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THE DETERMINATION AND CONTROL OF INDUSTRIAL DUST

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THE DETERMINATION AND CONTROL OF INDUSTRIAL DUST

PREFACE

In recent years, the subject of the health of workers in dusty trades has been receiving considerable attention from students of industrial hygiene and others interested in the various phases of this problem. When one realizes that the workmen employed in the dusty trades comprise the largest group exposed to any one industrial hazard, it is quite apparent that the importance of this problem has not been overestimated. Furthermore, it is now well established that exposure to certain kinds of dusts, such as those containing considerable amounts of quartz, has increased the morbidity and mortality rate from respiratory diseases; while metallic dusts, such as lead and its compounds, have been associated with general systemic poisoning of workers.

In view of the fact that certain kinds of dusts have been known to produce definite damage to the workers exposed to them, it is obvious that a knowledge of the properties of a given dust, which determines its capacity to produce injurious effects, is essential. Experience has shown that these properties are the composition of the dust, the quantity suspended in the industrial atmosphere, and its particle size.

In order to study all these factors involved in the industrial dust problem, it is necessary to conduct careful investigations. Such studies in industry serve a three-fold purpose. First, they enable one to evaluate the extent of the hazard; this is accomplished by obtaining occupational dust exposures, which disclose the dust-creating tasks. Second, if clinical studies are also made, dust counts may indicate the permissible amount of dust which may be breathed with impunity. Third, dust determinations are used in an attempt to control the hazard; this is effected by testing the efficiency of such devices which have been developed for this purpose.

The purpose of the present bulletin is to present the methods and instruments used in conducting dust studies in industry, the manner of interpreting the results of such studies, and their practical application to industrial problems, especially those phases dealing with the control of the dust hazard. The material in this bulletin is based largely on the practical experience gained by the authors in engineering studies of the dust problem in numerous industries in the United States. It is their sincere hope that this little volume will serve as a guide to engineers, chemists, and others interested in those studies designed to minimize the hazard associated with the inhalation of certain types of dusts.

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I. PRELIMINARY STEPS: THE SANITARY AND OCCUPATIONAL SURVEY[1]

In the study of industrial health problems it is necessary to accumulate certain fundamental data which may serve in the interpretation of these problems on a scientific basis. One outstanding example of such studies has been the investigations conducted in connection with the influence of the inhalation of atmospheric dust on the health of workers in industrial environments. In all such investigations there are certain preliminary steps of fundamental importance which must be undertaken in order to serve as a guide in the more detailed studies to follow. Roughly, these preliminary steps may be divided into two parts, (1) the sanitary survey, and (2) the occupational analysis.

THE SANITARY SURVEY

The sanitary survey of the workroom environment may be likened to the inventory of materials and stock which a business establishment usually undergoes annually. The sanitary survey may well be regarded as a listing of the facilities afforded the workers while in the industrial environment. When one realizes that one-third of the worker's day is spent in this environment, one clearly sees the necessity for a study of all those factors which bear on the health of the industrial worker.

In the course of certain studies conducted in munition plants during the last war, Winslow and Greenburg devised an inspection form which proved very useful in their studies of factory workrooms. (1) This form has been utilized in numerous investigations in industrial establishments throughout the United States, and it has been found in nearly all instances that the filling out of this form has proved a valuable guide and starting point in the study of the workroom environment Under items 1 to 4 provision has been made to record general sanitary and hygienic data concerned chiefly with the workrooms. Under numbers 5 to 11 are noted those industrial hazards created more particularly by special processes and materials used in these processes. Item 12 of the inspection card deals mainly with the occupational analysis and will be discussed in more detail in the section of this chapter dealing with this subject.

[1] Received for publication Aug. 25, 1934.

No.........

FIELD INVESTIGATIONS

1. City........ Establishment........ Date........
   Type of building........ Shop........ Location........
   Size........
   Crowded........
2. Ventilation—Natural........ Ample........ Deflectors........
   Artificial........

Temperature........						Remarks:
Dry........						
Wet........						
Humidity........						

3. Illumination—Natural........ General impression........ Maximum distance from window........
   Window space........ Ratio to floor space........
   Type of window........ Condition........
   Artificial—Type and no........
   Shadows or glare........ General impression........
4. General conditions—Refuse cans........ Cuspidor service........ Sweeping service........
   Fire protection........
   First aid........
   Coat rooms........
   Washing facilities........
   Eating facilities........
   Toilet facilities—Type and no........ Light........ Ventilation........ Condition........ Ample........
   Male........
   Female........
   Drinking water........
5. Safety hazards........
6. Fumes and gases........
7. Dust........
8. Specific poisons........
9. Exposure to heat or cold........
10. Fatigue........
11. Excessive noise........
12. Employees........

Process	Raw material	Finished product	Employees	Day shift				Night shift				Method of payment	Seats and backs	Replaceable by females	Hazards	Rest period	Exercise period
				Skilled		Unskilled		Skilled		Unskilled							
				M	F	M	F	M	F	M	F						
Total												Employees at full production........				Color	

Absenteeism and labor turnover.
Remarks:

In practice, the sanitary survey consists in carefully filling out the inspection form and jotting down any additional notes on items which may not be provided for in the survey form. Under certain conditions, such as may exist in a coal mine, or a cement mill, some of the items listed in the card may obviously be omitted. After filling out a survey card for each workroom in the entire plant a detailed analysis of the data contained in the cards is then in order. It is such an analysis that enables one to form a picture of the hygienic conditions in each of the workrooms studied and in the plant as a whole.

One or two illustrations of an analysis of data obtained in a sanitary survey of a plant will suffice to clarify the technic involved in such an analysis. Reference to the survey card shows that under item 1, the size of each workroom is obtained and that under item 12 the workroom population at full production is also recorded. In the example given below a survey of 50 workrooms was completed and the following table illustrates how the data on space allotment was handled:

TABLE 1.—*Distribution of workrooms according to per capita space allotment*

Square feet floor area per capita	Number of rooms in each group	Cubic feet per capita	Number of rooms in each group
Less than 25	3	Less than 250	2
25-50	7	250-500	3
50-100	15	500-1,000	12
100-150	20	1,000-1,500	23
150-200	5	1,500-2,000	7
More than 200	3	More than 2,000	3

According to the Tentative Code of the United States Public Health Service on Workroom Sanitation, 25 square feet of floor area per capita, or 250 cubic feet of air space per capita, may be considered as a fairly ample space allotment. In the light of the above standards the data indicated in table 1 show that 3, or 6 percent, of the rooms did not fulfill the requirement for area allotment and that 4 percent of the rooms did not meet the standard for per capita cubic content. Similar analyses may be carried out for the other items listed in the survey form.

Several years ago, in studying the dust hazard in a modern factory, it was considered best to conduct a sanitary survey of the numerous workrooms in this factory, in order to be able to locate the dusty workrooms and processes, and to plan the dust sampling schedules intelligently. As a result of such a sanitary survey numerous safety hazards were encountered in the various workrooms and in addition a lead and benzol hazard (unknown to the plant officials) were also disclosed.

To recapitulate, the sanitary survey of workrooms in any plant yields definite information concerning the presence and extent of various health hazards and often serves as a guide in establishing which hazards require further study in the form of actual quantitative analyses; such, for example, as the determination of hydrogen sulphide in the spinning room of a rayon silk manufacturing plant using the viscose process. Unquestionably, many problems arise in industry for which there are no simple solutions. Others require considerable expenditure of funds and ingenuity for their complete eradication. On the other hand, a sanitary survey of a factory will often disclose many small problems which require very little expenditure of money and effort for their elimination. The solution of such small problems may eliminate sources of ill health or un-

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OCCUPATIONAL SURVEY

A very important part of any study of workroom environment is the occupational analysis, which permits one to learn of the activities involved and the particular hazards associated with each occupation. Such an analysis also discloses the number of persons in each occupation, which gives one an idea of the importance of each hazard from the viewpoint of the numbers involved. Perhaps a typical example of such an analysis will serve to portray the value of the occupational survey. For the sake of simplicity an analysis of workrooms in which only one major hazard was found to exist is herewith presented, namely, the occupations involved in granite-cutting plants. The table below shows the various occupations followed in 14 typical granite-cutting plants (2).

TABLE 2.—*Analysis by occupation of certain granite-cutting sheds*

Occupation	Number of men	Occupation	Number of men
Granite cutters:		Sawyers	
Pneumatic-tool workers	565	Engineers	
Surfacing-machine operators	66	Firemen	
Sand-blast operators	4	Draftsmen	
Carvers and letterers	21	Foremen	
Lathe operators and others	41	Blacksmiths	88
Tool grinders	20	Carpenters	
Lumpers		Night watchmen	
Boxers		Clerks	
Cranemen		Salesmen	
Polishers		Superintendents	
Bed setters	164	Manufacturers	
Tool carriers			
Machinists		Total	972
Laborers			
Stone washers			

There are several important facts to be derived from a study of the occupations in granite-cutting plants, such as in the analysis presented in the above table. First, the processes involved in granite stone-cutting may be divided roughly into two parts, namely, those occupations dealing with the actual cutting of the stone and the additional labor necessary for the conduct of the former processes. Examination of table 2 shows that under the heading of granite cutters there are five general occupations. Also by far the greatest number of persons are engaged in tasks involving the production of dust. Furthermore, that 565 of the 702 persons creating dust are engaged in work involving the use of the hand pneumatic tool, a device well-known to be productive of enormous quantities of dust. It is at once obvious from such an analysis that considerable time should be devoted to the study of the dust exposure of granite cutters in general and of hand pneumatic-tool workers in particular. The results of such a study are presented in table 3.

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TABLE 3.—*Ranking the various occupations in the granite-cutting industry according to their dust exposure*

Occupation	Number of men exposed	Number of observations	Dust count (in millions of particles per cubic foot)		
			Minimum	Maximum	Average
All pneumatic hand-tool operators	[illegible]	88	2.4	201.0	58.2
Surface cutters:					
In shed	[illegible]	24	.6	165.7	41.0
Outside	10	10	14.0	102.2	43.9
Carvers and letterers	21	21	11.7	93.8	35.0
Tool sharpeners	20	14	6.3	62.0	22.1
General pneumatic-tool operators	121	42	2.5	64.0	31.2
Lathe operators	4	4	8.0	25.7	17.9
Polishers	43	16	1.3	31.8	9.0
Sandblast operators	4	6	1.9	13.4	6.2
Sawyers	10	4	4.0	4.9	4.6
Blacksmiths and others	103	5	.9	8.2	2.5
Office employees	10	4	1.5	2.4	1.9

As a result of a prolonged study of the health of the workers engaged in the various occupations of granite-cutting, it was possible to demonstrate that those persons engaged for many years in tasks associated with a dust exposure of less than 10 million particles per cubic foot of air were not suffering from silicosis or tuberculosis, the diseases most prevalent among these granite cutters. It was also possible to demonstrate that among these granite cutters, the incidence of silicosis and tuberculosis, all other factors being equal, was directly proportional to the degree of dust exposure.

The importance of an occupational analysis from the viewpoint of determining the extent of an occupational hazard is at once obvious. Such an analysis is of still greater importance in the subsequent steps necessary for the elimination of a condition known to be inimical to health. Unless one knows definitely which occupations in a workroom, containing many diverse processes and activities, are associated with unhealthful conditions, it is impossible to map out a constructive and effective program of prevention. We have just seen that in the case of the granite-cutting study the problem resolves itself to keeping the dust content of the workroom air below the level of that associated with those occupations found to be free from silicosis and tuberculosis, even after many years of industrial exposure; namely, those occupations exposed to less than 10 million particles of dust per cubic foot of air. The same technic may be applied to other industrial problems, which on first examination seem more difficult of solution than the case just cited. Perhaps another single illustration will demonstrate the value of the occupational analysis as a guide in the elimination of industrial health hazards.

Studies of industrial morbidity made by the United States Public Health Service indicate that the greatest percentage of lost time in industry is caused by respiratory diseases. One of these studies showed that pneumonia, in all forms, occurred in nearly twice the amount among iron and steel workers as it did among the employees of other industries, during a 3-year period of observation (3). A 5-year inquiry into the causes of high pneumonia sickness rates among iron and steel workers in a representative mill disclosed the fact that the largest number of pneumonia cases occurred in certain departments, such as in the blast furnace and open-hearth steel-making plants. When one realizes, however, that these departments contain anywhere from 60 to 100 different occupations, the task of a preventive program is a hopeless one unless definite information is obtained concerning such important factors as (1) the number of persons in each occupation, (2) the activities associated with each occupation, (3) the health hazards associated with each occupation, and (4) the incidence of penumonia for each occupation. Such data are available from an occupational analysis of each department. For example, in the iron and steel plant under consideration morbidity statistics for the period of 1924–27, showed that 38 cases of pneumonia occurred among the 1,637 bituminous coal miners employed during the same period in the mines operated in connection with this iron and steel plant. An occupational analysis disclosed the fact that there were 69 different occupations in the mines and that 33 of the total of 38 pneumonia cases were associated with only two occupations—those of pick mining and loading of coal. The pneumonia rate per 1,000 men for miners and loaders was shown, by this study, to be 31, whereas the rate for all other mine workers was found to be only 8.5. It is quite obvious, therefore, that of the 69 occupations involved in the mining of coal, one's attention should be concentrated on the activities of coal miners and loaders, in an attempt to determine those factors in the industrial process and environment which contribute to the high pneumonia incidence experienced by those workers.

In practice the making of an occupational analysis has for its basis the filling out of item 12 of the survey form previously mentioned. The data obtained cover such subjects as the manufacturing process, the raw materials entering into the process, and the finished product associated with the occupation of each employee. To obtain such data it is necessary for the investigator to become thoroughly familiar with the activities of each occupation and the processes of the workroom as a whole. One must not take anything for granted in a study of this sort. For example, in a study of the hazards involved in the application of radium paint to watch and clock dials in a certain workroom (4), one of the employees listed was the foreman supervising the work of the radium dial painters. Upon close study it was discovered that this worker, in addition to allotting and supervising the work of each painter, spent 1 hour a day in mixing paint for all the dial painters and once a month blended various radium powders in such a manner that he was exposed to the inhalation of enormous quantities of radioactive dust. This latter brief exposure to radioactive dust was of far more significance from the viewpoint of radium poisoning than his total exposure during his supervisory duties.

The remaining subjects listed under item 12 of the survey form are all of a simple nature, but are often of assistance in presenting a complete picture of the workroom environment, and at times serve to explain certain unusual phenomena. Take for example the subject of labor turn-over. In a certain lead storage battery factory the plant officials pointed to the small number of lead poisoning cases occurring in their plant to show that this disease was not an important problem in their workrooms (5). Investigation of the workroom atmosphere disclosed that in the lead-mixing and pasting rooms of this plant enormous quantities of lead dust were present, quantities sufficient to produce lead poisoning in a comparatively brief period of exposure, as judged by our present knowledge of lead poisoning. Further inquiries revealed the fact that the labor turn-over in these two workrooms was very great, in fact, so great that the men left employment before real serious symptoms of lead poisoning manifested themselves. The presence of a high labor turn-over in times of normal production is often highly suggestive of unhealthful or unpleasant working conditions.

The remaining subjects under the item dealing with employees, need no further comment, since their purpose will be quite obvious to the average investigator. It is often very helpful to obtain a sketch or blueprint of the workroom layout, on which may be noted such important items as the location of ventilating systems, points of sampling, and any other data bearing on the problem under study. These data may then be used in the subsequent steps of an investigation of this type, namely, the recommendations necessary to eradicate certain unhealthful or unpleasant conditions which the study may have disclosed.

II. THE INSTRUMENTS AND METHODS USED IN THE SAMPLING OF ATMOSPHERIC INDUSTRIAL DUSTS

GENERAL CONSIDERATIONS

Atmospheric dust may be defined either on a basis of one of its physical characteristics, such as size, or physiological grounds, depending on the effects produced on the human body by the inhalation of the dust. Drinker and Thomson (6), in their classification of dusts, fumes, and smoke, have defined dusts as "particles or aggregates of particles, 150 to 1 micron in diameter, that are thrown into the air by mechanical agencies * * * Examples are silica, talc, cement, organic dusts such as hard rubber, starch, and cocoa; flocculated fume and smoke products." In the present volume dusts will be interpreted as particles or aggregates of particles suspended in the atmosphere and of a size capable of being inhaled (in industry this size is usually less than 10 microns in diameter), and will be considered in two classes, namely, those which may be capable of producing fibrosis of the lungs or other respiratory conditions, and dusts which may cause systemic poisoning, as typified by certain compounds of lead.

