W.S. filters (A) (furnished by the U.S. Army Chemical Corps). This filtered air was then drawn through the Venturi section (B) where provision was made for the introduction of test dusts of various types at the throat. The orifice (C) was used to meter room air for dilution and as a source of dust. A Stairmand disc (D)(7) was provided to promote mixing of the clean and contaminated air. This device gives a relatively uniform velocity and dust concentration profile at the upstream sampling point (E) five duct diameters from the disc. The air-dust mixture then entered a treatment and settling chamber (F) equipped with eight pneumatic atomizing nozzles (G)*. Four nozzles were of the flat spray type and four gave solid cone sprays. A second sampling point (I) was placed five diameters downstream from another Stairmand disc (H). Air flow was provided by a high static pressure characteristic blower (J)**. Total air flow was measured by a Venturi meter (K) located at the blower discharge. All joints were tightly sealed.

Not shown in Figure 1 are simple elutriating towers used for controlling particle size of dusts admitted at the venturi throat (B).

When the water sprays were operated in the treating chamber (E), sufficient spray was entrained to interfere with downstream sample collection at (H). This was partially corrected by installing a droplet eliminator at

*1/4" FJ Spraying Systems Company, 4021-27 W. Lake St., Chicago 24, Ill.

**Lamson Corporation, Allen Billmyre Division, Syracuse 1, N.Y., Model 12-HR-10 Blower.

the chamber outlet constructed of a 4 inch sheet metal elbow with 325 mesh phosphor bronze screen soldered over the inlet.

Agglomeration Apparatus Number II

To overcome structural weaknesses and to extend the range of the investigation, the apparatus shown in Figure 2 was constructed to replace Model I. The major change was the substitution of the equipment shown in Figure 2 for the treating chamber of Figure 1. This change was made to facilitate subsequent investigations on the application of the Joule-Thompson effect to increase particle size.

The treatment chambers were constructed by dividing two 55 gallon open head drums by a sheet of steel plate welded through the diameter of the drum and extending to within three inches of the bottom. Four pneumatic atomizing nozzles of the type described above were installed in the lower half of one drum and a stainless steel perforated double plate screen* was placed in the upper half. This screen has one hundred and twenty 0.045 inch diameter holes per square inch. Sheet thickness is 0.010 inches and the space between is 0.005 inches. The spacing is maintained by dimpling the sheets and spot welding them together. Resistance loss characteristics are presented later. This material acts as an eliminator for water droplets and particulate matter, separated particles draining into the lower half of the drum.

The second drum was of the same general design but without screen or spray nozzles and was installed as a treatment chamber for later use in Joule-Thompson effect evaluation.

*Neva-Clog Filtering Medium, W. S. Rockwell Co., 200 Eliot St., Fairfield, Connecticut.

Test Suspensions and Generation Apparatus

Requirements for test suspensoids to be used in evaluating air cleaning performance include:

1. Small size, preferable 5 microns or less.
2. Homogeneous or uniform size if possible (minimal dispersion).
3. Availability of a sensitive chemical or physical test for suspensoid.
4. Known particle shape and surface characteristics (preferably spheres).
5. Freedom from unusual flocculation characteristics.
6. Easily generated in reproducible concentrations.

Initial tests were conducted using atmospheric air as a contaminant.

It met requirements 1, 3 and 5, as outlined above, but had unpredictable characteristics in items 2, 4 and 6 which limited its applicability considerably.

A second technique employed was the use of air elutriated cupric tartrate dust, introduced at the Venturi throat as described. Particle size distribution was satisfactory and a sensitive analytical method (Appendix II) was available for this material. Particle shape was not uniform, however, and the material could not be dispersed dry except at very low concentrations. Attempts to use the feeder developed in this laboratory (Appendix III) were unsuccessful because the dust compacted from vibration of the Syntron feeder.

To circumvent this, cupric tartrate was suspended in water, allowed to settle for twenty-four hours, decanted and then sprayed by means of a mist generator. The first generator was a simple nebulizer unit consisting of a compressed air jet blowing across the tip of a capillary tube aspirating from the elutriated suspension. Diluting secondary air dried the material and gave a dust whose upper size could be controlled by adjusting the settling time. This particular apparatus did not have sufficient capacity, however, to produce the desired concentrations of aerosol. To increase output, a pneumatic

spray-nozzle* (50 pounds per square inch air and liquid pressure) was connected to a copper cylinder containing the elutriated suspension as illustrated in Figure 3. Air pressure (50 psi) above the suspension was used to drive the material through the nozzle. However, it was still impossible to maintain concentrations which could be determined chemically in a 15 liter sample.

This apparatus proved successful for use with solutions of varying strengths of copper sulphate. Since copper sulphate is water soluble, particle size characteristics are functions of the spray droplet diameter and the solution strength. Heat is utilized to dry the aerosol (as shown in Figure 3) and fuse the copper sulphate into spheres. Copper sulphate melts at 200°C and after the water is driven off spherical particles are formed which retain this shape for at least 24 hours. Subsequently they tend to spontaneously return to their crystal structure on standing in air. A microphotograph of copper sulphate spheres is shown in Figure 4 and their size distribution is shown in Figure 5. A later report will describe in detail the performance of this type of aerosol generator. Particle diameter measurements indicate that 30 per cent of this aerosol is less than 2 microns (Figure 5). Concentrations of 10^{-3} grains per cubic foot can be maintained with a system air flow of 180 cubic feet per minute using 10 per cent copper sulphate solution.

For heavier loadings of larger size spherical material, glass microspheres were employed using the mechanical dust feeder described in detail in Appendix IV. A microphotograph of this material is shown in Figure 6. This material flows readily and has a mean particle size of 9 microns, as

*1/4" FJ Spraying Systems Company, 4021-27 W. Lake St., Chicago 24, Ill.

shown in Figure 7.

Performance of Components of Experimental Apparatus

1. C.W.S. Type 6 Filters

Efficiencies for this filter have been reported as 99.9 + % for 0.3 micron spheres (25). In order to study its performance as a precleaner for Apparatus I an adequate volume of filtered air was drawn through the apparatus to remove any atmospheric air present during assembly. Based on reports of the filter's performance, air passing through the apparatus after this cleaning period should be nearly dust free.

Using the Bausch and Lomb dust counter with a greased slide (Dow-Corning Silicone, 30,000 centistokes at 25C, or vaseline) as the sampling instrument (see Appendix I), samples were taken from the duct. By this method we were unable to obtain cleaned air which was consistently lower than 0.02 million particles per cubic foot of air using the standard Bausch and Lomb microscopic system.

All possible leaks were tightly sealed. Atmospheric air was then used as a contaminant and duct samples were again taken. The results of this study are shown in Table 1. Predicted and observed concentrations of duct concentrations agree well within limitations of the sampling method.

Possible explanations of these relatively poor efficiencies as compared to those previously reported may be filter dusting or deterioration.

2. Stairmand Discs

Stairmand discs (7) were used to give flat velocity and dust concentration profiles at the points of sampling. The dimension of this disc is

$\frac{D}{\sqrt{2}}$ (D equals duct diameter) and air passing through its annulus becomes extremely turbulent and mixes thoroughly, providing a uniform velocity profile at 3 to 6 diameters downstream. The maximum mean duct velocity was approximately 2000 feet per minute.

Table 2 lists Pitot tube readings made at four, five and six duct diameters downstream from the Stairmand disc. These data are in agreement with British observations (7) which were made at corresponding velocities.

Results

Table 3 is a summary of the results of twenty-two test runs with Model I agglomeration apparatus using cupric tartrate as the test dust. Six runs without sprays showed zero cleaning efficiency, indicating that the settling velocity of the test dust is below the range where significant removal can be accomplished by gravitational forces alone. An additional sixteen tests were made using the same apparatus and particulate material with the addition of eight pneumatic nozzles spraying water mist into the treatment chamber. The nozzles were arranged to spray concurrently (2 nozzles), counter currently (2 nozzles) and perpendicular to flow (4 nozzles). With all sprays operating, cleaning efficiency rose from 0 to 65 per cent (average deviation 20 per cent). Since the chief force available to remove dust from the air stream was gravity, increased particle removal can be accounted for on the supposition that the dust becomes wetted in passage through the fog chamber and adsorbs or absorbs enough water to increase in size and mass and then settles out. On this basis the increase in removal efficiency is a measure of the increase in settling velocity of the cupric sulphate dust due to adsorbed or absorbed moisture.

Figure 8 shows the distribution of the cupric tartrate aerosol used in Model I apparatus experimentation when sampled with a cascade impactor. Note that the 50 per cent size for slide 1 is less than that for slide 2. This has been observed in many cases when using the cascade impactor for duct sampling due to the changed impactor nozzle air flow characteristics under these conditions.

Table 3B indicates the mass distribution by size of cupric tartrate test dust upstream and downstream of the spray chambers, determined with the aid of the cascade impactor. If duct separation is being accomplished by gravitational settling alone it would be expected that the larger particles would be removed preferentially, and that the effluent would show a smaller mass media size than the influent air, but analysis of impactor samples indicates that there is a slightly larger per cent of large particles in the effluent air. This confirms the evidence presented previously that the test dust is adsorbing significant amounts of water in the spray chamber, and although the largest of the particles so wetted settle out, those that pass from the apparatus are, with their adsorbed water, larger on an average than when entering in the dry state.

These results were sufficiently promising that further investigation was deemed desirable. A new and sturdier apparatus, incorporating several refinements, was constructed (Model II, Figure 2). The principal changes were (1) all nozzles were arranged to spray countercurrent to air flow and (2) a more efficient type of droplet eliminator (Neva-Clog Filter) was added following the treatment chamber.

Agitation of an aerosol may accelerate the agglomerating tendencies of particulate matter. In the tests just described, the increase in degree

of agitation of the system due to the addition of the pneumatic sprays was believed of minor significance since the quantities of air and water used by the nozzles were relatively small additions to the main air stream (approximately 1.5 cubic feet of air and 0.037 gallons of water per minute). Total air flow was approximately 150 cubic feet per minute, and the pressure loss at this flow, excluding the resistance of the two Stairmand discs (used solely as sampling aids), was approximately 1.5 in. w. gage.

Tables 4, 6 and 7 summarize the results of a number of tests to determine (1) the effect of quantity of spray on removal efficiency, (2) effect of test dust loading on removal efficiency and (3) the effect of simultaneous additions of liquid (H_2O) and solid (glass spheres) co-agglomerating aids on removal efficiency of smaller solid particles (copper sulphate spheres).

Table 4 indicates that increasing the number of water droplets in the air stream greatly improves collection efficiency for both large (glass spheres) and small (copper sulphate spheres) particles. For the copper sulphate spheres, efficiency is increased 20 per cent with the use of 2 spray nozzles. Increasing the number of sprays from 2 to 4, increases efficiency an additional 50 per cent. For the glass spheres, per cent removal increases from 88 per cent without the use of sprays to 99.9 per cent with three sprays. Such a result would be anticipated from statistical considerations of the increased probability of collisions between test dust and water droplet with increasing numbers of water droplets per unit volume. The magnitude of the increase, however, is larger than anticipated.

An additional noteworthy result of these experiments is the high removal efficiency of the dry apparatus without the use of water sprays; 45 per cent for less-than-one micron copper sulphate spheres and 88 per cent for

9 micron glass spheres. Runs with the first apparatus (Model I) showed a zero removal efficiency on copper tartrate dust when the apparatus was run dry indicating that significant gravitational settling of the dry dust did not occur. The new component of agglomeration apparatus II was the Neva-Clog droplet eliminator, and the relatively high removal efficiency for copper sulphate spheres in the dry apparatus can be attributed to this screen. In the case of glass spheres having a mean size of 9 microns, settling cannot be entirely ruled out as a contributing factor since the mean settling velocity is 1.2 fpm. A small-scale apparatus, shown in Figure 9, was constructed to investigate the characteristics of the Neva-Clog screen independently of settling effects and sprays. Since it was desired to test the screen wet as well as dry, an arrangement was made to flood the screen by means of a controlled stream of water directed onto the top of the screen and allowed to flow downward by gravity.

Figure 10 gives the resistance of the Neva-Clog screen wet and dry for air velocities ranging from 90 to 425 fpm.

Table 5 indicates the results of efficiency tests using the Neva-Clog screen wet and dry with copper sulphate and glass spheres. Settling is believed to be a negligible factor in this experimental apparatus and sprays were not employed.

With glass spheres the screen showed a retention efficiency of 48 per cent when dry and 98.8 per cent when wet. The presence of a flowing film of water on the screen is thought to be beneficial from two mechanisms, (1) the water-film decreases the width of the air passages thereby increasing velocity and the centrifugal separating force and (2) the wet surface resembles a viscous filter and retains more material which contacts it (either

by impaction or through centrifugal action). As a result of such retention, a moist filter cake composed of the material to be removed is built up on the surface of the screen. This cake acts as an efficient air cleaner for materials having a similar composition. At a dust feed rate of 0.15 pounds of glass spheres per square foot of screen per minute, an air flow rate of 250 feet per minute and a water rate of 0.2 gallons per square foot of screen per minute, screen resistance rose from 3.4 to 12 inches of water gage in approximately 7 minutes due to accumulation of a moist filter cake. Although such a resistance increase is excessive for practical uses, it is felt that further investigation may indicate satisfactory methods for continuous removal of a portion of the filter cake so as to maintain high cleaning efficiency at a constant, moderate resistance. Such procedures as adjustment of the water rate so as to wash away the excess cake or use of mechanical scraping devices appear entirely feasible.