Since our interest in the dust problem has a purely industrial aspect, it is essential that any dust-sampling instrument which one will use should be capable of collecting effectively dust of a size present in the industrial atmosphere. As will be shown later, industrial dusts are mainly from 0.5 to 10 microns in size, so that an instrument capable of collecting these sizes with a fairly high degree of efficiency will meet the present-day requirements. The range in dust concentrations encountered in industries is very great, depending, of course, on the industrial processes, the devices installed for mitigating the dust created, and the efficiency with which such devices function. For these reasons, an ideal instrument should be one capable of sampling with equal efficiency in both high- and low-dust concentrations. This factor calls for the prerequisite of a dust-collecting medium which shall not add dust to any great degree to the dust in the sampled air. Furthermore, the collecting medium must be uniform in dust content, so that one or two control tests on this medium will be sufficient for a series of samples.

Since the dust content of industrial air is ever varying, it is essential that the dust-sampling instrument be capable of collecting air in large quantities at a rapid rate in order to obtain a representative picture of existing conditions. And, finally, the ideal instrument will

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be one that requires only a simple and fairly rapid method of analysis. Suffice it to say that an instrument designed for use in the field should embody all these principles and in addition be light in weight, portable and compact in construction.

To recapitulate, the final selection of a dust-sampling instrument for industrial use will depend on the collecting efficiency of the device, on its small errors in analysis, on its portability and on the ease with which a sample once obtained may be analyzed.

Many methods have been devised and used for the purpose of determining the quantity of dust in air. Knowles (7) lists some 53 different instruments developed and used for this purpose at one time or another. Because most of these instruments have proved impractical and are no longer in use, no discussion concerning them will be given. The reader is referred to an excellent review of this subject by Dr. Leonard Greenburg (8). However, it may be of some interest to review, briefly, the history of the development and use of some of the dust sampling instruments in vogue today.

HISTORY OF PRESENT DAY DUST SAMPLING INSTRUMENTS

The South African investigators began using the sugar tube method for the sampling of atmospheric dust in 1911 (9), and Lanza and Higgins in their Joplin study also availed themselves of the same technique (10). In fact, no other suitable method was then available. In 1912 the Committee on Standard Methods for the Examination of Air of the American Public Health Association recommended the sugar tube as the standard method for the sampling of atmospheric dust.

This method of dust sampling had several drawbacks, the chief of which were its slow sampling rate (the American Public Health Association Committee sampled 5 cubic feet in 18 minutes) and the fact that the sugar always contained a certain quantity of dust which introduced a variable, and sometimes considerably douthful, element into the final results.

To overcome the limitations of the sugar-tube method, various investigators attempted to devise other procedures for the sampling and anlysis of atmospheric dust. One of the most fruitful studies was that of Palmer (11), who in 1916 presented his water-spray apparatus for sampling dust. This method was adopted in 1917 by the Committee on Standard Methods of the American Public Health Association and was recommended as the standard technique for the sampling of dust in air. The United States Public Health Service began employing this apparatus in 1918 in its studies of dust in air.

In 1916 the South African investigators, desirous of obtaining a more portable type of instrument and one which would yield results

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more rapidly, described a new instrument known as the Kotzé konimeter (12). In this instrument a small volume of air, approximately 10 cubic centimeters, is impinged at a high velocity (30 to 80 meters per second) against the surface of a vaseline-coated glass plate, the vaseline serving to retain the particles of dust after they strike the plate. The plate is then removed and placed under the microscope, the adherent dust being counted at a suitable magnification. The United States Bureau of Mines, which had been using the sugar-tube method for dust sampling, began at once to study the performance of this new instrument.

In 1922, the instruments mentioned were the ones in most common use. In addition, however, the United States Bureau of Chemistry (13), in its dust-explosion work, employed an apparatus which consisted essentially of an adapter for holding a Whatman filter paper thimble through which air was drawn by a suction pump, thus sampling the atmospheric dust. By the difference in weight of the paper thimble before and after dust sampling, the weight of the dust was easily determined. Finally, mention should be made of the Anderson and Armspach (14) dust determinator which, in 1922, was in use by the American Society of Heating and Ventilating Engineers. This instrument measured the loss of pressure incident to forcing air through a piece of filter paper; this rate of loss of pressure was then regarded as a measure of the air dustiness.

Very briefly, such was the status of the technique of atmospheric dust sampling in the year 1922, when it became apparent that the various dust-sampling methods did not yield results which could be regarded as absolute or even comparable. In fact, sampling in a given industry, by different methods, usually gave findings which were not of the same order of magnitude. As a result, a conference of interested persons was held at the United States Bureau of Mines Experiment Station, Pittsburgh, Pa., in 1922. It was decided at that time to conduct a laboratory study of dust-sampling instruments.

The study was started in the summer of 1922 at the Pittsburgh Experiment Station. Suspensions of dust (five different powdered substances were used) were set up in an air-tight chamber and simultaneous samplings were carried out at first with the sugar tube, the Palmer apparatus, the konimeter, the filter-paper thimble, and the dust determinator.

During the course of the study a new instrument, the impinger, for the sampling of dust was devised. This new instrument was included in the later stages of the laboratory study of dust-sampling instruments described in the report published as Public Health Bulletin No. 144.

In this instrument the air to be sampled is drawn through a glass tube and impinged at a high velocity on a glass plate which is kept

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beneath the surface of the water or other suitable fluid in the collecting flask. The dust is momentarily arrested, wetted by the collecting fluid, and in this manner trapped. After a sufficient volume of air has been sampled, a portion of the collecting fluid is removed to a suitable counting chamber or cell for microscopic count to ascertain the number of particles in a manner to be described later. The remaining portion of the sample may be subjected to any desired analysis.

In the comparative study the dust-catching efficiency of the impinger was found to be high. Consequently, its physical principles and characteristics were the object of a special study, and finally a satisfactory and practical form of dust-sampling instrument, based on this principle, was evolved.

The apparatus (essentially in its present form), as described in Public Health Bulletin No. 144, possessed an efficiency of 94 to 97.5 percent when sampling a finely divided silica dust suspension at the rate of 1 cubic foot per minute. The tests used in estimating this efficiency were conducted by an optical method in which a portion of the dusty air being delivered to the collecting device was diluted with measured amounts of dust-free air until a "match" was obtained on comparison with the stream of air emerging from the dust-collecting device. The comparison, or matching, consisted in producing equal Tyndall effects (equal amounts of reflected light) by the two dust streams when they are simultaneously observed in a beam of light.

So far as the quantitative results of the dust-sampling instruments are concerned, the conclusion of the comparative study was as follows:

> Considering the dust caught by the Palmer as unity, the instruments take the following order: On basis of numbers of particles determined—impinger, 5.0; sugar tube, 2.1; and Palmer apparatus, 1.0. On basis of weight of dust determined—impinger, 2.1; thimble, 1.5; sugar tube, 1.6; Palmer apparatus, 1.0.

These results have led to the selection of the impinger as the most efficient apparatus for all-round industrial dust sampling. The instrument has been used in a number of studies in the dusty trades, in the studies of lead tetraethyl, and many other investigations to be mentioned later. Twelve years of field experience with the impinger apparatus have given confirmatory evidence of its value as a dust-sampling device.

DESCRIPTION OF PRESENT-DAY DUST-SAMPLING INSTRUMENTS

Of the various instruments mentioned in the history of the development of dust-sampling devices, two which are at present finding some use in dust determinations were developed since 1922. These are the Owens Jet Dust Counter (15) and Drinker's modification of the electrical precipitator device for dust collection (16). As a result of the comparative study carried out in 1922, the Palmer, and the Anderson and Armspach dust determinator are employed very little for dust sampling at the present writing. The instruments employed in dust studies are practically limited to the following: Impinger, Electrical Precipitator, Owens Jet Dust Counter, Paper Thimble, and Kotzé Konimeter. The text which follows describes the working principle of each of these five instruments, their construction and use, and their advantages and disadvantages.

The Greenburg-Smith impinger

The impinger apparatus (17) consists essentially of two portions: First, a source of sufficient suction to draw the air to be sampled

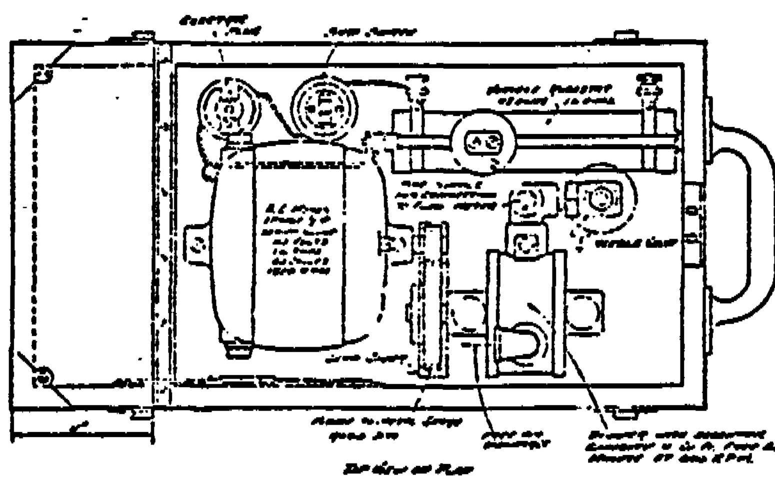

FIGURE 2.—Drawing of electrically driven suction apparatus, top view.

through the sampling device; and, second, the sampling device or impinger itself, which consists of a container and the impinger tube and plate. As a source of suction, an electrically-driven and a compressed-air-driven apparatus have been designed. A hand-driven apparatus developed at the United States Bureau of Mines will also be described.

Electric suction apparatus.—The electrically-driven suction apparatus is designed to be used in places where electrical energy is available. A photograph of the apparatus is shown in figure 1, and the mechanical details are presented in figures 2, 3, and 4. The motor is a series-wound, single-phase, 60-cycle, one-fifteenth horsepower, rated at 1.6 amperes, at 110 volts, with a speed of 1,800 revolutions per minute. This motor, being series-wound, operates on either alternating or direct current. The motor is geared to a rotary eccentric positive pressure blower by means of a set of gears having a 1 to 3 ratio. In order to minimize noise, the smaller of

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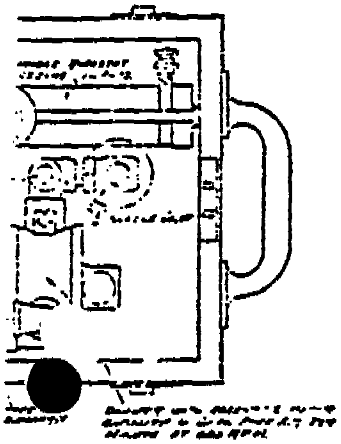

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FIGURE 1.—ELECTRICALLY DRIVEN SUCTION APPARATUS FOR IMPINGER.

these gear wheels is made of fiber, the larger being metal. The blower is rated at 4 cubic feet of free air per minute when rotated at a speed of 600 revolutions per minute, and is used as a source of suction rather than as a source of air pressure. Wired in series with the electric motor is a 98-ohm, 1.6-ampere variable sliding rheostat used for speed control of the motor. By employing such a rheostat a voltage of 110 or 220 volts may be used. To the intake or suction side of the blower is attached a ½-inch malleable-iron

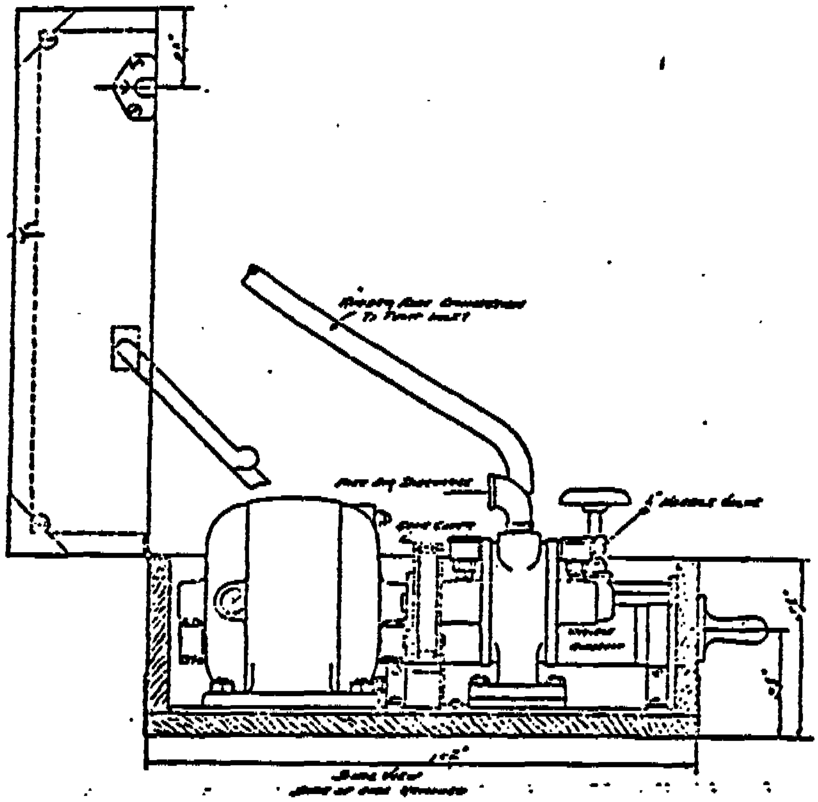

FIGURE 3.—Drawing of electrically driven suction apparatus, side view.

elbow fitting provided with two inlets. To one of the inlets a ½-inch brass needle valve is attached, which serves as a by-pass in regulating the rate of suction. The second inlet of the elbow is connected to a constriction-type glass flowmeter by means of a suitable length of noncollapsible rubber tubing; the flowmeter is fastened on the inside of the lid of the carrying case. The inlet side of the flowmeter is connected to the sampling flask by means of a second piece of noncollapsible rubber tubing. The latter piece of rubber tubing may be of any suitable length. The flowmeter scale is calibrated in a manner to be described later. A vacuum gage may be used instead of a flowmeter as a measuring device for the air flow.

The electric motor, blower, sliding rheostat, electric plug, and switch are all assembled on a metal plate 9 by 14 inches and ½ inch in thickness, and this plate is in turn firmly screwed to the base

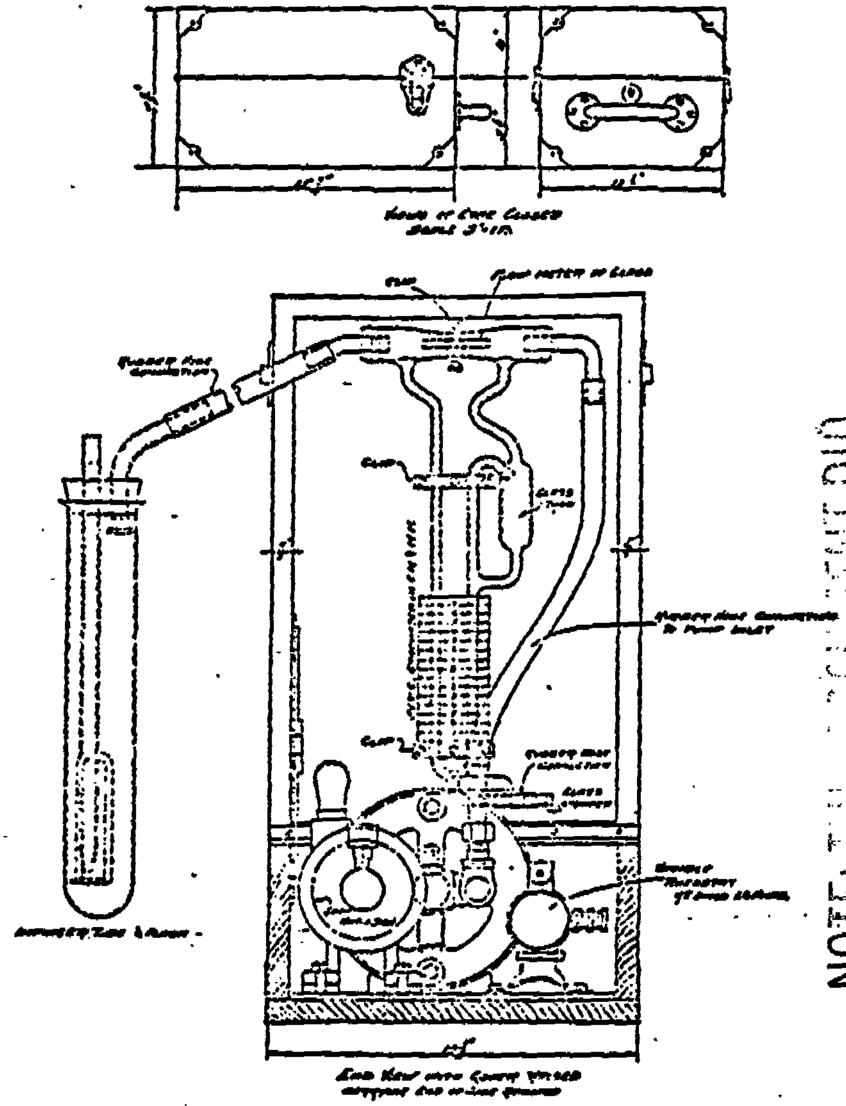

FIGURE 4.—Drawing of electrically driven suction apparatus, end view.

of the carrying case. The carrying case is made of ½-inch quartered oak, the outside dimensions being 10½ by 15½ by 9¼ inches. The weight of the apparatus is 45 pounds.