Using low concentrations of copper sulphate spheres (on the order of 0.001 grains per cubic foot of air) a reliable estimate of the retention properties of the screen could be obtained since the material is soluble and cannot, therefore, create a high efficiency filter-cake as was the case with the glass spheres described above. Table 5B indicates that the dry screen removed 24 per cent of the less-than-one micron particles at a superficial air velocity of 120 feet per minute. With the same flow conditions the wet screen removed 50 per cent of the material, and with double the air flow the screen removed 82 per cent of the test dust. This increase in efficiency with air flow indicates that impaction and centrifugal forces are important mechanisms in this device. Particle capture by impaction and contact are shown to be greatly aided by wetting of the screen.

These latter results indicate that the wetted screen has considerable retention efficiency even for low concentrations of fine particles. For aerosols containing insoluble materials this simple device may be made even more efficient by permitting a low resistance cake to form on the upstream side of the screen. Superficial face velocities of 240 fpm were the highest flows investigated, but higher rates may result in higher retention efficiencies.

By reducing the copper sulphate concentration used in the sphere generator and constructing a larger settling chamber (30 inches) to remove oversize droplets, dry copper sulphate spheres with a mean size of approximately 0.3 microns were prepared. Table 5 indicates the effect of dust concentration on efficiency of the Model II particle agglomeration apparatus. A distinct trend of decreasing removal efficiency with decreasing dust concentration is evident. This agrees with the results cited previously on the effect of number of sprays with a constant dust loading. The explanation in both cases is thought to be the greater probability of favorable collisions between water droplets and dust particles as concentration of either or both increases.

Table 7 shows the results of tests using water sprays and glass spheres as co-agglomerating agents for 0.3 micron copper sulphate spheres. Comparing the results with those shown in Table 4B, considerable improvement on collection efficiency can be noted (from approximately 15 per cent to approximately 60 per cent). There appears to be a slight trend in the direction of increasing removal efficiency with copper sulphate loading. In view of the tests described above on the wetted screen without the use of sprays and settling chamber, it is probable that the increased efficiency

can be accounted for by the formation of a glass sphere filter cake on the Neva-Clog screen. This cake, rather than increased agglomeration, may have been the principal mechanism responsible for the increased efficiency, and the apparent increase in efficiency with increase in copper sulphate dust loading may have been due to the presence of a progressively thicker filter cake as the tests continued.

Conclusions

Significant increase in size and mass of small particles may be accomplished by the addition of a third component to an aerosol. This effect was clearly evident when using a fine water spray as the addition component. Increases in concentration of the solid phase of the aerosol and increases in concentration of the added liquid phase each tend to increase agglomeration. This is in accord with results predicted from theoretical considerations.

Interpretation of results of experiments using additions of a solid third component as the co-agglomerate of a solid phase of an aerosol were complicated by the presence of other separating mechanisms, such as filtration through a bed composed of the added solid material. Substantial increases in removal of a test dust were observed using simultaneous additions of solid and liquid co-agglomerate, although further investigations are needed to evaluate the fraction of the removal due to filtration, settling and agglomeration.

Investigations on efficiency of the Neva-Clog droplet eliminator screen indicated that high removal efficiencies on low concentrations (< 0.001 grains per cubic foot of air) of small particles (< 1 micron) may be achieved

by additions of an inert filter-aid.

These results indicate the need for further investigations to determine the most efficient methods of inducing adsorption or absorption of moisture on solid suspensoids. The Joule-Thompson effect suggests one such alternative method and a few preliminary experiments have been performed. Although the results were not encouraging, refinements in technique and apparatus are contemplated. The investigation of adsorption by the use of fine water sprays should be extended to a large variety of suspensoids differing in size, shape, composition, surface characteristics and radioactivity to determine the limits of applicability of this method.

Techniques are now available for generating constant, reproducible and large volumes of aerosols containing suspensoid concentrations varying from 0.001 to 10 grains per cubic foot and ranging in mean size from 0.25 μ to 50 μ .

II. Field Testing of Commercial Air Cleaning Equipment

Introduction

Testing of commercial air cleaner installations under industrial conditions was considered desirable for the following reasons (in order of their importance):

1. To collect data on commercial equipment and various industrial aerosols under conditions which cannot be duplicated in the laboratory.
2. To compare performance data obtained on known aerosols in the laboratory to conditions that exist in industrial practice.
3. To determine the applicability of sampling techniques and instruments developed in the laboratory.

Sampling Instruments

A single sampling instrument and analytical technique applicable to all types of air cleaners regardless of dust loading or particle size would be ideal. Practice indicates, however, that specific instruments or techniques have certain limitations. Two examples are given below.

- a. The thermal precipitator is considered to be 100 per cent efficient for collection of fine dust (less than 5μ) when used under prescribed conditions. For sampling from ducts connected to air cleaning devices, the low collection rate of the thermal precipitator (8-10 ml. per minute) limits its use for isokinetic sampling.
- b. The cascade impactor described by May (21) was investigated with considerable interest as it seemed it might provide a rapid and simple method for particle sizing. Dust loadings encountered in most industrial systems, except downstream of extremely efficient cleaners prove, unfortunately, to be too dense for proper use of this instrument. Dilution with dust free air is necessary and in addition, the entry characteristics of the instrument are unsuited to isokinetic sampling in ducts.

For selection of appropriate sampling instruments and analytical techniques, the following rough classification is used:

- a. Heavy loadings (greater than 0.1 grains per cubic foot) and coarse dust (90 per cent (by weight) greater than 1 μ diameter).
- b. Heavy loadings and fine dust (90 per cent less than 1 μ diameter).
- c. Light loadings and fine dust.

This report presents preliminary results on an investigation of field sampling instruments and techniques for conditions encountered in classification (a). Investigations are in progress on the other classifications.

Weight efficiency and size distribution of particulate matter upstream and downstream are essential factors in rating air cleaners. For loadings above 0.1 grains per cubic foot and particles greater than 1 micron, weight efficiency can be conveniently determined gravimetrically with the use of paper thimbles as a collecting device provided the air or gas temperature is below the charring temperature of the paper (approximately 300°F.). Studies on standard laboratory paper thimbles (28) indicate that for silica particles between 1 and 2 microns in size, loadings between 0.15 and 0.50 grains per cubic foot and flow rates in the vicinity of 1 CFM, efficiency rises from 81 per cent to 100 per cent within the first 37 seconds of sampling (due to building up an efficient filter cake on the surface of the filter). A 15 minute sample at 1 CFM with a loading of 0.1 grains per cubic foot, at 100 per cent efficiency, would give a dust deposit on the filter thimble of

$$\frac{0.1 \times 15 \times 1000}{18.43} = 100 \text{ mg.}$$

This represents a significant weight increase on a 0.5 gram thimble and for low density dusts (specific gravity 2 to 3) with normal packing characteristics, this will give filter cake thickness ranging from 1/2 to 1-1/2 mm. Material for particle size determination by microscopic measurement may be

obtained from the filter cake provided an adequate sample has been collected after the over-all efficiency of the filter approaches 100 per cent and if enough filter cake has accumulated to prevent significant numbers of fines from passing the paper. Both weight and size distribution may be obtained from a single 15 minute sample when conditions are favorable. Under some conditions a filter cake satisfactory for particle sizing may not be built up during the 15 minute sampling time. For example, the effluent from a high efficiency cleaner may be very low in solids, or the suspensoid may be a high density material which will give an adequate weight increase to the filter thimble, but insufficient bulk to form a satisfactory filter cake for sizing. Under these and similar circumstances, longer sampling times are indicated. In the event the influent dust concentration is so great that the capacity of a single thimble may be exceeded, several separate upstream samples may be collected during the time a single long-period sample is collected from the clean side. For sizing, the filter cake of the several upstream samples may be pooled.

Microscopic sizing, while laborious, is considered more reliable than results obtained from indirect instruments (employing such principles as sedimentation, elutriation, etc.). The latter devices for highest accuracy should be calibrated for each material according to density, size, surface characteristics and shape (these latter being the principal uncertainties).

Isokinetic sampling is necessary for the collection of representative samples of air borne material conveyed in pipes or ducts. Because of flow rate variations, abnormal velocity contours following bends or other disturbances to uniform flow and limitations in precisely locating sampling stations under field conditions, some latitude in sampling rate in the interests of

simplicity is acceptable without affecting the over-all accuracy of the sample for particles less than about 50 μ .

In industrial practice conveying velocities for particulate material are seldom less than 2000 fpm or greater than 5000 fpm, hence three sampling velocities were selected which adequately cover this range and give approximate isokinetic sampling rates. Sampling nozzle velocities of 2500, 3500 and 4500 fpm were selected and for ordinary conditions it is possible to select a nozzle velocity not more than 500 fpm different from measured velocity.

Since filtering efficiency may be influenced by sampling velocity, it was decided to make the filtering velocity for simultaneous up and downstream samples identical. If the cleaner under study is efficient (>95 per cent), it becomes necessary to sample a larger volume of the effluent air to obtain a significant dust deposit. This was resolved by sampling the collector discharge at a rate three times that employed for collection upstream. A filter thimble having three times the filtering area provides a large downstream sample with equal filtering velocities upstream and downstream. Increasing the downstream filter area has the disadvantage of requiring three times the dust to produce the same filter cake thickness. The remedy is increasing sampling time as indicated above. The sampling rates selected were 1 CFM for the dirty side sample and 3 CFM for cleaned air. With volume rate fixed, approximate isokinetic sampling is achieved by the use of 2 sets of three interchangeable sample heads. Sampling apparatus and sampling heads are shown in Figure 11. The filter thimble is located immediately behind the head of the sample probe to eliminate the possibility of some of the dust load being deposited on the inner walls of the sampling

ducts. This location also proves of value when sampling in ducts carrying hot, highly saturated gases. By inserting the assembled sampling probe in the duct facing in the direction of flow for a few minutes, the brass head, thimble holder and tubing reach the gas temperature. After this, the probe is turned to face downstream and sampling begun without danger of cooling and condensing water vapor on the paper filter surface.

In practice, duct velocity is measured with a standard pitot tube and the sampling head giving the velocity most nearly corresponding to the measured duct velocity is selected. Since the volume rate is always the same, nothing further is involved beyond the usual precautions which apply to any sampling procedure. Dust loading is calculated on the basis of the volume sampled.

Filters are weighed using a dry weighing technique and particle sizing is performed with 90 x oil immersion objective and 20 x eyepiece (a magnification of approximately 1800 diameters) using a Porton Graticule (21) as the sizing reference.

Field Tests

Ten commercial air cleaners operating as we found them, were tested with the sampling apparatus and analytical techniques described above. These installations included 3 American Air Filter filter units (two using single layers of Air Mat paper and one using cotton cloth leaves), 1 Pangborn cotton bag collector, 2 AAF Rotoclones and 4 tangential rectangular inlet cyclones designed by the company using them. In general, the proportions of these cyclones resemble those commonly used in wood working industries. Fluffy zinc stearate was the dust being separated in five of the collectors,

talc in two collectors, and one collector was cleaning air containing each of the following: wood dust, aluminum dust and cotton flock. Table 8 shows the type of dust associated with each of the collectors tested.

The filter installations and the two Rotoclones offered no special sampling problems as both entering and leaving air were either confined to ducts or discharged to the atmosphere in a rectilinear flow pattern. The 4 cyclone collectors, on the other hand, discharged directly to the atmosphere and the flow pattern of the exit air was in the nature of a vortex flow. In addition, dust concentrations were non-uniform across the flow. In this latter type of equipment, it was necessary to make velocity and dust concentration traverses of the exit duct, and by weighting the dust concentration at each location according to the fraction of the total flow carried by that section, arrive at an estimate of the true total dust discharge.

Since a convenient field method for measuring cleaning efficiency of a cyclone collector discharging to the atmosphere has not previously been described, Appendix V, attached, gives in detail the data collected and calculations involved in an analysis of a typical installation.

Table 8 indicates that the cloth filter units, bag and leaf, are better than 99 per cent efficient for two typical industrial dusts (talc and zinc stearate). A highly efficient unit was required in the case of the zinc stearate operation because the cleaned air was recirculated to the workroom. For the other installation, the loading of talc in the Pangborn bag unit was 4.3 grains per cubic foot, and at a flow rate of 7,000 CFM a high recovery of talc was deemed economically desirable.

The two AAF Air Mat paper filters removing zinc stearate dust did not appear to be functioning properly. These units were placed outdoors, but were

supplied with warm, humid workroom air. In cold weather, sufficient moisture condenses on the paper to weaken it and tears quickly appear. These results probably do not represent the true efficiency of the dry paper but it is felt that paper filters are not rugged enough for such industrial service.

The Rotoclone units were installed as primary cleaners, their discharge going to filter units for final cleaning. Approximately 80 per cent of the material was being removed by the Rotoclones. This decreases the load on the final filter, but it is obvious that a Rotoclone cannot be used by itself as a final-type cleaner where a high degree of dust removal is required.

The four cyclones were removing coarse dusts. Even though efficiency was close to, or above, 90 per cent the two cyclones handling talc and cotton flock were passing sufficient material to produce a community nuisance. These cyclones shown in Figure 12 would not be considered well designed for high dust removal efficiency.

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Appendix I

Instruments and Methods Employed for Aerosol Evaluation

The desired objective in air cleaning is a complete removal of particulate matter. Such a goal is difficult to achieve. However air equivalent to rural air (less than 0.2×10^{-3} grains per cubic foot) can be achieved and for most contaminants this is a permissible loading for discharge into the ambient atmosphere.