Compressed-air suction apparatus.—In many industrial establishments, mines, and quarries, compressed air is readily available. By means of a very simple device called an ejector, the energy of the compressed air may be converted into suction and then utilized with the impinger tube and flask for the sampling of the dust in air. Hatch has recently described a suction device of this type which has the added feature of a constant flowmeter (18). Details of this instrument are presented in figure 5. This device uses about 50 cubic feet of free air when functioning and a constant rate is obtained with it regardless of the variation in air pressure, so long as this pressure is within the limits of 30 and 75 pounds per square inch. For an indicating device a simple pressure gage, connected to the compressed air supply, is employed.

The constant flow in this meter is due to the fact that the pressure drop across the orifice (p_1-p_2) is greater than the critical pressure, which for air is 0.53 p_1 (where p_1 is the upstream and p_2 the downstream pressure). Under this condition the flow depends upon p_1 only, and since this remains constant (within the limits of barometric pressure), the rate of air flow has a constant value. With a barometric pressure equal to 30 inches of mercury and the pressure loss through an impinger device equal to 2.9 inches, $p_1=27.1$ inches. To meet such a requirement $p_1-p_2 \geqq 14.5$ inches ($\geqq 0.53\ p$), and p_2 (absolute) must be less than 12.6 inches of mercury, that is, −17.4 inches of mercury gage pressure. A suction in excess of this value is obtained with the aid of a No. 2 Hancock ejector, when the pressure in the air line is between 30 and 75 pounds. The orifice as designed by Hatch and his co-workers was found on testing to yield rates of flow from 28 to 29 liters a minute (about 1 cubic foot per minute) with a maximum variation of 3.5 percent.

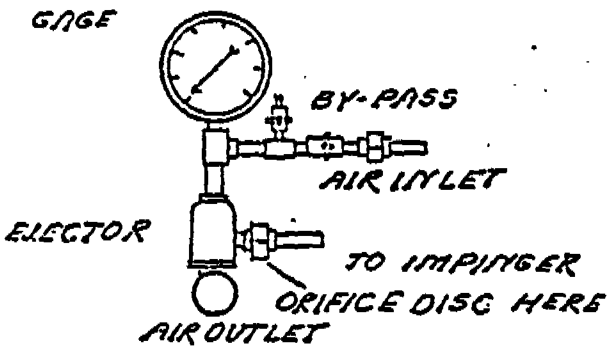

FIGURE 5.—Compressed-air-driven suction apparatus for impinger.

Hand-driven suction apparatus.—Early in the course of the studies at the United States Bureau of Mines Experiment Station at Pittsburgh, the necessity became apparent for a hand-actuated apparatus, to be used in work places lacking electric power or compressed air. Such a device was designed and constructed and is fully described in Public Health Bulletin No. 144. The apparatus in its present form (fig. 6) consists of a tripod of metal tubing supporting a vertical post and a horizontal bar at its apex. The horizontal bar is provided with an ordinary bicycle seat. To the vertical post at a suitable level (adjustable) there is attached a positive pressure blower (used as a source of suction) of the same size and capacity as that used with the

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electrically-driven type of apparatus. In this case, however, all of the excess metal of the blower has been removed by machining in order to reduce the weight of the apparatus. The blower is geared to a pair of crank handles by a pair of gears having an 8 to 1 ratio. The suction inlet of the blower is attached to the impinger sampling bottle which is supported near the top of the vertical post of the tripod. The steel tubing of which the tripod and its appendages are constructed may be dismantled and the complete apparatus fitted into a canvas case somewhat resembling a gun case. The weight of the complete apparatus is approximately 17 pounds.

A revolution counter attached to the large gear records the number of its revolutions. Calibration of the instrument with a gas meter showed that the volume of air sampled per revolution of the pump

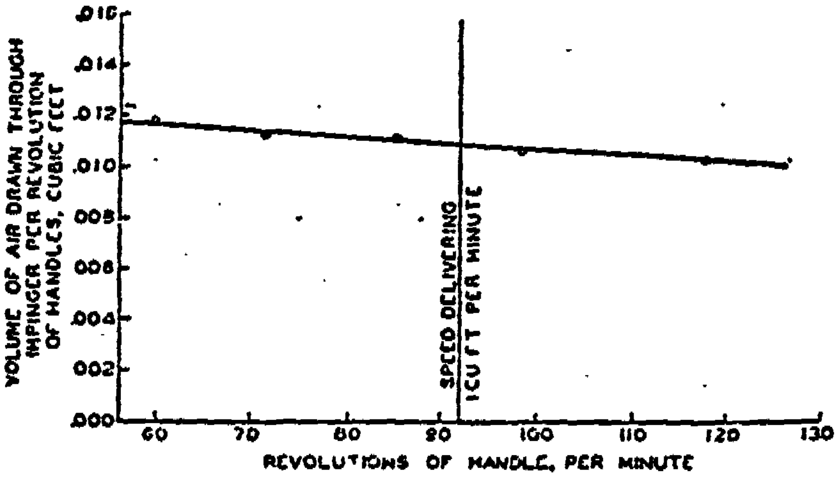

FIGURE 7.—Calibration curve of rotary pump for hand-driven suction apparatus.

varied somewhat with the rate of revolution. The calibration curve presented herewith (fig. 7) is taken from Public Health Bulletin No. 144. The particular pump tested aspirated 1 cubic foot of air per minute when operated at 92 revolutions per minute.

When the apparatus is in use the operator turns the crank at the rate of approximately one and one-half revolutions per second, maintained as constantly as possible, for an appropriate length of time. The number of revolutions per minute is determined by dividing the total number of revolutions by the time of sampling. From a curve similar to that shown the volume per revolution is calculated, which is multiplied by the number of revolutions to give the total volume of air sampled.

For general field use, the compressed-air device has been found to be the most satisfactory form of apparatus.

Impinger tube and sampling flask.—The impinger tube in the model of the apparatus described in Public Health Bulletin No. 144

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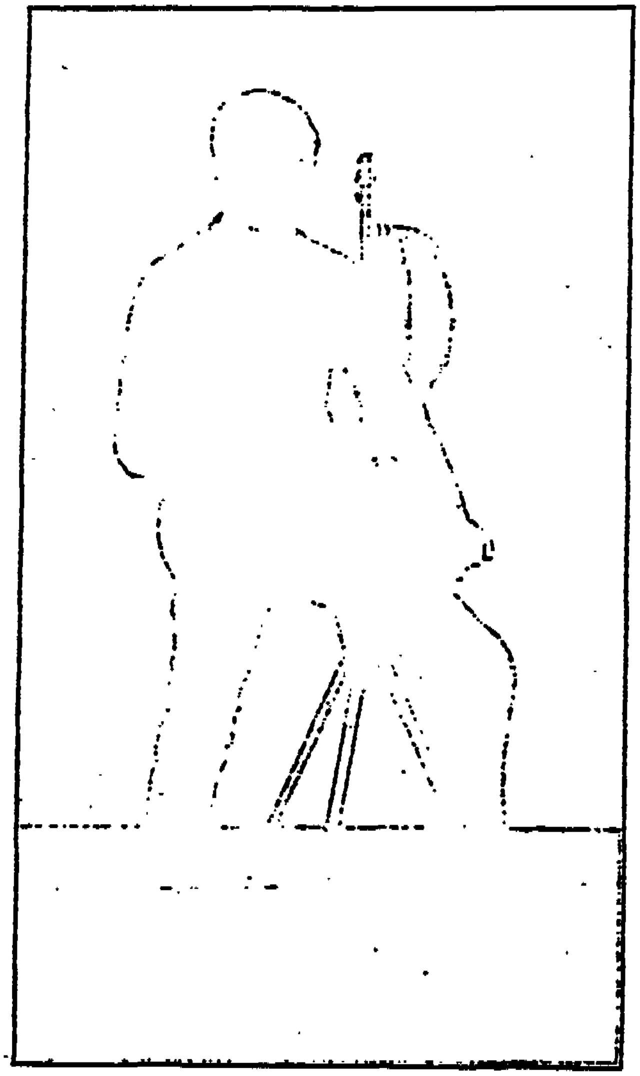

FIGURE 5.—HAND-DRIVEN SUCTION APPARATUS FOR IMPINGER.

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(p. 67) consisted f a piece of Pyrex glass tubing, drawn down to a tip with a 2.3-millimeter orifice. To this tube a metal tripod and circular impinging plate were attached by means of a bronze split-

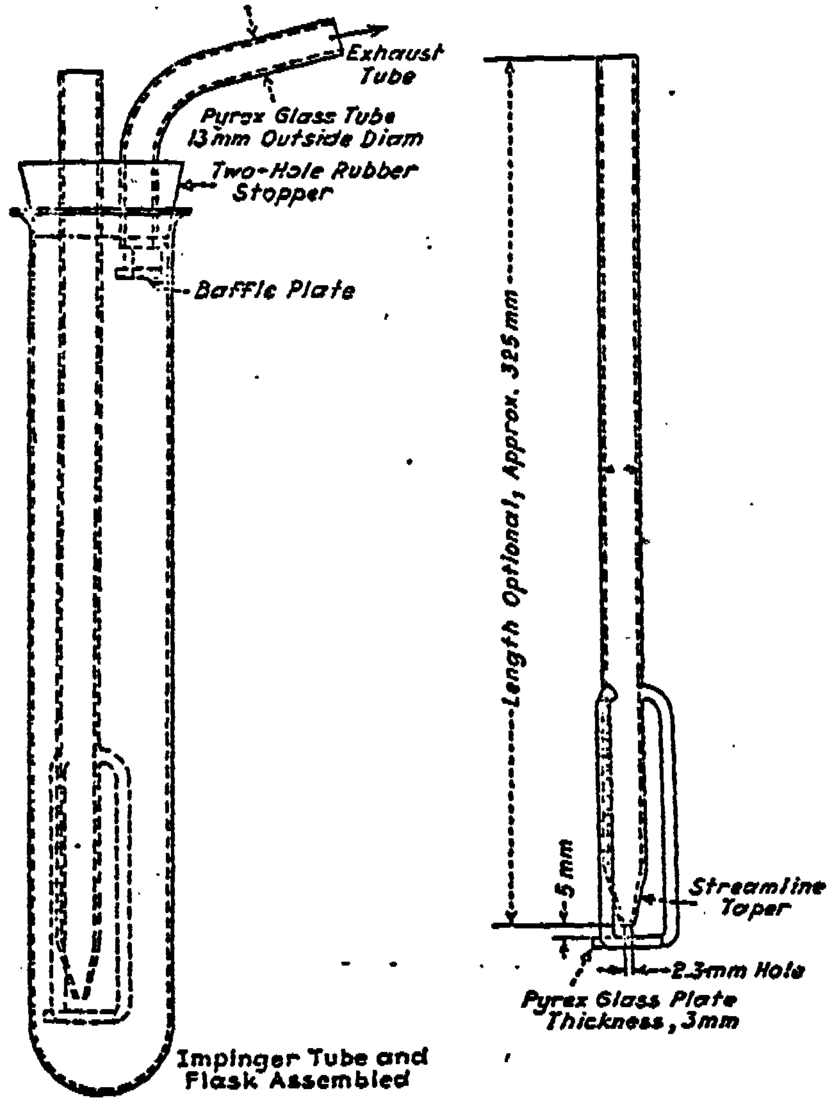

FIGURE 2.—Drawing of impinger tube and flask.

sleeve clamp. The distance between the orifice and the upper surface of the plate was kept at 5 millimeters.

In practice, this impinger tube yielded satisfactory results. Nevertheless, it was felt that it would be preferable to eliminate the use of metal, particularly where acid or alkali was to be used as the collecting fluid. Accordingly, there was designed and constructed the all-glass impinger tube shown in figure 3, with circular glass

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impinger plate about 2.5 millimeters in diameter, fixed by three supporting rods about 9 centimeters long to the impinger tube at a distance of 5 millimeters from the orifice. The tube was 13 millimeters in outside diameter. Pyrex glass was used throughout. Tubes of this type have been employed without an undue amount of breakage.

A few modifications have been made in the impinger flask. Originally, a round 16-ounce glass bottle fitted with a 2-hole rubber stopper was used. A short time later a 500-cubic centimeter Pyrex glass assay flask (wide-mouth conical Erlenmeyer type) was substituted, which proved to be very satisfactory.

In certain studies it was found desirable to obtain dust samples in the region of the mouth and nose of a worker in order to secure a more representative picture of the air actually breathed. This was done in a very ingenious manner by the Australian workers, Badham, Rayner, and Broose (19) who utilized as the sampling flask a cylinder 12 inches in length, and 2 inches in inside diameter. The cylinder was fastened to the worker by a specially designed strap passing around the chest. We have employed a similar flask made in the form of a tube sealed at the lower end, 300 millimeters in length and 50 millimeters in diameter, provided with the 2-hole rubber stopper (shown in fig. 8). For protection from the impact of large pieces of flying material, as well as for convenient support, the tube was placed inside of a cylindrical leather holster which in turn was made fast to the chest of the worker by means of a pair of straps fastened about the chest and shoulders. Thus, the inlet end of the impinger tube was fixed at a point very close to the nose and mouth of the wearer. As before, the outlet tube from the sampling cylinder is connected to the source of suction by means of a convenient length of noncollapsible rubber tubing. Figure 9 shows this form of impinger sampling cylinder with its leather holster, as used in our studies.

Whether bottle, flask, or cylinder is used, sufficient liquid should be kept in the container during use to cover the impinger plate to a depth of approximately 3 centimeters. In the cylinder type of flask 100 cubic centimeters are sufficient to accomplish this, whereas if the Erlenmeyer type of flask is used, 250 cubic centimeters are required. A baffle plate on the exhaust tube, as shown in figure 8, is sometimes advantageous.

A more compact and convenient impinger flask and nozzle has been recently developed for field use (18). The modifications in the design of the impinger have in no way altered the basic principle on which the instrument operates. Figure 10 shows the latest form of the impinger flask and nozzle.

The modified impinger does away with the glass impinging plate, utilizing the bottom of the flask for this purpose. The suction con-

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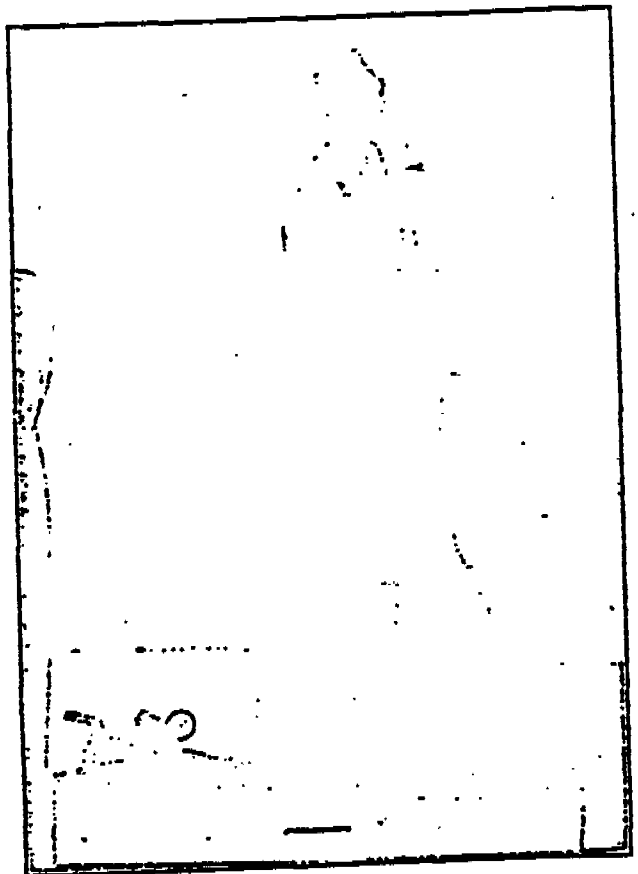

FIGURE 9.—IMPINGER SAMPLING TUBE ATTACHED ABOUT NECK OF WORKER.

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nection is combined with the inlet tube, thus simplifying the device still further. The essential portions of the device consist of a straight piece of Pyrex glass tubing 15 mm in outside diameter and approximately 275 mm in length. The tube is drawn down in stream-line form at its lower end, to a tip with a 2.3 mm orifice. In sampling this orifice is kept approximately 5 mm from the bottom of the flask, a guide line on the flask indicating this distance. The flask is 50 mm in diameter and 210 mm in height and requires a fluid (water) volume of only 75 cc to give the proper depth of immersion to the nozzle.

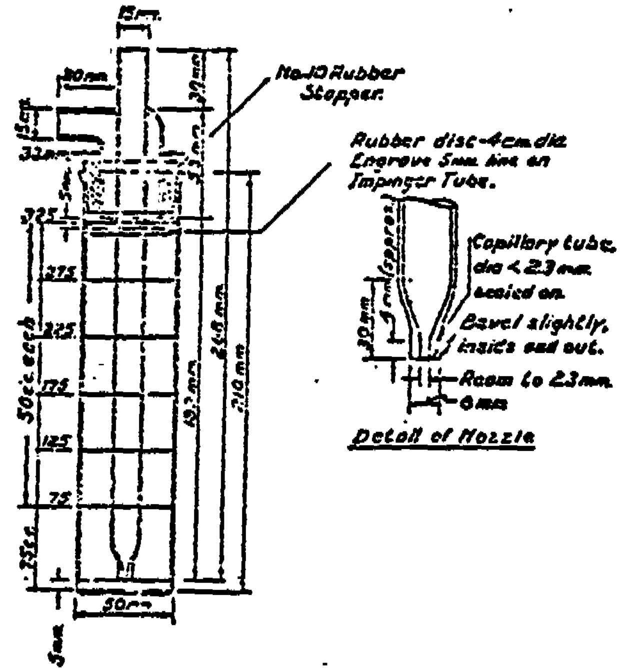

FIGURE 10.—Drawing of modified impinger and detail of nozzle, with construction specifications.

An entrainment trap in the form of a rubber ring prevents the possible loss of the liquid (and dust) with the outgoing air.

Since the impingement distance in this instrument is not fixed, as in the previously described type, it was necessary to determine the limits within which this distance, as well as the angle of impingement from the perpendicular, varied. Studies conducted on these factors by the designers of this instrument showed that as regards the angle of impingement (using silica dust) one can have a maximum displacement of the nozzle without changing the efficiency obtained when the nozzle is in the vertical position. Also, it was found that the impinging distance can be varied from 2 to 12 millimeters without impairing the efficiency against silica dust to any appreciable degree. The data pertaining to the experiments made on this modified device are shown in the following tables, 4, 5, and 6:

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TABLE 4.—*Effect of impinging distance on efficiency of impinger*

[Sampling rate=28.3 liters per minute]

Impinging distance (mm)	Percent efficiency				
	Silica	Tobacco smoke		Magnesium oxide	
		Wet	Dry	Medium	Fine
2	+98	95	83	84	83
5	+95	89	81	77	85
7	97	87	80		81
10		84	72		83
12	97			75	
13		81	73		49
15	94				

TABLE 5.—*Effect of varying angle of impingement*

[Impinging distance=5 mm; sampling rate=28.3 liters per minute]

Adjustment of impinger nozzle	Percent efficiency		
	Silica	Wet smoke	Magnesium oxide [1]
Maximum angle from perpendicular	98	[2] 87, 77	60
Perpendicular	+98	[2] 89, 85	77

[1] Medium size. [2] At high and low concentrations respectively.

TABLE 6.—*Effect of sampling rate on efficiency of impinger*

[Impinging distance=5 mm]

Sampling rate (liters per minute)	Percent efficiency				
	Silica	Tobacco smoke		Magnesium oxide	
		Wet	Dry	Medium	Fine
15.0		57			15
20.0	91		60		25
23.0		76			
25.0	96		73	72	34
28.3	+95	90	79	77	55
35.0	+95	93	87	84	62
39.0		94			
42.5		94			
45.5		95			

Method of sampling—Calibration of the impinger apparatus.—It is necessary to calibrate the air-measuring device of the impinger apparatus so that one may control the rate and quantity of air sampled. The technique employed for this purpose with the hand-actuated suction apparatus has already been described. With the electrically driven suction device a suitable flowmeter or vacuum gage is commonly used as the measuring device, while the ejector instrument ciency of impinger

Percent efficiency			
...acco smoke		Magnesium oxide	
...	Dry	Medium	Fine
86	82	64	55
90	81	77	55
87	80	....	81
84	72	....	53
		75	
81	73	....	49

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Percent efficiency		
Silica	Wet smoke	Magnesium oxide
95	[illegible]	69
[illegible]	[illegible]	77

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Percent efficiency			
Tobacco smoke		Magnesium oxide	
...et	Dry	Medium	Fine
37	....	....	15
	69	....	23
76	....	....	
90	72	72	38
93	79	77	35
	87	81	62
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uses a pressure gage as an indicator for the air flow through the impinger. For calibration, the apparatus should be assembled in a manner precisely similar to that employed in field sampling, but with the outlet tube of an accurate five-light, dry, test gas meter attached to the inlet of the impinger apparatus. A calibration curve is then obtained, showing the relationship between rates of air flow, as measured by the gas meter during observed intervals of time, and the readings on the scale of the flow meter or vacuum gage. The scale reading corresponding to 1 cubic foot per minute may then be ascertained. The air-measuring device should be calibrated at frequent intervals and always after any readjustment of the apparatus. In the field, the predetermined reading should be maintained throughout the course of each sampling period by adjustment of the needle valve.

Prior to the taking of dust samples in the field it is important that the suction apparatus be carefully inspected and completely cleaned so as to insure proper functioning when in use. Care should be exercised to insure against leaky connections in the air circuit.

Choice and preparation of sampling fluid.—In spite of the generally contrary belief, many dusts, including even silica, are soluble in water (20). This is to a great extent due to the large surface area exposed to the solvent by small particles of suspended material. A proper sampling fluid should be used in order to avoid solution. As a rule distilled water is used and by conducting the analyses within 24 hours, it is possible to avoid significant dust loss. Preferably, the counting should be done on the day of sampling. In the case of those dusts not easily wetted by water, such as coal dust, a mixture of 25 percent alcohol and 75 percent water yields excellent results. The alcohol increases the wetting power of the solution and at the same time greatly reduces the solubility of mineral dusts in water. Possible action on the rubber stopper of whatever collecting fluid may be chosen should be appropriately controlled.

It is important that the sampling fluid itself be comparatively free from suspended matter. Distilled water should be prepared, if possible, by one of the continuous types of water stills and, after distillation, should be permitted to stand for about 24 hours, the upper part being drawn off for use. If alcohol is employed, it should be redistilled before use.

Preparation of sampling flasks.—Prior to taking samples in the field the desired number of sampling flasks are thoroughly cleaned with hot cleansing solution, rinsed several times in tap water, and finally rinsed with the fluid used as the sampling medium. The stoppers are thoroughly freed from adventitious dust by several washings in tap water and finally in the sampling fluid. The required amount of sampling fluid is placed in each impinger flask, a cleaned solid-rubber stopper is put in place, and a cap of paper is fastened over the top by means of a rubber band. The flasks are now ready for transport to the place where samples are to be taken.

Field technique in sampling.—In taking dust samples the location of the sampling place, the time during which sampling is conducted, and the duration of sampling are all chosen in an effort to obtain the data required by the study in progress. Obviously the requirements of the study under way govern the procedure to be employed.

The two-hole rubber stopper fitted to the impinger tube and exhaust elbow may be transported in a spare flask containing some of the sampling fluid. Such a procedure serves both to protect the impinger tube and to keep it clean and ready for use. The exposed ends of the impinger tube and exhaust elbow should always be protected against accidental contamination.

After the selection of the sampling position, the stopper of one of the impinger flasks is replaced by the two-hole rubber stopper containing the impinger tube and exhaust elbow. The solid stopper is put on the spare bottle, thus protecting the rinse fluid and at the same time preventing contamination of the stopper. This completely equipped impinger is now placed in the leather holster, while the holster in turn is securely strapped about the worker or held by an assistant at the desired sampling point. The holster serves a two-fold purpose: First, it serves to protect the glass tube from breakage by flying objects in the work place, and second, it fixes the entrance to the impinger tube very close to the nose and mouth of the worker. The outlet or suction elbow of the sampling flask is connected with the source of suction by means of a suitable length (commonly 25 feet) of noncollapsible rubber tubing.

In certain cases it is not feasible to place the impinger flask about the neck of the worker, nor is it convenient to have an assistant hold the flask near the worker. Under these conditions a length of rubber tubing (about 15 feet) may be connected to the inlet of the impinger apparatus (the impinger tube) and the free end fastened at the desired sampling point. With a sampling rate of 1 cubic foot per minute, dust particles pass through a ½-inch tube 15 feet long in less than a second, hardly sufficient time to allow settling to take place.

The duration of the sampling period should be such as to yield a satisfactory suspension of dust for analysis, and is thus dependent on the concentration of dust in the atmosphere. Under the usual industrial conditions, samples of from 10 to 30 cubic feet of air are sufficient to yield enough suspended dust for analysis. Since a sampling rate of 1 cubic foot per minute is maintained, this will require a sampling period of from 10 to 30 minutes. A stop watch is used to measure this period.

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After the sample has been taken, the impinger tube is withdrawn. The tube is rinsed both inside and out with some sampling fluid from a fresh bottle, the rinsings being added to the original sample and the sampling flask stoppered and capped for transport to the laboratory. Should the impinger tube be found to be contaminated with adherent dust after rinsing, it should be carefully cleaned or, better still, replaced by an unused tube. Spare tubes should always be carried.

Notes are promptly made of all the pertinent data with reference to each sample.

ALTERNATING CURRENT PRECIPITATOR

Professor Philip Drinker and his colleagues at the Harvard School of Public Health have had a good deal of experience during the past 12 years with electrical precipitators for collecting atmospheric particulate matter. As a result of their work they have found that non-rectified alternating current is superior to rectified current for precipitating dry, poorly conducting suspensions, such as most industrial dusts of hygienic significance. Figures 11 and 12 present the essential parts of such precipitators. The tubes are made of pyrex of a size called for by the particular problem involved. The large tube shown in the drawing is adaptable for dust sampling at 15,000 volts, whereas the smaller tube is used at lower voltages and rates of air flow. A General Electric Co. luminous-tube transformer is used for obtaining high voltages. This transformer unit weighs 32 pounds, operates from a 110-volt, 60-cycle line and furnishes a secondary current of 30 milliamperes at 15,000 volts. By means of a rheostat in the primary circuit, the voltages can be regulated from 8,000 to 15,000. In this apparatus the midpoint of the high voltage winding is grounded to the metal casing of the transformer. Fuses are placed in both the low-tension lines, rather than in the main line, so that these fuses blow in case of a disruptive discharge.

A rather fine wire of gold-plated drill steel is used in the larger size tube for the precipitating or central electrode, whereas it has been found best to use fine platinum, gold, or copper wire in the smaller tubes. The outer electrode is made of either metal netting, of metal foil, or of copper wire wrapped spirally along the tube. Such wrappings must be pulled tight by hand and may be kept in place by electrician's tape. Celluloid foil or filter paper placed inside the tube is used as the collecting medium. The precipitating electrode must be kept well up the tube to insure efficient collection on the celluloid foil or filter paper; this precaution precludes dust from being caught on the glass tube itself.

Since gases of a toxic nature may be produced in the operation of the precipitator, and moreover, since these gases destroy the rubber stoppers and tubing used in the device, it is advisable to insert a

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chamber containing activated charcoal in the circuit (see sketch) in order to absorb these gases. In view of the destructive action of the gases on the rubber parts of the apparatus it is advisable that the instrument be inspected frequently for damaged parts.

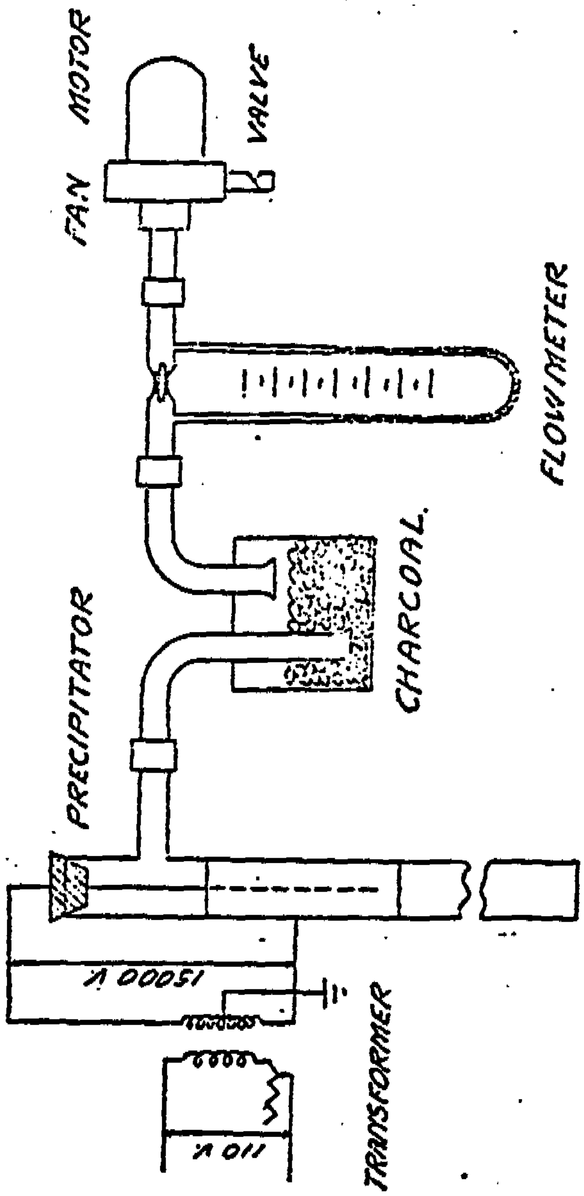

FIGURE 11.—Drawing of electrical precipitator assembly

As a source of suction one can use either a compressed air ejector, with a calibrated glass flowmeter, or a hand-size vacuum cleaner fan employing a small metal orifice meter for measuring the air flow. The resistance to air flow of the precipitator tube is small, so that all the resistance to be overcome is due mainly to the charcoal trap. At a sampling rate of about 50 liters a minute, this resistance has been found to be 10 to 15 cm water gage.

In operation a sufficient volume of air is passed through the precipitating tube to yield a visible deposit of dust. The foil or filter-paper containing the dust deposit is then removed from the tube and placed in a receptacle for transmittal to the laboratory. The practical operating efficiency of the precipitator is nearly 100 percent. If low efficiencies are obtained, they are probably due to either high rates of air flow, low voltages or too great a diameter in the tube,

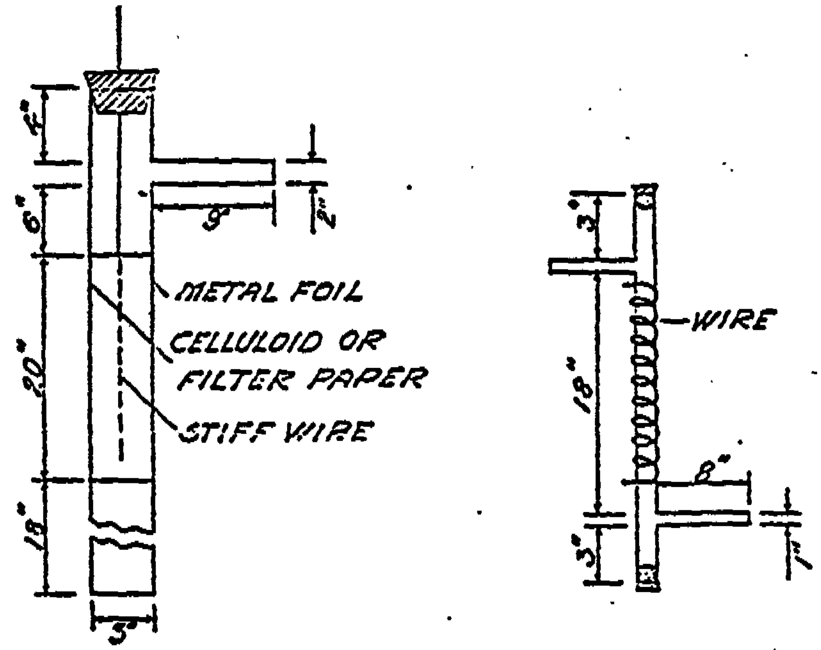

FIGURE 12.—Drawing of two useful sizes of Pyrex precipitator tubes.

factors which may be easily corrected. The method of analysis and the various advantages and disadvantages of this device will be discussed at the end of this section. A list of equipment for collecting dust samples by the precipitation method is given by Professor Drinker in his article appearing in the Journal of Industrial Hygiene, for December 1932.

PAPER THIMBLE APPARATUS

Paper filters for collecting dust in air have been used for many years by numerous investigators. In 1905, Simon in Germany used a paper thimble for determining dust in blast furnace gases (21). Mariner and Hoskins utilized this principle in studying the extent of smoke pollution in Chicago in 1915 (22). However, it was not until 1922 before definite data were available on the various characteristies of this device when Trostel and Frevert reported the results of their studies of the paper thimble in connection with the development of this instrument for the collection and examination of explosive dusts in air (13).