A number of methods (4) are available for quantitating particulate atmospheric contaminants. The simplest methods depend upon determination of mass concentration by gravimetric or chemical analyses. Particle enumeration by counting is perhaps the most positive evaluation of an air cleaning device although the chief difficulty is in obtaining an absolute count.

As mentioned in the previous report (1), there are several methods used for rating filters and air cleaning devices. The most specific and difficult test for a filter to pass is a reliable and reproducible dust count in the cleaned air. The presence of a relatively few particles in a satisfactorily cleaned air sample makes it possible to obtain an adequate index of performance.

In our research and development we have utilized collection impingement and dark field illumination counting techniques since this combination produces reliable and reproducible counts. Although absolute values are not obtained, the efficiencies and effluent concentrations are highly indicative of the degree of air cleaning.

1. The Bausch and Lomb Dust Counter (8) was used in quantitating aerosol concentrations when atmospheric air was used as a contaminant. This device was selected because of its relative simplicity of operation and

quantitation. For those not familiar with its characteristics, these are detailed below:

"This dust counter is in principle an Owens jet dust counter with several features added to make it a more practical instrument for general field use. The essential features of the Bausch and Lomb are a pump, a moistening chamber, a slit 6 by 0.4 mm., a circular glass collecting slide and a microscope.

The pump which has a capacity of 28.3 cc (1/1000 cm. ft.) is provided with valves to permit the flow of air in one direction only. The velocity of air through the slit averages approximately 125 meters per second as compared with a reported velocity of over 200 meters per second with the standard Owens instrument. Dust particles drawn in by the pump adhere to the glass slide because of moisture that condenses upon them as a result of the pressure drop and subsequent lowering of temperature incurred by the air passing through the slit. Saturation and subsequent condensation are insured by preliminary humidification of air in the moistening chamber which is lined with a damp blotter. The moisture evaporates but the dust remains securely fixed to the glass slide. The moistening chamber has attached a rubber bulb that is used to draw the air to be tested into the chamber. Air is drawn through the slit by the pump.

The dust counter has a standard microscope with a magnification of 200 diameters. The ocular is provided with a grid of two rows of 30 micron squares. The illumination is semi-dark field, produced by an Abbe condenser with a dark field stop."(8)

In our work, instead of depending solely on condensation, slides were greased with a silicone oil (Dow-Corning DC-200; 30,000 centistokes at 25°C). Davies (26) found that the Bausch and Lomb instrument when used with a greased slide gives efficiencies comparable to the thermal precipitator if the same counting procedure is used.

According to Brown and Feicht (6), the theoretical limit of resolution of this microscopic system is 0.46 micron and the approximate limit of visibility is about 0.4 micron. The same authors state that the light field microscopic system used in the quantitation of Greenburg-Smith (10) and Bureau of Mines midget impinger (11) samples has a limit of

resolution of 0.9 micron.

2. Filter papers were used for the collection of cupric tartrate and cupric sulphate aerosols. In early tests Sanderson's method (Appendix III) was used for quantitating copper; the filtering medium used was Yagoda spot test papers. (No. 598-Y, 100 square mm. reaction area) The filtering face velocity was 100 feet per minute. This paper was selected so that the stain produced by the analytical procedure could be limited in area for ease in comparison with standard stains (Appendix II). The filter paper holder used is shown in Figure 13. The inserts were used to limit the sample to the paper reaction area.

In later analyses spot test papers were replaced by Whatman No. 42 filter paper using the above holder and a filter area of 384 square mm. This gave a filtering velocity of approximately 25 feet per minute. Snells' method (Appendix III) was used for copper determinations.

Silverman and Ege (14) report a mean efficiency of 86.7 per cent for lead fume collection on Whatman No. 42 filter paper at velocities of 14-30 feet per minute. Their estimated mean fume size was 0.1μ . On this basis it was believed that cupric tartrate and copper sulphate dusts are quantitatively retained by this filter paper.

3. Alternating current electrostatic precipitators of the type described by Drinker (15) have been used as an absolute method of collecting copper sulphate aerosols. Pyrex precipitator tubes 1 cm. in diameter with a center electrode of B & S No. 28 gage platinum wire were used. The outer electrode consisted of aluminum foil tightly wrapped around the tube with a copper wire drawn tight in order to make a suitable projection for an alligator clip lead from the transformer. The transformer output was

15,000 volts and not rectified.

Aerosol Size Distribution Determination

Determination of size distribution of a polydisperse aerosol flowing in a duct is based on two procedures; first, sampling of a true aliquot in a form suitable for examination; second, actual measurement of the collected material.

A true aliquot is obtained by sampling isokinetically (16), that is, the aliquot is withdrawn from the air stream at duct velocity. This requirement is not critical for particles below 20 microns (17).

The collection method should not change size distribution by agglomeration, fracturing or dispersing particles already aggregated when sampled.

Methods which have been used for obtaining aerosol samples for particle size investigation include the following devices:

1. Filters (18)
2. Settling chamber (19)
3. Thermal precipitator (20)
4. Electrostatic precipitator (19)
5. Owens jet dust counter (3) and Bausch and Lomb
dust counter (8)
6. Greenburg-Smith impinger (10)
7. Cascade impactor (21)

Advantages and limitations of these devices for particle sizing are as follows:

1. Filters are satisfactory for aerosol sampling if a sample of sufficient volume or loading is obtained so that a filter cake of the dispersoid is created. This will provide reliable results when the size dispersion is not extreme. When a cake is not present selective filtration can result in penetration of smaller particles. Particles as small as 0.1μ can be efficiently removed by layer filtration. Soxhlet extraction thimbles*

*Whatman Extraction Thimbles, single thickness 10 mm. diameter; 50 mm. length

were found to be satisfactory for work done on glass microspheres* as the mean size was 9 microns with a standard geometric deviation of 2 microns.

2. Settling chambers, first applied to industrial aerosols by Green (19), will efficiently remove particles above 0.2 microns. Under proper conditions no influences are present to change the size distribution. The primary limitation of this device is small sample size (approximately 50 ml.). Difficulty may also be encountered in collecting isokinetic samples because of the volume limitation.
3. Thermal precipitators give excellent deposition of all particles up to 20 microns (Green and Watson (20)) in size. These authors did not observe that any agglomeration was created by the device. The total sample volume is limited by a sampling rate of 7 ml. per minute. This limitation makes duct sampling complex as the only feasible sampling procedure consists of aliquoting an isokinetic stream.
4. The alternating current precipitator (15) yields 100 per cent collection when the electrostatic field, flow rate and particle number concentrations are properly adjusted. Devices available during this study can give efficient removal at rates up to 50 liters per minute. The electrostatic field was produced by 15,000 volts in a 1 cm. tube. Particle concentrations (loadings) were not in a range which would cause overloading of the unit.

Material may be collected for sizing either on celluloid placed in the inner periphery of the collecting tube or on glass microscope slides placed in the field. Although alternating current fields are known to produce agglomeration this was not apparent in the samples collected during these studies, due in all probability to the very light loadings used.

*Minnesota Mining and Manufacturing Co., Glass Beads No. 120

5. The Owens jet dust counter and the Bausch and Lomb modification are useful because the material collected can be examined directly by microscope. Particle sizing may be complicated by super position of particles for high concentration of aerosols. These are grab sampling devices with volume limitations of 50 and 28.3 ml. per stroke respectively. Satisfactory sampling from ducts is complicated by the volume-time relations of the hand pump and by total volume limitations.
6. Greenburg-Smith impinger ordinarily meets requirements for adequate sample volume, but has two limitations. Its efficiency is variable and low for particles less than one micron at its usual sampling rate of 1 cubic foot per minute and second, the aerosol is collected in a liquid medium, which restricts its use to insoluble suspensoids.
7. The cascade impactor has been used by May (21), and modified by Laskin (22,23) and Sonkin (24). The advantages of these devices are a high flow (17.5 liters per minute or 0.585 cubic feet per minute) and deposition of the particulates in four decreasing size fractions which can be examined directly under a microscope. For a particular aerosol system, particle size information may also be indicated after calibration, by a chemical analysis of the four fractions (five in the case of Laskin's modification). Disadvantages of May's unit are, first, the smallest size collection is > 1.5 microns and second, the first slide is meaningless in dust sampling since the design air flow pattern cannot be maintained when sampling isokinetically. Laskin's modifications (22) are principally in construction but the impaction stages are followed by a filter paper which collects particles less than 1.5 microns. The same disadvantage in duct sampling exists regarding the first stage of the impactor. Sonkin (24) increased

air velocities through the impaction jets so that sonic velocity is approached in the last stage. His data on methylene blue and glycerol-water aerosols show collection efficiencies of 95 per cent. We have used a Laskin type unit for collection of cupric tartrate dispersoids for sizing.

Appendix II

Procedure for Determining Copper Tartrate in Aerosols

Sanderson (12) described a method for filtering air borne cupric tartrate dust and quantitating the copper directly on the filter paper.

As modified in this laboratory, samples were drawn through the center portion of Yagoda spot test papers* sampling at a rate of three liters per minute. This corresponds to an approach or face velocity of 100 feet per minute.

After collection of the sample, one or two drops of HCl (1:1) were added to the spot and after partial drying, one or two drops of glass distilled H₂O were added. The solution was then neutralized by exposure to NH₃ vapor. After evaporation of the water was almost complete, a drop of 0.1 per cent solution of rubeanic acid in methyl alcohol was added. The paper was allowed to dry and the resulting green to black stain compared with standards.

The limit of sensitivity of this method is 0.1 microgram of copper with an upper limit at approximately 5 micrograms of copper. Standards preserved for one year under glass have not faded significantly (Figure 14).

*Yagoda Confined Spot Test Papers (No. 598-Y). Confined reaction areas 100 sq.mm. Carl Schleicher and Schuell Company, New York, N. Y.

Appendix III

Sodium Diethyl Dithiocarbamate Method for Soluble Copper

The sodium diethyl dithiocarbamate method for copper described by Snell (13) and used for our analyses is as follows:

1. To sample add 1 ml. HNO_3 (1:1). This step is unnecessary if the compound is soluble in water.
2. Dilute to 50 milliliters with glass distilled H_2O .
3. Add 2 grams citric acid and after dissolving
4. Add 1:1 N NaOH until the pH is not less than 9 (very definite pink color on spot plate with phenolphthalien).
5. Dilute to 70 cc and add 10 ml. of 0.1 per cent aqueous sodium diethyl dithiocarbamate.
6. Stir and add to 100 ml. separatory funnel.
7. Add 2.5 ml. of CCl_4 , shake vigorously for one minute and draw off CCl_4 layer into a 10 ml. Klett tube.
8. Repeat step 7 for three additional extractions.
9. Readings of the yellow color are then made on the Klett colorimeter using the No. 42 (blue) filter.
10. Micrograms of copper are then obtained from a calibration curve determined by treating standard solutions in the method described above.

The optimum sensitivity range is between 2 and 25 micrograms of copper.

Appendix IV

Turn Table Dust Feeder

The dust feed system shown in Figure 15 produces a steady flow of well dispersed, non-aggregated test dust. Dust feed can be controlled to give total dust output of from 200 to 5000 grains per minute with a true dust density of 2.5, and the maximum particle size delivered can be adjusted by suitable air flow volumes in the elutriation tower.

A dust ribbon falling from a magnetic vibrating feeder is caught and supported on a No. 200 mesh wire screen turn table and rotated to a position under the elutriating tower. A compressed air jet lifts the dust from the screen and directs it into the elutriator. By means of a low speed centrifugal fan the controlling velocity in the tower can be adjusted to support particles less than a predetermined size; rejects (oversizes and agglomerates) falling into a collecting bin below. Particles pass through the fan and are air borne in a stream whose dimensions are controlled by suitably proportioned jets. Microscopic examination of greased slides held in front of the jet showed almost complete absence of agglomerates and oversized particles. The dust jet is directed into the suction opening of the apparatus under test. If projected into a duct with a considerable volume of clean air, mixing is promoted by use of a Stairmand disc a few pipe diameters upstream of the entrance.

Description of Apparatus

1. The vibratory feeder is a Model F-0 Vibra-Flow Feeder manufactured by the Syntron Company, Homer City, Pennsylvania. It consists of two pieces, the feeder and the control box. The feeder trough is approximately 18" long, 6" wide and 15" high, and can deliver from "grams per minute" to "tons per hour". The control box is a voltage control and about one-third the size

of the feeder. The vibratory feeder is supplied with dust from a hopper placed above it, and it is usually necessary to use a vibrating device to maintain steady flow from this hopper. It is possible, however, to get good results with steady hand feeding.