Description of apparatus

Figure 13 shows the details of the thimble and brass capsule which holds it in place. The thimbles used are single thickness, Whatman

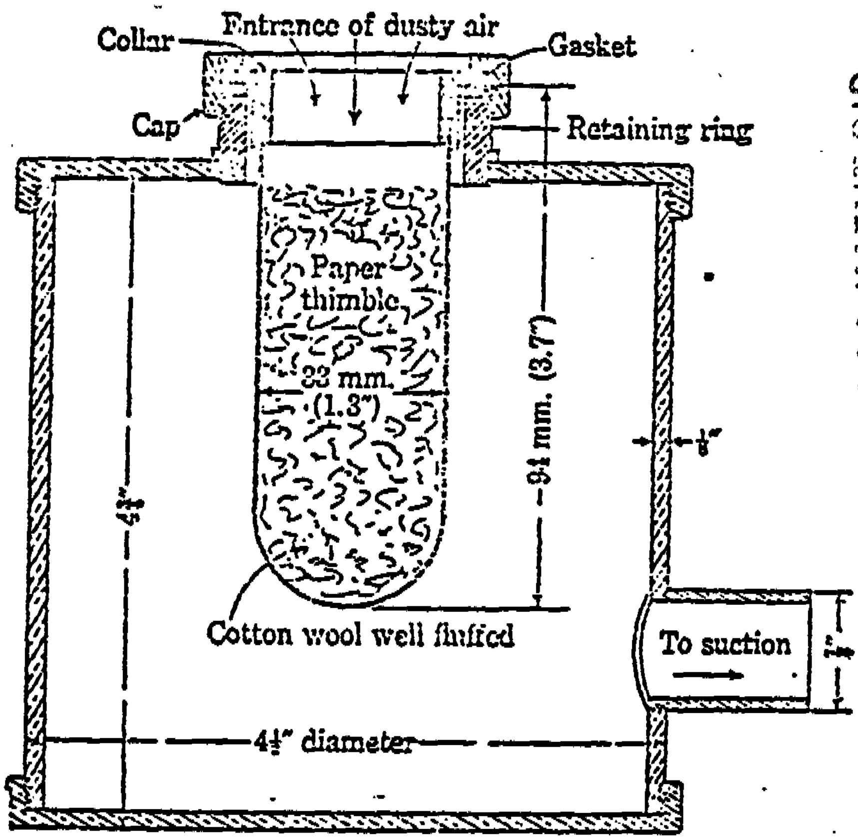

Figure 13.—Details of paper thimble and suction capsule.

extraction shells, 33 by 94 mm, with a small amount of cotton wool (weight about 125 mg), well fluffed out, inserted inside the thimbles for the purpose of supporting the dust and to preclude the possibility of clogging the pores of the paper. The suction side of the capsule is connected to either a calibrated foot pump, an electrically driven blower, or an ejector device of the type described with the impinger outfit. In operation the dust-laden air enters the opening of the brass capsule, as indicated in the sketch, passes into the paper thimble, and after depositing the dust escapes into the expansion compartment of the capsule and thence through the suction device;

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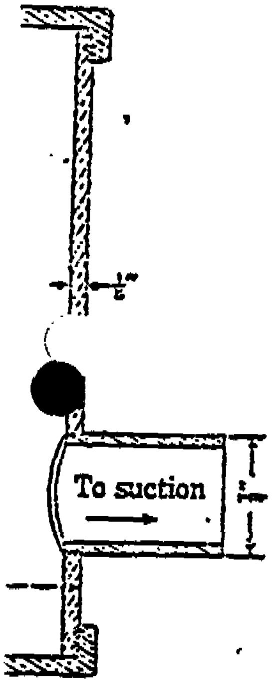

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the latter, be it an ejector, electrically driven blower, or foot pump, is provided with a metering device for measuring the air flow, which is usually maintained at the rate of 2 cubic feet per minute.

Before using a thimble it must be dried to a constant weight. This may be accomplished by one of two ways. First; thimbles can be given a preliminary drying at 90° to 95° C. for 3 to 7 days in an ordinary drying oven, and then just before using they are dried in a vacuum oven for 7 hours at 90° C. and weighed. To obtain a check weight they are exposed overnight to room air and again dried in vacuum for 7 hours. After sampling, the same 7-hour vacuum drying period is employed. Second, the thimbles which have had the preliminary treatment may be dried just before use in an ordinary hot-air oven for two days at 90° to 95° C. This period is sufficient to bring them to constant weight with no check drying being necessary in this instance. After sampling the same 2-day drying period is followed. Two blank thimbles, not used in the collection of dust, are dried, and weighed according to one of the two methods outlined, which enables one to check the constancy of the thimble weights during the drying period.

The thimbles are placed in a special glass weighing container after removal from the oven and are allowed to cool in a dessicator. A counterpoise weighing bottle is placed on the pan of the balance opposite to the one containing the thimble, thus compensating for moisture condensation on the somewhat large surfaces of the bottles. The thimble and bottle are weighed rapidly to the nearest milligram and then the empty bottle is weighed. The difference in weight represents the dry weight of the thimble. After a sample of dust is collected the thimble is placed in the drying oven and brought to constant weight, as described. The increase in weight of the thimble is the dry weight of the collected dust. This weight is divided by the volume of air sampled, yielding a weight per unit volume, such as milligrams per cubic foot, etc.

Efficiency of thimbles

Tests on the filtering efficiency of the paper thimble were conducted by Trostel and Frevert on various dusts of different sizes. These tests showed that the device recovered nearly 100 percent of the dust sampled. Against tobacco smoke of a 0.27 micron size the thimble device was found by optical methods to be 46 percent efficient. Against silica dust of a size from 1 to 2 microns (average industrial size of dust), the optical method showed 100 percent efficiency after 37 seconds of sampling had elapsed. Again, gravimetric tests with very finely divided cornstarch showed this instrument to be practically 100 percent effective in collecting dust.

It might be expected that since paper is highly hygroscopic that the rates of air flow through thimbles would be different in atmospheres of varying humidities. This possibility, if true, would tend to increase the resistance through the thimble, thereby decreasing the rate of air flow and vitiating the volume readings on the metering device. In order to test the effect of humidity on the thimbles, tests were conducted at 25, 50, 75, and 90 percent humidities for a total period of 7 days. The thimbles were first dried to constant weight and the rate of air flow determined. Then the 7-day test on the thimbles was made until their regain in weight was constant, when the rate of air flow was again determined. It was found that the rate of air flow over the range of relative humidities tested was not affected, even at the highly saturated condition of 90 percent.

The application of this device to industrial dust sampling will be discussed more fully in the portion of this section dealing with the various advantages and disadvantages of the instruments covered in this discussion.

THE KONIMETER

The konimeter instrument, which samples dust by impinging air at a high velocity against a sticky glass plate, was developed by Sir R. N. Kotzé for use by the Miners' Phthisis Prevention Committee of South Africa. The type of konimeter most frequently used in this country is the one employing a circular glass plate which is revolved to produce a ring of dust spots near the periphery.

Description of Instrument

The circular type of konimeter is depicted in figure 14. It consists essentially of a valveless cylindrical suction pump and a dial of brass; the piston of the pump is actuated by a spring which insures uniform operation. About 10 cc of air are sampled per stroke, the exact amount being determined by calibration of the instrument. This may be accomplished by attaching the suction side of the device to a graduated gas burette containing water and noting the amount of water displaced. The dial chamber contains a circular glass plate, resting on a hard-rubber ring so arranged that the air from the surrounding atmosphere is drawn, upon releasing the piston, through a nozzle 0.0225 inch (0.57 mm) in diameter and is impinged upon the plate, located 0.0197 inch (0.5 mm) from the end of the nozzle. For the purpose of retaining the dust effectively, a thin film of petrolatum is usually smeared on the glass plate. The glass plate is attached to a toothed brass ring, which engages a pinion operated on a rod extending outside the instrument. The glass is revolved to expose fresh surfaces as needed. The instrument is provided with 29 sectors on the ring, each one numbered so as to record each dust spot or sample.

The konimeter is compact, simple to operate, is only 6½ inches long, and weighs but 2.2 pounds.

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Method of sampling

Prior to obtaining samples of aerial dust with the konimeter it should be carefully cleaned and prepared for use. The orifice of the nozzle may be cleaned with a horsehair or other suitable material and the volume of the device is determined from time to time in the manner already mentioned. The glass plate is covered thinly with filtered petrolatum, by rubbing evenly over the plate with a clean glass stirring rod containing a quantity of petrolatum about the size of a

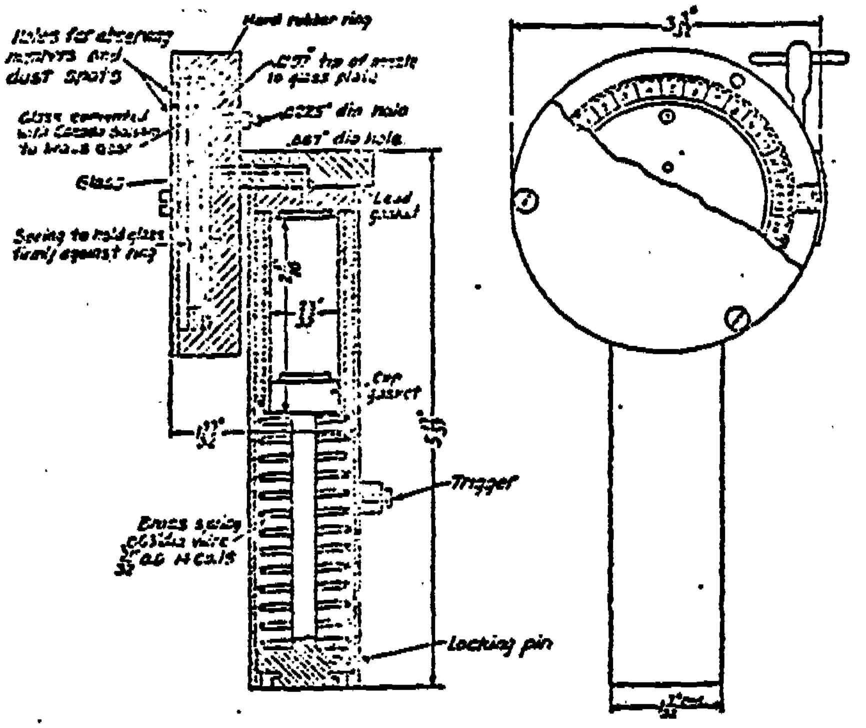

FIGURE 14.—Details of konimeter device.

pinhead. The parts of the instrument are then assembled and the rod operating the pinion which engages the toothed brass ring and glass plate is so moved as to expose sector no. 1 opposite the nozzle. To obtain a sample of dust the piston is pushed inward until it is caught and held in place by a locking pin provided for that purpose. The orifice at the back of the konimeter is held at the sampling point and a sample is procured by pressing the trigger which releases the spring. Air rushes in through the nozzle at a high velocity impinging its dust content in the petrolatum film on the glass plate. To obtain another sample the pinion is turned to bring the next sector into position. The method of examining the dust samples will be treated in the next section which deals with this subject.

The efficiency of the konimeter, when sampling in moderately dusty atmospheres, has been found to be about 1.5 times that of the impinger device, both in laboratory tests and in comparative studies conducted in the field under practical operation (23) (24).

OWENS JET DUST COUNTER

Principle of instrument

The jet dust counter was devised by Dr. Owens, of London, England, for the study of atmospheric smoke in connection with the work of the Advisory Committee on Atmospheric Pollution. The principle of this apparatus is very similar to the konimeter. The device depends for its action on the principle that when air containing dust passes through a narrow orifice facing a glass surface a short distance away from the jet, the dust will adhere to the glass. In the Owens instrument this result is achieved by causing a very fine, ribbon-shaped jet of air to strike a microscope cover glass situated about 1 mm from a slot-shaped opening forming the jet. The air, before entering the slot, is passed through a damping chamber, and the velocity in the jet is such that a fall of pressure results, in this way bringing about a condensation of moisture. The air is then deflected and the dust, being unable to turn the corner, strikes the cover glass; the velocity of the air drops, the pressure and temperature rise, causing the water to be evaporated and to leave the dust behind.

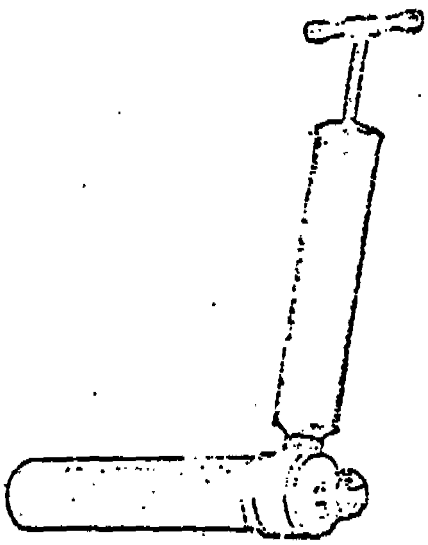

FIGURE 15.—Owens jet dust counter assembled for use.

Description of instrument

Figure 15 shows the instrument in its assembled form while figure 16 depicts the essential portions of the device in more detail. The apparatus shown in figure 16 consists of a brass sleeve B open at the top and bottom and screwed internally for the reception of the part K. This part (K) is perforated by a central hole for admitting the air to a narrow slot formed diametrically across the hole by means of two semicircular metallic plates, held in position by a ring R attached to the plug K.

Into the upper opening of the sleeve B is fitted a screwed plug C, provided with an attachment consisting of a spindle L which penetrates the sleeve formed in the plug C and ends at the outer end in a

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knurled head J, and at the other end in a carrier plate O. This carrier plate receives the cover glass and has two stops on its edge to aid in centering it. A flat spring P is fixed above the plate O with its ends bent round so as to hold the cover glass firmly against the plate O when the glass is in position. A spiral spring M, located between the plate O and the plug C, keeps the cover glass pressed downward over the slot of the instrument when the plug C is screwed into place. To insert the cover glass on the carrier plate O the plug C with its attachments is held in one hand and the knurled head J withdrawn sufficiently to press the spring P against the plug C, thereby lifting the bent ends of the spring P from the plate O, allowing a cover glass to be inserted. When the knurled head J is released it is drawn back by the spring M, the spring P comes out of contact with the plug C and the bent ends press down on the cover glass, thus holding it tightly in place. When the plug C is screwed into position in the instrument (in the sleeve B), the stops upon plate O make contact with the ring R which forms the cell around the slot. The distance of the cover glass from the slot is thus fixed and the cover glass may be rotated to any position by means of the knurled head J.

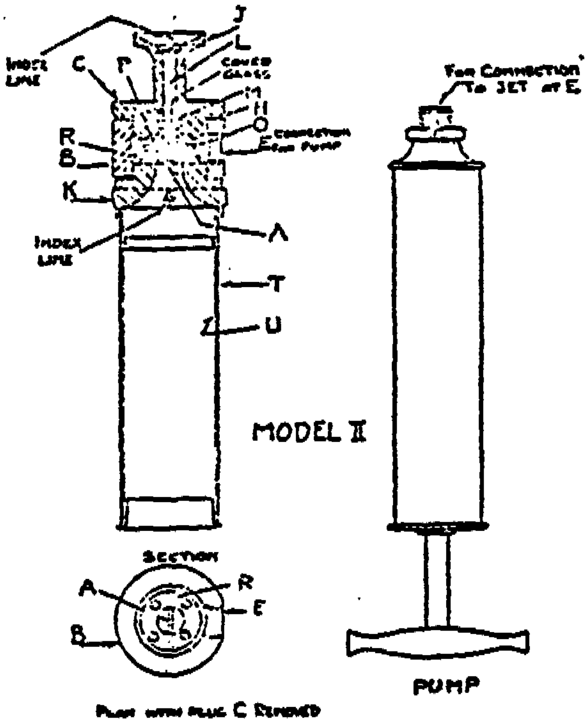

FIGURE 16.—Details of Owens jet dust counter.

The washer H makes an air-tight joint between the plug C and the sleeve B. Inside the sleeve B and surrounding the cover glass is an annular recess which communicates with a connection E for attachment to an air pump of 50 cc capacity. A damping chamber T is furnished, which is detachable from the plug K by unscrewing. This chamber is lined with blotting paper which is wetted prior to using the instrument.

Method of operation

Prior to sampling one should make sure that the slot is clear of any obstruction. It may be cleaned by means of a slip of thin paper pushed through from below. The air pump should be tested for leakage from time to time. This is accomplished by holding a moistened finger over the opening, drawing out the plunger smartly, holding it a few seconds, then letting it go, when it should return to the bottom of the pump. If the plunger does not return it may be necessary to grease it slightly with vaseline or renew the valve.

To obtain a dust record the pump is fixed to the connection E, and before the plug C is removed three or four strokes of the pump are made in order to fill the damping chamber with the air to be tested, leaving the pump plunger pushed in all the way. The blotting paper in the damping chamber should be wetted before sampling is started. The plug C is rapidly removed and a carefully cleaned cover glass is inserted upon the ring R, after which the plug C is quickly replaced and screwed in tightly. The pump plunger is then pulled out smartly so as to draw in 50 cc of air through the jet. If more air is desired the plunger can be operated again after allowing an interval of 15 or 20 seconds to elapse in order to allow the air to absorb moisture from the damping chamber. The plug C is then removed, the cover glass dropped out on the hand, when it is ready for mounting.