2. The turn table is 7 inches in diameter. The annular space between the hub and the circumferential ring (2") is covered with No. 200 (mesh) phosphor bronze screen soldered in place. The circumferential ring is attached to the hub by four radial rods. One-quarter inch below the turn table a fish-tail burner top introduces the compressed air jet. The long axis of the jet is positioned along a radial line from the hub. The driving motor (approximately 1/20 HP) is geared to drive the turn table at 2 RPM on a centrally located vertical shaft. Below the turn table but above the motor and driving gears a collecting bin catches particles rejected by the elutriator. If the dust is very valuable or limited in quantity, rejects may be reused as repeated handling tends to break up the aggregates. The collecting bin is stationary and the turn table shaft and compressed air jet (also stationary) pass through it.
3. The elutriating tower is a 3-foot length of 4-inch diameter lucite tubing. It is placed, when operating, in a vertical position with the bottom end about 2-1/2 inches above the turn table and directly over the compressed air jet. A rapping device prevents accumulation of dust on the tower walls and subsequent irregular "slugs" of dust as these accumulations break away and enter the upward flowing air stream. We have obtained best results with a 2-3 pound lead hammer striking the outer tube wall at about 60 blows per minute. The hammer is activated by a 1/70 HP motor at 69 RPM. A cam mounted on the motor shaft draws the hammer shaft and pulls the head about

2 inches away from the tube wall. It then falls free under gravity. On top of the tube, using a suitable smooth transition piece, a low speed (1800 RPM), low volume (60-75 cfm), low pressure centrifugal blower is mounted. The rectangular outlet from the fan is connected by a transition to a 1 inch tube fitted with interchangeable nozzles of various sizes. These nozzles vary the resistance in the system, and hence the air volume, permitting variations of velocity in the elutriating tower. A variable speed control for the motor-driven centrifugal fan would give wider control. The velocity required to support a particle of a certain size, density and shape in the elutriating tower can be estimated from Stoke's law. They have been confirmed in these studies by experimental values.

4. The Stairmand disc is made of thin sheet metal and placed in the center of the duct with its face perpendicular to the duct axis. The disc size, as described previously, is the pipe diameter divided by the square root of 2.

The apparatus may, of course, be scaled up or down and maximum dust feed rates increased or decreased in proportion. We have operated this apparatus for over a hundred hours without any difficulties. The unit described is constructed in three units (1. vibratory feeder assembly, 2. turn table assembly and 3. elutriator and discharge assembly) for flexibility. It has given satisfactory performance on mineral dusts and with 10 micron glass spheres. Very light and fluffy materials ball up on the vibratory feeder and are dispersed too much by the air jet. The principal objection to the apparatus is that a quantity of dust escapes from the turn table in the region of the air jet. After a few hours of operation the area adjacent to the apparatus gets covered with settled dust. We

have been able to control this with exhaust hoods placed around the apparatus, but if a new one is constructed attention should be given to housing the lower part of the apparatus in a dust tight enclosure.

Appendix V

Determination of the Efficiency of a Typical Commercial Cyclone Collector Discharging Directly to the Atmosphere

A. Cyclone Dimensions and Air Flow Rate

- (1) Cyclone Diameter - 5.5 feet
- (2) Entry Duct - 11 inch round
- (3) Exit Duct Diameter - 2.5 feet
- (4) Centerline Velocity Entry Duct - 4900 fpm
- (5) Total air flow - 2650 cfm

B. Exit Duct Velocity Traverse (15° below horizontal in direction of flow)

<u>Distance from wall</u> <u>inches</u>	<u>Velocity</u> <u>fpm</u>
0.5	2370
1.0	2300
1.5	2300
2.0	1920
3.0	1790
5.0	895
7.0	800
10.0	560
13.0	400

(see Figure 16 for plot of velocity contour)

C. Dust Samples

Dust Conc. upstream of collector gr/cu.ft.	Location of downstream dust sample, inches from exit duct wall	Duct Conc. downstream of collector gr/cu.ft.	Ratio of dust loading - Up and down- stream conc.
0.86	0.5	0.28	0.33
0.94	1.0	0.11	0.12
0.76	2.0	0.08	0.10
0.42	4.0	0.04	0.09
0.53	7.0	0.04	0.07

(see Figure 17 for plot of dust contour)

D. Calculation of Average Dust Loading

(1)	(2)	(3)	(4)	(5)
Radial segment of exit duct - inches from exit duct wall	Average Velocity fpm	Fraction of total gas flow	Average dust loading	Column 2 x column 4
0 - 2.49	2150	0.396	0.21	0.0831
2.5 - 4.99	1300	0.240	0.095	0.0228
5.0 - 7.49	800	0.146	0.07	0.0102
7.50 - 9.99	550	0.101	0.05	0.0051
10.00 - 12.49	350	0.065	0.04	0.0026
12.50 - 15.00	<u>270</u>	0.050	0.01	<u>0.0005</u>
Total	5420			0.1243

(2) Dust loading of exit air = $0.1243 \times \text{inlet loading}$

(3) Separator efficiency = 87.6%

(4) Average inlet dust loading = $\frac{0.86 + 0.94 + 0.76 + 0.42 + 0.53}{5} = 0.7 \text{ gr/cu.ft.}$

(5) Total dust escaping cyclone collector = $0.1243 \times 0.7 = 0.078 \text{ gr/cu.ft.}$

or $\frac{0.087 \times 2650 \times 8 \times 60}{7000} = 15.8 \text{ pounds of dust escaping each 8 hour shift}$

42

- 42 -

FIGURE 1. Diagrammatic sketch of agglomeration apparatus I

FIGURE 2. Detail diagram of agglomeration apparatus II

44

FIGURE 3. Aerosol generator for soluble salts (copper)

- 44 -

FIGURE 4. Microphotograph of copper sulfate spheres
(mean size 0.7 microns)

FIGURE 5. Count-size distribution of copper sulphate spheres
(magnification 1800 diameters)

FIGURE 6. Microphotograph of glass microspheres
(mean size 8.3 microns)

FIGURE 7. Count-size distribution of glass microspheres
(magnification 100 diameters)

FIGURE 8. Size distribution of copper tartrate dust by cascade impactor (magnification 1800 diameters)

50

FIGURE 9. Experimental apparatus for determining Neva-Clog screen resistance characteristics. (Same material as detailed in Figure 2)

FIGURE 10. Air flow resistance characteristics of Neva-Clog screen dry and wet

FIGURE 11. Stack sampling unit for field sampling and collector evaluation

FIGURE 12. Cyclone construction of units studied in field survey

FIGURE 13. Sampling unit for collection on confined spot test filter papers

FIGURE 14. Test paper standards for copper using rubeamic acid method

56

FIGURE 15. Turn-table dust feeder

FIGURE 16. Typical cyclone exit duct velocity distribution

FIGURE 17. Typical cyclone exit duct dust loading contour

TABLE 1

EFFICIENCY TESTS ON ATMOSPHERIC DUST USING TYPE 6 C.W.S. FILTERS
(As Determined by Bausch and Lomb Dust Counter Using Greased Slide)

Total Q	Room Air Q	Filtered Q	Room Air MPPCF*	Filtered Air MPPCF	Actual Station Concentration MPPCF	Theoretical Station Conc'n MPPCF	No. of Strokes
129 CFM**	4 CFM	125 CFM	1 (Av.)	0.0033 (Reading)	(1) 0.01	0.03	10 (Venturi)
129	4	125	1	0.02	(2) 0.02	0.05	10
143	5	138	1	0.0033	(1) 0.01	0.04	10
143	5	138	1	0.02	(2) 0.01	0.05	10
162	32.2	130	0.24 (Reading)	0.17 (Av.)	(1) 0.07	0.27	10 (Orifice)
162	30.6	131	0.24	0.02	(1) 0.05	0.06	20
162	30.6	131	0.24	0.02	(1) 0.07	0.06	20
162	31.9	130	0.24	0.02	(1) 0.23	0.06	20
162	31.9	130	0.24	0.02	(2) 0.05	0.06	20
162	31.9	130	0.18	0.02	(1) 0.05	0.05	20
162	31.9	130	0.18	0.02	(2) 0.04	0.05	20
162	31.9	130	0.18	0.02	(1) 0.04	0.05	20
162	31.9	130	0.18	0.02	(2) 0.04	0.05	20