The dust record is mounted on thin, tin rings cemented onto a microscope slide. Several such slides are previously prepared for this purpose. This may be done by placing a few drops of the cement, which accompanies the instrument, onto the slide and placing a tin ring onto the glass, squeezing gently down on the ring. The dust record is mounted dry, face down, so that oil immersion may be used in examining the record. To mount the coverslip one merely places three small drops of the cement onto the tin ring and then places the coverslip gently on it, pressing down so as to allow the cement to flow around the ring and complete the seal. Two rings may be placed on one slide if one so desires. When one is finished with an examination of a record, the coverslips, rings, and slides may be salvaged for further use by placing them in a dish of water, thus loosening the coverslip and ring from the glass. After proper cleaning these objects may be used again.

SUMMARY

An attempt has been made to describe the most frequently used instruments employed in dust sampling at the present time, in such a manner that very little difficulty should be experienced in operating the five instruments discussed in this chapter. Illustrations of the instruments, their principle of operation, calibration, and method of sampling have been given in some detail. In the following table (table 7), a summary of some of the characteristics of these instruments is given. It may be seen that all of the devices have a high sampling efficiency. Although each instrument has some disad-

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vantages, experience has shown that there is a specific use for each device. The impinger apparatus, which is the one used most universally, both in this country and abroad, can be employed for sampling in both high and low dust concentrations, and has the added advantage that the samples may be analyzed microscopically, chemically or gravimetrically. In fact, it has also proved useful for sampling fumes and gases, provided certain precautions are exercised (25) (26). The electrical precipitator is not used very frequently for dusts, finding its greatest field in the sampling of smoke and fumes. The paper thimble has been used for the sampling of radioactive dusts very successfully and is constantly employed in sampling organic dusts in connection with dust explosion prevention work. The Owens Jet Dust Counter was primarily developed for the sampling of outdoor dusts and smoke and is still used for this purpose quite universally. It is not practical for the sampling of industrial dusts of high concentration, the dust record being so thick as to make it impossible of enumeration. However, it has been used successfully for obtaining samples of industrial dusts for the purpose of particle-size measurements. This use will be dealt with in more detail in section IV. The konimeter is very useful in obtaining rapid samples in moderate concentrations of aerial dusts. For quantities of 15 to 18 million particles or less per cubic foot of air it is very efficient and should find considerable use in control work and in preliminary studies. For such investigations the Owens and konimeter have the added advantage that they require no power for operation, are very small and compact and do not need a highly skilled observer to obtain samples, although some skill is required in the enumeration of the dust records and in the interpretation of results.

So far this discussion has been limited to the collection of dusts of the type capable of producing fibrosis of the lungs or upper respiratory damage. For the collection of poisonous dusts, such as lead, the impinger or electrical precipitator have been found to be best suited for this purpose. The paper thimble has been used successfully for the collection of radioactive dusts, but on the whole the impinger and precipitator collect such dusts in a manner best suited for the subsequent chemical analysis. In the case of the impinger when used in sampling lead dusts, care should be taken that the sampling flask is of lead-free glass and that the distilled water also contains no traces of this compound. It is customary to run a blank for every 10 samples or so, which takes into account any lead present in the reagents. In sampling for minute traces of poisonous compounds, it is very essential that sufficiently large samples be obtained, enough to contain adequate amounts of the material for the particular method of analysis to be employed. It is apparent that both the impinger and electrical precipitator fulfill this requirement owing to their high air sampling rates.

TABLE 7.—*Summary of characteristics of certain dust-sampling instruments*

Instrument	Characteristics							
	Principle of operation	Efficiency against industrial dusts (percent)	Application	Method of quantification	Skill in quantification	Sampling skill	Volume of sample	Advantages of instrument	Disadvantages of instrument
Impinger	Impingement	95+	General	Count, gravimetric, chemical.	Considerable.	Some	Any amount; rate=1 cubic foot per minute.	1. High sampling efficiency in either low or high dust concentrations. 2. Sample can be quantificated by counting, weighing, or chemical analysis.	1. Requires power for operation.
Electrical precipitator.	Electrical precipitation.	100	do	do	do	Considerable.	Any amount; rate=10 to 25 liters a minute.	1. High sampling efficiency in either low or high dust concentrations. 2. Sample can be quantificated by counting, weighing, or chemical analysis. 3. Large samples obtained rapidly.	1. Requires electric power for operation. 2. Some danger from high voltages.
Paper thimble	Filtration	100	do	Gravimetric, chemical.	Some	Very little.	Any amount; rate 1 to 2 cubic feet per minute.	1. High sampling efficiency. 2. Samples large volumes rapidly. 3. Laboratory technic requires only drying and weighing for most dusts. 4. Samples may be kept indefinitely without deterioration.	1. Samples cannot be counted. 2. Drying of thimbles is a very slow process.
Owens jet dust counter.	Jet condensation.	99+	Outdoor dust and for particle-size studies.	Count	do	do	10 to 1,000 cc.	1. Light, simple, and quick to operate. 2. High efficiency for atmospheric smoke. 3. No power needed for operation. 4. Laboratory technic requires only a microscope.	1. Dust cannot be weighed or analyzed chemically. 2. Obtains only "grab" samples due to small sampling volume. 3. Impractical in high dust concentrations. 4. Selective action; efficient only for dusts 2 microns or less.

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Owens jet dust counter.	Jet condensation.	90+	Outdoor dust and for particle-size studies.	Count	do	do	50 to 1,000 cc.	weighing [illegible] 4. Samples may be kept indefinitely without deterioration. 1. Light, simple, and quick to operate. 2. High efficiency for atmospheric studies. 3. No power needed for operation. 4. Laboratory technic requires only a microscope.	1. Dust cannot be weighed or analyzed chemically. 2. Obtains only "grab" samples due to small sampling volume. 3. Impractical in high dust concentrations. 4. Selective action; efficient only for dusts 2 microns or less.
K[illegible] ref.	[illegible]	9+	For concentrations less than 15 million particles per cubic foot.	do	do	do	10 cc.	1. Light, simple, and quick to operate. 2. Efficiency high for moderate concentrations. 3. No power needed for operation. 4. Laboratory technic requires only a microscope.	1. Dust cannot be weighed or analyzed chemically. 2. Obtains only "grab" samples. 3. Not practical in high dust concentrations; limited to 15 or 20 million particles, or less, per cubic foot.

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III. THE QUANTIFICATION OF INDUSTRIAL DUSTS

PNEUMOCONIOSES-PRODUCING DUSTS

General considerations

The method of quantification used on the samples of aerial dust collected by the various instruments described in the previous section will be governed largely by the fact that our interest in the dust problem is primarily a hygienic one. In the case of fibrosis-producing dusts it has been found that the particle count offers the best index of the hazardousness of a dusty operation, especially in extensive studies of the problem dealing with the health of workers in dusty trades. Obviously, the method of enumeration which is utilized should be governed by the consideration of the size of the dust which is of hygienic significance. To date, the relative significance of various sizes of dust particles in the production of lung fibrosis has not been satisfactorily established. However, we do know that the inhalation of certain industrial dusts has been found to be associated with definite injury to the pulmonary tissues. Hence, a knowledge of the size frequency of these industrial dusts will in a measure determine the method of enumeration to be employed in order to evaluate the industrial dust hazard.

At present there are several sources of information which cast some light on this subject. One is the work of pathologists, who have determined the size of dust particles recovered from silicotic lung tissue; another source is the work done in connection with the retention of dusts, while additional information is presented by particle-size studies which have been made on industrial dusts.

Moir (27), Watkins-Pitchford (28), and Mavrogordato (29), of South Africa, have shown that most of the dust particles recovered by them from both human and animal silicotic lungs were between 1 and 3 microns in size. Only 13 percent of the particles were found to be less than 0.5 micron. These results are somewhat similar to those obtained by Scheid of Germany (30). Drinker, in comparing the size frequency of the particles measured by Moir with the particles found by him in the sputum of men employed in ore mills, found a very close correspondence (31). Recent experiments by King and Dolan (32) on the metabolism of silica indicate that extremely fine particles of quartz, those less than 3 microns in size, are rapidly dissolved in the mildly alkaline body fluids, and are excreted in the urine. The results of these findings raise two very pertinent questions; namely, (1) to what extent are minute particles of dust retained by the human lungs, and (2) do appreciable percentages of industrial dusts ever fragment into those minute sizes less than 0.5 micron?

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The work of Drinker (33) and his associates, and that of Brown (34) on the retention of certain dusts and fumes by man when known amounts were breathed, seem to indicate that the coarser suspensions were retained more effectively than the more finely divided materials. Percentage retention was found to be directly proportional to particulate size and to the density of the dust suspension in the air. Sayers and his colleagues (35), in a study of the health hazards associated with the use of tetraethyl lead gasoline, found that fine particulate matter such as the lead dust from automobile exhaust gas using ethyl gasoline was retained to an average extent of only 15 percent of the amount inhaled. Shaw and Owens, upon measuring the amount of dust in expired air of London inhabitants, found that only 25 percent of the dust was retained (36). The average size of the dust inhaled in their experiments was about 0.5 micron. This work on dust retention seems to indicate that dust particles of a size less than 0.5 micron play but a small role in the problem of industrial dust inhalation, and in a manner furnishes an answer to the question raised earlier in this discussion; namely, the extent to which minute particles of dust are retained by human beings.

The answer to the second question—that is, the ability of the ordinary industrial process to fragment appreciable quantities of dust to a size less than 0.5 micron—is partially answered by a particle-size study of the dusts actually suspended in industrial atmospheres. Such a study made by the authors in the course of their numerous investigations in dusty industries reveals the fact that practically all of the dust particles examined by them (more than 10,000 particles in about 50 samples) are between 1 and 3 microns in size, about 70 percent of the dust particles lying in this range. Only about 20 percent of the particles were found to be less than 1 micron, the average median size being 1.3. Although no two dusts were found to have exactly the same size frequency, differing at times for the same dust created by different operations, it was found that for all practical purposes the dust particles fall into very narrow limits, the majority being between 1 and 3 microns (37).

From the foregoing information it is evident that in order to obtain a representative sample of industrial dust in air, one should employ an instrument capable of arresting with a high degree of efficiency all kinds of dusts, of sizes ranging from 0.5 to 5 microns at both high- and low-dust concentrations. The instruments described in the previous chapter fulfill this requirement. In addition, the method of counting the dust particles in the samples should have small analytical errors and should reveal only those significant particles present in industrial atmospheres. It should not be the aim to count all the dust particles present in the samples (which may be accomplished by either the use of high magnifications, dark-field illumination, or combinations of both), since it is necessary to differentiate between the dust content in normal air and industrial air. As has been just indicated, this difference is sharply marked insofar as the dust particles between 0.5 and 5 microns are concerned; but this difference would be masked and lost should we include in our determination the particles of ultramicroscopic size which are present in vast numbers in all air.

The method of dust counting to be described in the following pages fulfills the requirements set forth in the present discussion with reference to industrial dusts. As a proof of the value of the method of dust counting to be presented, high correlations have been obtained between counts in various industries and the degree of silicosis and tuberculosis among the workers exposed to the dusts investigated (2). It is obvious, therefore, that the technic of dust analysis which is now being used extensively in this country and which is described in the pages to follow, constitutes a valuable index of the hazardousness of dust inhalation.

Quantification of impinger samples

Counting in cells.—Earlier in this bulletin it was pointed out that practically all dusts are, to some extent, soluble in water and, hence, counts should be conducted within 24 hours after sampling. Such a practice tends to prevent any undue flocculation as well as solvent action on some of the minute dust particles.

As soon, therefore, as the samples can be transferred to a satisfactory place for counting, the stopper of the flask is removed and carefully washed, the washings being added to the contents of the flask. Next the entire sample may be filtered into a previously cleaned graduated flask through a screen of appropriate fineness (325 mesh) so that only particles smaller than 40 microns in diameter are permitted to pass through. If the dust suspension in the graduated flask is too dense, further dilution is advisable. This dilution may conveniently be such that the number of particles counted in each microscope field is about 50 to 75. The contents of the graduated flask are next thoroughly agitated in order to obtain a uniform suspension, and two portions of about 1 cubic centimeter each are removed with a pipette so as to just fill, without bubbles, two Sedgwick-Rafter counting cells (see fig. 17). The cells have been previously cleaned very carefully in order to remove any adventitious dust, and have been kept protected from dust particles by the cover slip.

In making dust counts an eyepiece micrometer known as a "Whipple disk" is employed. (See fig. 17.) This disk has a large square engraved on it, covering a large part of the field, and this square is divided into 100 medium-sized squares, 1 of these in turn being further subdivided into 25 very small squares. Using an ordinary microscope provided with a suitable eyepiece and objective and fitted

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with an Abbe condenser, the proper tube length of the microscope is determined by calibration with a stage micrometer, so that the side of the large square of the eyepiece covers 1,000 microns (1 mm). (A 7.5X eyepiece, 16 mm objective, and a tube length of 178 mm has been found to yield this result.) The large square of the eyepiece ruling, therefore, encloses the dust in an area of 1 square millimeter; and since the cell is 1 millimeter deep, all the dust suspended in 1 cubic millimeter of the water is under the ruled field. This examination is accomplished by raising and lowering the lens system so as to focus throughout the entire depth of the cell. As a source of illumination an ordinary small electric microscope lamp may be employed. In order to provide a high degree of visibility for refractile objects it is best to lower the Abbe condenser system below the usual focusing point and to restrict the opening in the iris diaphragm.

The dust is allowed to settle for 20 minutes before counting is done. In general, only particles less than 10 microns in diameter are counted. The inclusion of particles larger than 10 microns in the filtered speci-

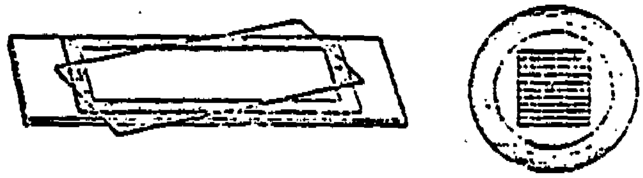

FIGURE 17.—Sedgwick-Rafter counting cell and Whipple ocular micrometer disk.

men would make but little change in the total count. The average diameter of a particle for the purpose of this exclusion is judged by inspection. In practice it is necessary to count the dust in only one-quarter of each ruled field, the entire field having been examined for uniformity. Such counts on 5 fields, so dispersed as to be representative, are made on each of the 2 Sedgwick-Rafter cells. These 10 counts are averaged, but this average is not to be taken as the final count until a corresponding control count has been subtracted. In all cases a sampling flask which is handled in the plant, but through which no air has been aspirated, is used as the control for the particular series of samples taken in that plant on that particular day, and counts are made on this control fluid in the same manner as on the fluid through which the air sample has been impinged. The control sample takes into consideration any dust which may be present in the eyepiece micrometer, in the lenses of the microscope, in the Sedgwick-Rafter counting cell, and in the sampling fluid itself. From the average gross count obtained on the impinger sample, the average control count is to be subtracted to give the average net count per microscopic field.

The average net count per ¼-microscopic field is multiplied by 4 to yield the average count in the total field. Since the Sedgwick-Rafter cell is 1 millimeter deep, this figure represents the number of particles in a cubic millimeter of the diluted sample. This value is multiplied by 1,000 to give the count per cubic centimeter of sample and again by the total number of cubic centimeters of fluid to which the original specimen was diluted. This product is divided by the number of cubic feet of air sampled. In summary, the number of particles per cubic foot of air = average net count per ¼ field times a factor, where the factor =

$$\frac{4\times 1{,}000\times \text{total volume of diluted sample in cubic centimeters}}{\text{Volume of air sampled in cubic feet}}$$

The record should show the sample number, date, sampling location, and volume of air in cubic feet. The steps in counting should be recorded as to date, volume of fluid, volume taken for dilution, calculated total volume at final dilution, average gross count per ¼-microscopic field, average control count, average net count, factor according to above formula, and finally number of particles expressed in millions per cubic foot, together with any additional notes.

Table 8, which follows, shows some typical dust counts obtained with the impinger apparatus in the various industries listed.