Theoretical Station Concentration

$$= \frac{\text{Room air Q (CFM)} \times \text{room air concentration (MPPCF)} + \text{filtered air Q (CFM)} \times \text{filtered air concentration (MPPCF)}}{\text{Room air Q (CFM)} + \text{filtered air Q (CFM)}}$$

*Million Particles Per Cubic Foot of Air

**Cubic Feet Per Minute

TABLE 2

VELOCITY PROFILES DOWNSTREAM FROM STAIRWIND DISCS

Position from wall Inches	4 DIAMETERS		5 DIAMETERS		6 DIAMETERS	
	Velocity Press. Inches H ₂ O	Velocity F.P.M.	Velocity Press. Inches H ₂ O	Velocity F.P.M.	Velocity Press. Inches H ₂ O	Velocity F.P.M.
½	0.20	1790	0.35	2470	0.20	1790
1	0.20	1790	0.35	2470	0.20	1790
1½	0.25	2040	0.40	2580	0.20	1790
2	0.25	2040	0.45	2730	0.25	2040
2½	0.30	2240	0.50	2888	0.30	2240
3	0.30	2240	0.50	2888	0.30	2240
3½	0.30	2240	0.45	2730	0.30	2240

TABLE 3

EVIDENCE OF AGGLOMERATION SHOWN BY MODEL I

A

Aerosol	No. of Tests	Conditions	Average Efficiency	Average Deviation
Cupric tartrate	6	dry	0%	--
Cupric tartrate	16	8 spray nozzles	65%	20%
(concentration range 0.02-0.2 grains per 1000 cu.ft.)				

B

MASS DISTRIBUTION OF DUST AS DETERMINED BY A MODIFIED CASCADE IMPACTOR
(AFTER PASSING THROUGH MODEL I WITH 8 SPRAYS)

Upstream		Downstream	
slide 1	22.9%	slide 1	29.6%
2	26.9%	2	24.4%
3	26.9%	3	20.9%
4	23.3%	4	25.1%

TABLE 4

EFFECT OF INCREASING WATER SPRAY CONCENTRATION UPON SEPARATION EFFICIENCY

(a) Varying amount of H₂O spray (0.7μ copper sulphate as suspensoid)

Sampling Method	No. of Sprays	% Removal
No. 41 Whatman filter paper	0	45.0
No. 41 Whatman filter paper	2	54.0
No. 41 Whatman filter paper	4	78.0

(b) Varying amount of H₂O (9μ glass spheres as suspensoid)

Sampling Method	Loading	No. of Sprays	% Removal
	Grains per cu.ft.		
Sohxlet filter	2.6	0	88.0
Sohxlet filter	2.3	1	97.0
Sohxlet filter	2.9	2	99.7
Sohxlet filter	2.8	3	99.9
Sohxlet filter	1.9	4	99.7

TABLE 5

EFFICIENCY OF NEVA-CLOG DROPLET ELIMINATOR SCREEN

(a) Efficiency with 9μ glass spheres

Screen	Face Velocity fpm	Efficiency %
Dry	120	48.0
Wet	120	98.8

Loading - 4 grains per cubic foot

(b) Efficiency with 0.3μ copper sulphate spheres

Screen	Face Velocity fpm	Efficiency %
Dry	120	24.0
Wet	120	50.4
Wet	180	74.1
Wet	240	81.7

Loading - 0.001 grains per cubic foot

TABLE 6

EFFECT OF VARYING LOADING OF 0.3μ COPPER SULPHATE ON EFFICIENCY

Sampling Method	Loading Grains per cu.ft.	No. of Sprays	% Removal
A.C. precipitator	3.96×10^{-4}	4	19
A.C. precipitator	4.28×10^{-4}	4	16
A.C. precipitator	1.97×10^{-4}	4	14
A.C. precipitator	1.49×10^{-4}	4	0
A.C. precipitator	1.46×10^{-4}	4	0

TABLE 7

EFFECT OF 9μ GLASS SPHERES AND WATER SPRAYS ON REMOVAL EFFICIENCY OF 0.3μ COPPER SPHERES

Sampling Method	Glass Sphere Grains/cu.ft.	CuSO ₄ Grains/cu.ft.	% Removal of Cu.
A.C. precipitator	2.5	1.71×10^{-4}	57
A.C. precipitator	2.5	1.77×10^{-4}	46
A.C. precipitator	2.5	2.62×10^{-4}	65

TABLE 8

FIELD TESTS ON COMMERCIAL AIR CLEANERS

AIR CLEANER			Operation	DUST				Air flow rate CFM	Efficiency
Cleaning Principal Employed	Manufacturer	Type		Material	Particle Size		loading gr/CF		
					Mean μ	Std. Dev.			
Cloth filter	Pangborn	Cotton bag	Rubber dusting	Talc	1.3	3.4	4.3	7,000	99.85
Cloth filter	American Air Filter	Cotton leaf	Rubber dusting	Fluffy Zinc stearate	0.9	1.6	0.6-1.0	400	100*
Paper filter	American Air Filter	Airmat paper	Rubber dusting	Fluffy Zinc stearate	0.9	1.6	0.1	3,300	95
Paper filter	American Air Filter	Airmat paper	Rubber dusting	Fluffy Zinc stearate	0.9	1.6	0.3	750	33**
Centrifugal	AAF Rotoclone	B	Rubber dusting	Fluffy Zinc stearate	0.9	1.6	0.6	3,300	88
Centrifugal	AAF Rotoclone	B	Rubber dusting	Fluffy Zinc stearate	0.9	1.6	1.7	750	78
Cyclone	Plant**** Construction	Simple Rect.,Inlet	Abrasive cleaning	Talc	2.8	3.1	2.2	2,300	93
Cyclone	Plant**** Construction	Simple Rect.,Inlet	Planing mill	Wood	***	***	0.1	3,500	97
Cyclone	Plant**** Construction	Simple Rect.,Inlet	Grinding	Aluminum	***	***	0.7	2,400	89
Cyclone	Plant**** Construction	Simple Rect.,Inlet	Flocking	Cotton flock	***	***	0.7	2,600	88

*Weight increase on downstream sample tube not significant

**Filter leaves torn due to condensed moisture on paper

***Approximately 99 per cent by wt. of dust greater than 0.5 μ in size

****See Figure 12 for proportions of cyclones

END OF DOCUMENT