TABLE 8.—*Average dust count in certain dusty trades*

Industry	Dust count in millions of particles per cubic foot of air
Slate finishing mills:	
Floormen	1594.0
Loaders	1272.0
Disc-crusher operators	212.5
Talc mining:	
Jack-hammer drillers	2130.8
Muckers	44.3
Talc finishing mills:	
Crushers and cylindermen	14.6
Packers	60.1
Marble carvers	19.1
Marble cutters	22.5
Granite quarrying:	
Leyner drillers	114.4
Jack-hammer drillers	112.1
Plug drillers	26.9
Cement mill, average of all operations	26.0
Granite cutting:	
Hand pneumatic-tool operatives	92.3
Machine pneumatic tool operatives	25.0
Attendant labor	17.0
Anthracite coal mining:	
Miners and miners' helpers	221.5
Attendant labor	21.1
Bituminous coal mining:	
Coal cutters and coal loaders	112.3
Attendant labor	3.9
Silverware manufacturing:	
Dusty processes	2.9
Nondusty processes	1.7
Municipal dust (street cleaners):	
Congested district	4.1
Residential district	1.5
Cotton industry:	
Carding room	8.6
Weaving and spinning room	4.5

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This value is mul-
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	Dust count in millions of particles per cubic foot of air
	125.0
	127.0
	312.5
	2130.8
	44.8
	14.0
	60.1
	19.1
	32.5
	144.4
	112.1
	36.9
	36.0
	23.2
	31.9
	12.9
	231.8
	31.1
	112.3
	2.9
	5.2
	1.7
	4.1
	1.3
	5.6
	1.5

Gravimetric analysis of impinger samples.—The weight of the dust sampled by the impinger may be determined in 1 of 2 ways. The microscopic analysis consumes but a very small amount of the sample, at times as little as 2 cc. The remaining portion of the sample may be evaporated to dryness in a platinum or other suitable dish and weighed on an analytical balance. This weight (subtracting the weight of the empty dish) will yield the total weight of the sample and dividing by the number of cubic feet sampled will give the total weight per unit volume, correction being made for the dust contained in the volume of water used in the microscopic analysis. To determine the amount of organic and inorganic matter present in the sample, the dust in the container is ignited in a muffle furnace. The new weight is the inorganic matter present, while subtracting this weight from the total gives the amount of organic matter in the sample.

An alternative method of gravimetric analysis consists of filtering the portion of the sample not used microscopically through an ignited and weighed Gooch crucible, drying the crucible in an oven at 105° C. for 4 hours or more, and weighing again. The crucible may then be ignited in a muffle furnace if it is desired to determine the percentage of organic and inorganic matter. In all analyses, regardless of the method used, control weights are necessary on the distilled water itself for every set of 10 or more samples.

During the conduct of various dust studies both weights and counts have been obtained on the dust samples collected by the impinger apparatus. The following table shows the correlations between counts and weights on the various dusts investigated:

TABLE 9.—*Correlation between particle counts and weights of industrial dusts in air*

Dust	Number samples	Coefficient of correlation	Millions of dust particles equivalent to 1 milligram
Bituminous coal	40	0.547	31
Anthracite coal	53	.771	41
Granite	220	.755	31
Metal grinding and polishing dusts	174	.694	19
Cement	95	.694	15
All dusts	611	.726	25

It may be seen from the results of the above table that high correlations exist between counts and weights. However, it has been the general experience that weight determinations are more time consuming than particle counts and require no less skill in their performance. This is the main reason why the microscopic method of dust quantification has been widely used.

Quantification of electrical precipitator samples

The dust collected on the strip of celluloid foil used as the collecting medium in the electrical precipitator, may be washed into a graduated flask and then examined microscopically in a manner similar to that used for impinger samples. For gravimetric analysis one only needs to place the foil with its adhering dust into a special type of weighing bottle and determining the weight on an analytical balance. This weight subtracted from the weight of the bottle and empty foil yields the total weight of collected dust. Titration methods for soluble dusts may be used in lieu of direct weighing.

Quantification of paper thimble samples

The method of quantificating paper thimble samples and the precautions to be used in the analytical work involved, have already been presented in detail, in that portion of the previous section dealing with this device.

Quantification of konimeter samples

The konimeter samples lend themselves only to the counting process. The glass plate upon which the samples are obtained is adjusted on the microscope stand with the aid of a special holder with a pinion similar to that on the konimeter itself. This device enables one to bring the various dust spots into view much easier than could be attained with the naked eye. The microscope is provided with an ocular and objective and so adjusted to give approximately a 200-diameter magnification. An 8-millimeter objective and a 10X ocular have been found to give this result. A micrometer screen placed in the ocular is so designed as to have two cross lines which outline 9° sectors (fig. 18).

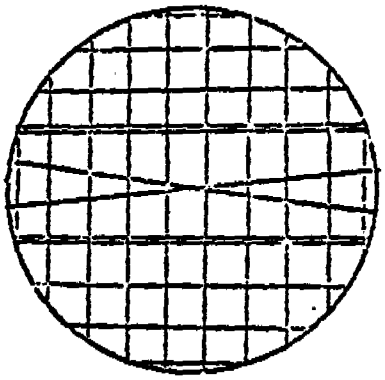

FIGURE 18.—Konimeter ocular micrometer disk.

Before counting a sample a blank determination is run on unused portions of the glass plate, usually on four sectors. This blank number, due to impurities in the petrolatum, is subtracted from the subsequent counts. The petrolatum (vaseline) generally used has a refractive index of 1.48, enabling most dusts in industry to be readily visible.

The dust spots are adjusted under the microscope so that the sectors divide them symmetrically. All of the particles in one sector are then counted; by rotating the eyepiece other portions of the spot are brought into the sector. Counting four such sectors on one spot has been found to give a representative result. Subtracting the blank and then multiplying by 10 (36° have been counted and 10 times the count will give the dust in the entire circle, 360°) will give the dust count in the entire spot. If the instrument samples a volume of 10 cc then it is not necessary to multiply by 10, since the 36° count

… give the number of particles per cc as shown in the following computation:

$$\frac{\text{Number of particles in 4-9° sectors, or } 36° \times 10}{10 \text{ cc}} = \text{number particles per cubic centimeter.}$$

…ntification of Owens jet dust counter samples

The Owens record, which consists of a linear deposit of dust, may be …ated under the microscope with the aid of a 16 mm objective and …k ground illumination (fig. 19). Dark ground illumination may … readily obtained by inserting a suitable stop under the substage …ndenser. Counts of the particles are generally made using a $\frac{1}{12}$-inch, … immersion objective. In order to facilitate counting, the eyepiece … provided with a net-ruled micrometer of 1 mm squares (fig. 20). With the aid of this eyepiece micrometer, a count of the number of particles in a strip one square wide is made across the entire record at one or two places, and an average taken. This figure multiplied into a factor, depending on the magnification used, will give the number of dust particles on the record. To determine the factor it is first necessary to ascertain the number of strips in the length of the record; this may be done under low magnification. For example, with a $\frac{2}{3}$-inch objective 50 strips in the length of the record are found; then the $\frac{1}{12}$-inch objective, which is found to magnify 10 times as much as the $\frac{2}{3}$-inch, will have 500 strips. Suppose that 300 particles are found in a strip across the record using a $\frac{1}{12}$-inch objective and that the volume of air sampled was 50 cc: the number of particles per cc will then be:

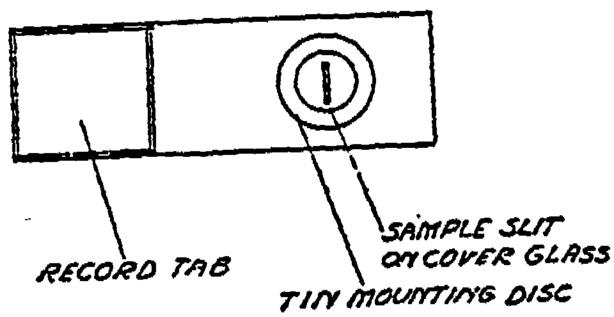

FIGURE 19.—View of Owens record mounted on slide.

$$\frac{300 \times 500}{50} = 3000$$

If S represents the number of strips found in the record, N the number of particles per strip and C the number of cc drawn through the jet in taking the record, then the number of particles per cc of air $= \frac{N \times S}{C}$.

If the same volume of air is used for all the samples and the same eyepiece and objective are employed, then the factor $\frac{S}{C}$ will remain constant. The microscope should be supplied with a mechanical stage to facilitate moving the record across the field.

Another method of enumerating the dust particles in an Owens record has recently been suggested by two Russian scientists, Kagan and Broumstein (38). Their method is a graphic one using distribution triangles, and according to them it is more accurate and takes less time than the method given by Owens, described here. For details of the graphic method the reader is referred to the original article.

QUANTIFICATION OF POISONOUS DUSTS

Of the five instruments described in this book, only the impinger, electrical precipitator, and, in a limited sense, the paper thimble are useful in collecting dusts which may be analyzed by chemical methods. The thimble has been utilized for the collection of radioactive dusts, which permitted the contents to be completely ignited, in place, under such conditions as to avoid any dust loss (4). The resulting ash was then analyzed by fusion, in place (in an 8-inch pyrex test tube), with acid potassium sulfate. It is apparent that the thimble may only be used under conditions in which it is possible to ash the thimble without loss of the material under analysis. The impinger and electrical precipitator have no such restrictions placed on them. In the case of both instruments it is only necessary to collect a sufficiently large enough sample to enable one to determine the dust accurately with the specific method of analysis employed. A sensitive and reliable method of analysis is the other requirement when dealing with dusts to be determined chemically. Blanks on the reagents are run in the usual manner.

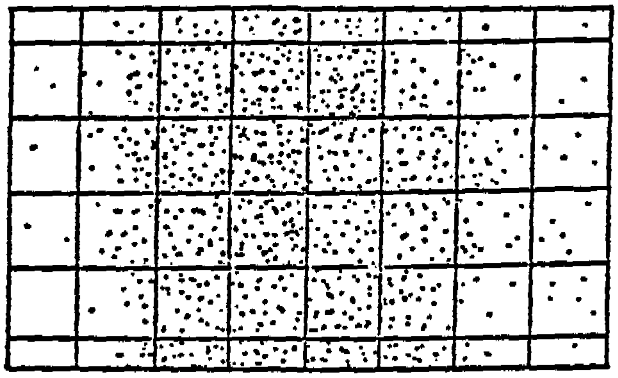

FIGURE 20.—Typical Owens dust record and ruled ocular disk.

Both the impinger and electrical precipitator have been used for the collection of such dusts as lead compounds, zinc compounds, cadmium compounds, etc. Specific methods of analysis are used, depending on the material and the quantity present in the sample. Perhaps a single example will suffice to illustrate the technic involved in the analysis of certain poisonous dusts, namely, the determination of minute amounts of lead collected by the impinger apparatus, using lead-free distilled water as the collecting medium (5) (39). The sam-

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ples thus obtained are analyzed in a central chemical laboratory using lead-free reagents. The method which is extremely important, follows:

Fifty cubic centimeters of 1:1 nitric acid solution are added to the sample and the mixture is evaporated to dryness on a hot plate. Care should be taken to avoid spattering. The residue is digested with 5 cubic centimeters of 1:1 hydrochloric acid solution. The mixture is evaporated to a volume of about 2 cubic centimeters and diluted to 100 cubic centimeters with distilled water. In cases where the original residue is small the dilution at this point is halved. The solution is neutralized with 25 percent sodium hydroxide till just alkaline to methyl orange (use ½ percent aqueous methyl orange, 4 drops) then (1:2) hydrochloric acid till the faintest pink appears. Cool. Precipitate by passing H_2S gas through the solution for 1 hour. Stand over night. Filter on a 12.5 cm Whatman No. 40 filter paper. Wash with freshly prepared H_2S water to which has been added 0.1 percent of its volume of HCl.

Wash the precipitate off the paper, using hot (1:1) HNO_3, into the beaker in which the sulphide precipitation was made. Wash well with hot water. Wash down the sides of the beaker and the inside and outside of the gassing tube, using hot (1:1) HNO_3 followed by hot water. Remove the gassing tube.

Evaporate the solution to a small volume on a hot plate and transfer to a 100 cc beaker. Add 1 cc of H_2SO_4 (specific gravity 1.84) and evaporate to fumes of H_2SO_4. Cool. Take up in 30 cc of a mixture of 10 cc 95 percent ethyl alcohol (C. P.) and 20 cc of water. Stand over night.

Filter on a 7 cm hard filter paper (Munktell No. 1–F). Wash the beaker and the paper thoroughly, using a solution containing 1 cc H_2SO_4 (specific gravity 1.84), 10 cc ethyl alcohol (C. P.) and 20 cc water. Dissolve the precipitate off the paper into a 600 cc beaker, using 10 cc hot 10 percent ammonium acetate, followed by hot water. It is well to wash the beaker first and decant the solution through the filter. Dilute the filtrate to 300 cc, using cold water, add 2 drops HNO_3 (specific gravity 1.42). Neutralize after adding 4 drops of a solution of methyl red in 50 percent alcohol, by adding 25 percent NaOH to alkalinity, then (1:2) HCl to a faint pink color, then 1 cc of (1:2) HCl is added in excess. Cool. Precipitate by passing H_2S gas through the solution for 1 hour. Stand over night.

Filter as before with extreme thoroughness. Dissolve the sulphides from the paper with hot (1:1) HNO_3, catching the solution and washings in the beaker in which the sulphide precipitation was made. Wash the paper thoroughly with hot water, and wash the sides of the beaker and the inside and outside of the gassing tube with hot (1:1) HNO_3 followed by hot water. Remove the gassing tube. Evaporate the solution to a small volume, 1 to 2 cc, and transfer it to a 150 cc beaker. Dilute to 80 cc with cold water. Neutralize, after adding 4 drops of an aqueous solution of phenolphthalein (½ percent in 1 percent NaOH), using 25 percent NaOH free from iron and aluminum. The solution is made alkaline. An excess of 5 drops of 25 percent NaOH is added. Acidify with 5 percent acetic acid till pink color just disappears, and add 2 cc of 5 percent acetic acid in excess.

Bring to a boil and precipitate as chromate by adding 1 cc of a 1 percent K_2CrO_4 solution. Place on a steam bath 1 hour and stand in a warm place at least 60° C. over night. Filter on a Munktell No. 1–F filter paper. Wash beaker carefully with hot water and the paper very thoroughly with hot water to remove all possible traces of soluble chromate. Dissolve the precipitate from the paper, into a 250 cc volumetric flask containing 100 cc water, using 15 cc cold (1:2) HCl, followed by cold water. Wash the beaker and rod and decant through the paper.

In a 250 cc volumetric flask prepare a standard containing sufficient $K_2Cr_2O_7$ solution to be equivalent to 0.30 milligrams of lead, precipitated as $PbCrO_4$. Add 100 cc water and 15 cc cold (1:2) HCl. To each of the samples and the standard add 2 cc of a 1 percent solution of s. diphenyl carbazide in glacial acetic acid. Dilute to 250 cc and mix thoroughly. Estimate the lead in the samples by comparing the intensity of the pink colors, using a colorimeter.

The following tables present some typical results of lead determinations using the impinger apparatus for the collection of the samples and the method just described for the quantification of these samples. It may be observed that the instrument and method of analysis is capable of yielding results, ranging from the minute amounts of lead found in streets to the greater quantities encountered in a lead storage battery plant.

TABLE 10.—*Lead content of air in a storage battery plant*

	Milligrams of lead per 10 cubic meters of air	
	Occupation	Department
Mixing		120
Oxide reclaim (laborers)		150
Pasting		30
Paddler, scraper, take-off	73	
Sweeper and trucker	[illegible]	
Unspecified and other	30	
Put-up, grid, and paste feeder	31	
Inspector	30	
Pickerman	15	
Foreman and clerk	2.3	
Burning		3.7
Unspecified and other	3.7	
Burning inspector	3.8	
Burner, laborer, helper	3.6	
Casting:		
Total (except pitmen)	1.2	1.2
Pitmen	10	
All other departments		2.0
Planté	2.9	
Battery specialty	2.9	
Developing and forming	2.2	
Lead plate	2.3	
Marine and [illegible]	2.0	
[illegible]	1.9	
Primary battery (dry cell)	1.7	
Separators	1.5	

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	Milligrams of lead per 10 cubic meters of air	
	Occupation	Department
		120
		1?0
		20
	[illegible]	
	8.3	8.7
	3.7	
	3.4	
	3.6	
	1.2	1.2
	19	2.0
	[illegible]	

TABLE 11.—*Summary of tests for lead dust in the air of nonlead-using industrial establishments*

Industrial establishment	Workshop	Milligrams of lead in 10 cubic meters of air
[illegible]wear factory	Sewing room	0.25
[illegible]t and overall factory	do	.25
[illegible]chine shop (travel)	Lathe room	.24
[illegible]ery	Bake room	.21
[illegible] factory	Automatic cigar rolling	.18
[illegible]	Calendering room	.17
[illegible] products manufacturing	Fur-trimming room	.15
[illegible]	Mix-bottling room	.11
[illegible] heel factory	Heel turning	.10
Tapestry manufacturing	Tapestry weaving	.10
[illegible] shop (steel)	Lathe room	.10
[illegible]ry cleaning factory	Pressing room	.09
[illegible] bag manufacturing	Sewing room	.08
[illegible] manufacturing	Cutting room	.08
Baking powder factory	Shipping room	.07
[illegible]ery	Mixing and baking room	.07
[illegible]cream plant	Mixing room	.02
Retail grocery	Salesroom	.02
Electric appliance manufacturing	Sheet metal working	.01
Chocolate factory	Mixing chocolate products	.00
Dairy	Pasteurizing room	.00
Waste packing factory	Grading wastepaper	.00
[illegible] manufacturing plant	Curing room	.00
[illegible] factory	Trousers-manufacturing room	.00
Food packing factory	Olive-packing room	.00
Total samples		25
Average		.10

TABLE 12.—*Comparing lead dust in the air of automobile repair shops, streets and nonlead-using industries in 14 cities*

Sampling location	Total samples	Average volume of samples (cubic meters)	Milligrams of lead in 10 cubic meters of air [1]	
			Average	Maximum
Automobile repair shops	25	2.4	0.12	1.11
Nonlead-using industries	25	2.0	.10	.25
Streets [2]	28	2.1	.09	.24

[1] The minimum values were zero for each of the 3 sampling locations.
[2] A sample taken in the country showed .04 milligram of lead in 10 cubic meters of air.

TABLE 13.—*Percentage distribution of samples as to lead content (air of automobile repair shops, streets, and nonlead-using industries in 14 cities)*

Lead in milligrams per 10 cubic meters of air	Percentage			Number		
	Street samples	Automobile repair shop samples	Nonlead-using industries samples	Street samples	Automobile repair shop samples	Nonlead-using industries samples
[illegible]	68	64	36	19	16	11
[illegible]	18	21	28	5	6	7
[illegible]	3	0	12	1	0	3
[illegible]	11	4	4	3	1	1
[illegible]	0	4	0	4	1	0
[illegible] and over	0	4	0	0	[1] 1	0
Total	100	100	100	28	25	25

[1] 1.11 milligrams in 10 cubic meters.

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IV. THE DETERMINATION OF THE CHARACTER AND COMPOSITION OF INDUSTRIAL DUSTS

With reference to fibrosis-producing dusts it has been demonstrated during the past few years that the properties of a dust which determine its capacity to produce pulmonary pathology are the nature of the dust, that is, its mineralogical composition, its particle size, and finally the quantity of dust dispersed in the atmosphere. The instruments and methods used in determining the quantity of dust in the air have already been treated. The present section discusses the other two characteristics of dust which are of importance in industrial hygiene studies.

SIZE OF INDUSTRIAL DUSTS

So far as the size of the dust particles is concerned, it is apparent that in order for any given dust to produce injury to the lungs it must gain access to the parenchyma of the lungs, the site where the harmful effects of the dust take place. It has already been shown that not all of the particles of inhaled dust gain access or are retained by the human lungs. For these reasons it is of some value to determine the size of the dust present in the industrial atmospheres.

It has also been demonstrated in the previous section that particles of a size greater than 10 microns in longest dimension are very seldom found in the lungs. This absence of larger particles has been shown to be partly due to the fact that the number of such particles greater than 10 microns in size present in industrial air is comparatively small when particles in the lower size range are considered. Due to gravity which causes rapid settling of suspensions and due to the protective action of the mucous surfaces of the upper respiratory tract, these larger particles do not penetrate to the terminal portions of the lungs. Hence, it is obvious that attention should only be given to those particles which are less than 10 microns in longest dimension.

Instruments and methods used in determining particle size of dusts

The obvious procedure for the sampling of atmospheric dusts for particle-size studies would be to employ the same instrument utilized in sampling dust for quantification. In the past, however, the Owens jet dust counter has been employed extensively for such investigations, although of late impinger samples have been utilized

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r of atmospheric dusts for
the same instrument uti-
In the past, however, the
oyed extensively for such
samples have been utilized

for this purpose; comparative results between the two instruments will be shown in a later portion of this discussion. The Owens jet dust counter, described in section II, obtains a sample of dust from the air in more or less unaltered condition, since with this device the atmospheric dust is directly projected on a naked cover slip. Moreover, the instrument is small, compact, requires only hand power, and samples are obtained quickly and easily without needing much skill of operation. Once these samples have been obtained and mounted in a manner already described, the dust particles may be measured by the use of a filar ocular micrometer at a magnification of 1,000 diameters (oil immersion objective) (40). The horizontal diameter of at least 200 dust particles in several representative fields are measured for each sample. With this magnification it was found possible to measure particles as small as 0.5 micron in size, while particles smaller than this size are easily distinguished at this magnification and their presence recorded.

Photographic methods have been suggested and used for measuring dust particles, but in order to obtain good photomicrographs it is essential that the dust particles be in one plane, free from Brownian movement, and well dispersed. Since industrial dusts are seldom of a uniform size, it is difficult to fulfill the first requirement. Comparisons have been made between the results obtained with the direct filar measurements and the photographic method on typical industrial dust samples. This comparison demonstrated that the simpler and less expensive filar method yielded practically the same results. Since the filar method fulfills the requirements of this problem it is suggested for use in such studies.

Once a sample has been measured in the manner outlined, the results of such readings may be analyzed in the form shown in the following table. This table presents the size-frequency distribution of various industrial dusts and compares these findings with outdoor dust.

Table 14.—*Size-frequency distribution of various industrial dusts as compared to outdoor dust*

[Average frequency in percent]

Kind of dust	Number of samples	Median	Size group in microns: 0-0.49	0.5-0.99	1-1.49	1.5-1.99	2-2.49	2.5-2.99	3-3.49	3.5-3.99	4-4.49	4.5-4.99	5-5.49	5.5-5.99
Outdoor dust	379	0.5	54.0	41.0	3.5	0.5								
Sandblasting	5	1.4	1.4	19.7	34.7	20.3	12.0	5.2	2.8	1.6	1.1	0.3	0.3	0.3
Granite cutting	4	1.4	2.0	19.0	33.6	24.5	10.4	4.4	3.1	.6	.9	.3	1.0	
Trap-rock milling:														
Crusher house	1	2.4		13.0	33.0	33.0	10.5	2.5	2.0					
Screen house	1	1.3	2.0	31.5	23.0	16.0	15.0	4.5	7.5	.5				
Disc crusher	1	.9	10.0	45.0	31.0	6.0	3.0	4.0	1.0					
Foundry parting compound	5	1.4	.5	22.0	42.0	17.3	9.2	5.0	1.5	2.0	.5			
General foundry air	1	1.2		26.0	45.0	17.0	9.0	3.0						
Talc milling	1	1.5		16.0	32.0	26.0	12.0	7.0	6.0	2.0	2.0	2.0		1.0
Slate milling	1	1.7	1.0	13.0	27.0	17.0	14.0	14.0	6.0	4.0	1.0		1.0	
Marble cutting	1	1.6		17.0	37.0	21.0	10.0	11.0	3.0		1.0	2.0	2.0	1.0
Soapstone	2	2.4	3.2	14.0	19.0	13.0	11.0	6.5	6.5	4.5	3.3	3.3	2.5	11.5
Aluminum dust	1	2.3	3.0	9.0	20.5	11.0	11.5	9.0	6.5	3.0	5.5	4.0	7.0	10.6
Bronze dust	1	1.5	1.0	12.0	31.5	25.0	21.0	8.0	1.5					
Anthracite-coal mining:														
Breaker air	2	1.0	7.0	51.0	26.0	8.0	3.0	3.0	2.0					
Mine air	1	.9	11.0	60.0	17.0	7.0	3.0	1.0	1.0					
Coal drilling	1	1.0	1.0	55.0	34.5	7.5	1.5		.5					
Coal loading	3	.8	11.5	54.3	24.3	5.5	1.5	.7	.2					
Rock drilling	1	1.0	4.0	43.0	23.5	12.5	6.5	1.5	.5	1.5				

An examination of the data in table 14 discloses a striking difference between the size-frequency of outdoor dust and indoor industrial dust. Ninety-seven percent of the outdoor dust particles were found to be of a size less than one micron in diameter, with a median [2] of 0.5. Practically no dust particles larger than 1.5 microns were found to exist in outdoor air. These results on the size-frequency of outdoor dust are similar to those obtained by Owens in London. In contrast with this result it is found that only 3 percent of the industrial dust particles are less than 0.5 micron and but 32 percent less than 1 micron. The average (median) size of these particles was found to

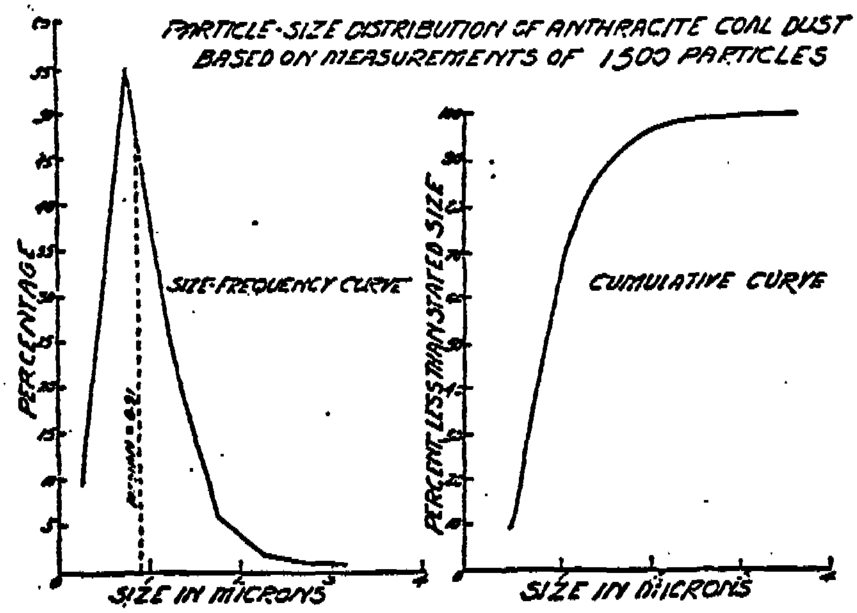

Figure 21.—Particle-size distribution of anthracite-coal dust.

be 1.4 microns. It is evident from the results shown in table 14 that the majority (60 percent) of the dust particles present in the industrial atmospheres investigated was found to be between 1 and 3 microns in average diameter with but 7 percent of the particles exceeding 3 microns.

Figure 21 shows a typical graphic illustration of the size distribution of industrial dusts, plotted from some of the results in table 14. Figures 22 and 23 are photomicrographs of these dusts, indicating visually the size of the dusts encountered in industry.

It may be said that since the impinger apparatus is used to collect samples for dust counting that the samples obtained with this instrument should also be used for particle-size measurements. This would be a just criticism if the two instruments did not collect the significant

[2] The median is the center item in an array and may be strictly defined as a point on the abscissal scale of a frequency distribution with 50 percent of the items on either side.

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sizes of dust particles with the same degree of efficiency. The Owens' samples lend themselves more readily for particle-size measurements than do impinger samples, since the sample in the form obtained is immediately available for microscopic examination, may be readily photographed and moreover collects the dust directly on a cover slip in practically the form it exists in the atmosphere. In order to determine the sizes of particles obtained by the two instruments comparative studies were made on several samples collected with the Owens and Impinger. The Impinger samples were prepared by placing several drops of the dust suspension in the water on a microscope slide, evaporating the water rapidly on an electric hot plate, and covering the smear of dust with a cover slip. The particles were measured under oil immersion with the filar micrometer method. Table 15 presents the comparative measurements and indicates that a very close relationship exists between the size of dust particles collected by the two instruments. For all practical purposes, therefore, the Owens apparatus may be used in collecting dust samples for preticle-size studies.

TABLE 15.—*Comparison between Impinger and Owens dust measurements*

Size group in microns	Owens		Impinger	
	Number	Percent	Percent	Number
0-0.49	42	6.0	6.0	41
0.5-0.99	367	53.3	52.6	373
1-1.49	193	27.6	29.0	203
1.5-1.99	45	6.9	6.0	42
2-2.49	14	2.0	3.7	26
2.5-2.99	10	1.3	1.3	9
3-3.49	6	.9	.4	4
Total	700	100.0	101.0	700

COMPOSITION OF INDUSTRIAL DUSTS

The methods used in determining the composition of certain poisonous dusts, such as lead compounds, have already been discussed in the previous chapter. Concerning the so-called "fibrosis-producing dusts", the work of the past 20 years on the problem of dust inhalation has demonstrated that, in general, the degree of health hazard associated with the inhalation of any dust, all other factors remaining constant, is dependent upon the mineralogical composition of the dust. For example, it is now established that the inhalation of certain types of dust, such as granite dust (2) will in time produce fibrosis of the lungs, frequently associated with tuberculosis. In other cases exposure to dust may result in the production of a far lesser degree of fibrosis without subsequent tuberculosis; this is true of cement dust (41). And finally, there are certain types fficiency. The Owens' particle-size measurements ole in the form obtained i. amination, may be readily dust directly on a cover slip osphere. In order to deter- two instruments compara- s collected with the Owens were prepared by placing the water on a microscope an electric hot plate, and slip. The particles were filar micrometer method. rements and indicates that ne size of dust particles col- ractical purposes, therefore, collecting dust samples for

nd Owens dust measurements

Owens		Impinger	
[illegible]	[illegible]	Percent	Number
[illegible]	6.0	6.0	41
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	6.0	[illegible]
[illegible]	2.0	2.7	[illegible]
[illegible]	1.3	1.3	9
6	.9	.4	4
700	100.0	100.0	700

IAL DUSTS

ie composition of certain s, have already been dis- ing the so-called "fibrosis- 0 years on the problem of in general, the degree of tion of any dust, all other t upon the mineralogical is now established that the as granite dust (2) will in tly associated with tuber- ay result in the production subsequent tuberculosis; lly, there are certain types

FIGURE 23.—PHOTOMICROGRAPH OF ANTHRACITE-COAL AND SILICA DUST, 1,000X.

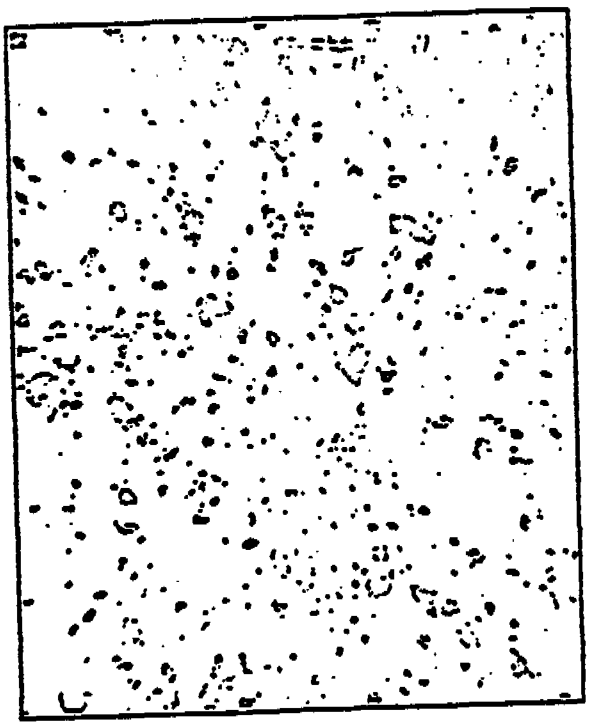

FIGURE 22.—PHOTOMICROGRAPH OF ANTHRACITE-COAL DUST, 1,000X.

NOTE: ...

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of dusts which produce little lung fibrosis, as typified by marble dust (42). In general, it has been found that those dusts which are high in quartz content are the ones which most readily produce a disabling fibrosis of the lungs. Hence, the necessity for knowledge concerning the chemical and mineralogical composition of a dust is obvious.

Concerning the chemical composition of various mineral dusts found in industry the reader is referred to such treatises on this subject as The Analysis of Silicate and Carbonate Rocks, by W. F. Hillebrand (43), and The Commercial Granites of New England, by T. Nelson Dale (44), both of the United States Geological Survey. It has been found, however, that a chemical analysis of a mineral dust will not disclose the various percentages of minerals existing in the dust. For example, a chemical analysis of granite dust will not reveal the percentage of quartz present in the dust, but will only tell the analyst the total silica, combined and uncombined. For this reason there is presented herein a discussion of this very vital subject with reference to one of the important industrial dusts—namely, quartz-containing dusts. Much of the material which follows is taken from an article prepared by Dr. Adolph Knopf, professor of physical geology at Yale University and consultant to the United States Public Health Service (45).

SILICA

Silica is the name given to the chemical compound silicon dioxide (SiO_2). It occurs in nature most commonly in the crystalline form as the mineral quartz. Several other minerals are also composed of silica, for example, tridymite, cristobalite, opal, and chalcedony, but in comparison with quartz they are relatively rare.

A long-established convention has led to the reporting of chemical analyses of rocks and minerals in terms of certain chemical compounds (usually oxides) rather than in terms of chemical elements. During analysis the silicon is isolated in the form of silica, and consequently the chemical analysis of an average granite, for example, is reported as containing 70 percent of silica. About 30 percent, or roughly one-third of this granite, consists of quartz, whereas the other two-thirds of the granite is made up chiefly of minerals that are complex salts of silicon-bearing acids. Such minerals are known as "silicates." The remainder of the silica reported in the chemical analysis of the granite, amounting to 40 percent, is locked up in the silicate minerals, chiefly feldspar and mica.

The distinction between free silica and combined silica

This arbitrary convention of reporting rock and mineral analyses in terms of oxides has necessitated the use of the expressions "free

NOTE:

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