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Dust Control in

by Dust

Members of the

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PRESENTED BY

H. B. Meller

REPORT

of

PREVENTIVE ENGINEERING COMMITTEE

of

AIR HYGIENE FOUNDATION OF AMERICA, INC.

on

MEASUREMENT AND CONTROL OF
INDUSTRIAL DUSTS

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FOREWORD

The following report is an important part of the program that Air Hygiene Foundation elected to carry out in its first year. Bulletin No. 1 of the Legal Series contained the results of a study of the pertinent statutes and court decisions of all States in the United States. The present bulletin on the measurement and control of industrial dusts relates to the preventive engineering aspects of the problems of industrial diseases caused by factory air contaminants. The medical phases will be covered in another bulletin which will be ready for distribution in the very near future.

In submitting this report, the Preventive Engineering Committee has stated its opinion that, because of the very recent publication of the treatise on **Industrial Dust—Hygienic Significance, Measurement, and Control**, by Drinker and Hatch, it seemed unnecessary to repeat information thus readily available. The report is therefore restricted to a thorough discussion of troublesome and controversial topics that confront hygienists and industrialists in the general field of dust control and also an outline of the scientific research that is needed to solve various important problems in this field.

The Preventive Engineering Committee consists of Professor Philip Drinker, Harvard School of Public Health (Chairman); Dr. J. M. DallaValle, U. S. Public Health Service; Mr. Theodore F. Hatch, Division of Industrial Hygiene, Department of Labor, New York, N. Y.; Mr. H. M. Nichols, B. F. Sturtevant Company; Mr. S. C. Vessy, W. W. Sly Manufacturing Company; and Mr. William P. Yant, Director of Research, Mine Safety Appliances Company.

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Managing Director

Thackeray Avenue and O'Hara Street,
Pittsburgh, Pennsylvania,
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no.1-2, pt1-7

MEASUREMENT AND CONTROL OF INDUSTRIAL DUSTS

In the preliminary report by this committee (Annual Meeting, February 11, 1936) an outline was given of the essential steps to be taken in the control of dustiness. We have no intention now of repeating or elaborating upon procedures such as these and with which we feel the members of this Foundation are familiar. Thus, there is no point in urging upon the members such improvements as general housekeeping, changing a process so that dustiness will be rendered unobjectionable, use of protective devices such as dust respirators or air line respirators, and the making of dust surveys.

Instead of supplying such details we refer the reader to a few publications, discussed in this report, and suggest that these publications supply the detailed information which we omit. In the present report we have endeavored to discuss frankly the troublesome and controversial items which are coming up at the present time in the general field of dust control, and to outline future research needed in this field. The committee would be glad to take an active part in pushing forward such research.

The technical literature on dust control is not extensive and is highly specialized. This committee does not definitely indorse or recommend any particular book or pamphlet by anyone, but is glad to list, with comments, such material as its own members find useful in their work. The dates of publications show plainly the youthful age of this branch of engineering.

(1) Harrington, D. and Davenport, S. J.: **Review of Literature on Effects of Breathing Dusts with Special Reference to Silicosis.** U. S. Bureau of Mines, Information Circulars 6835, 6840, 6848, 6857, 6892. This report is 331 pages in length, mimeographed, with a bibliography of 441 references. It is understood that it is to be published presently in book form and that it will then have both a name and a subject index. Chapter 4 (I. C. 6840 and 6848) is devoted to "Prevention of Dust Diseases." The first part of this chapter deals with the pathology and with methods of dust determination, while the latter part contains data on the engineering and medical control of dust diseases.

Very little of this review, except that in Harrington's own

specialty of safety in mining and mine ventilation, is critical. There are no design data at all. At the present writing, (September, 1936) the series is in great demand and is hard to obtain.

(2) Bloomfield, J. J. and DallaValle, J. M.: **The Determination and Control of Industrial Dust.** U. S. Public Health Service Bulletin No. 217, April, 1935. Price 15 cents. This bulletin is 165 pages in length, has a bibliography of 73 references (in which page numbers are omitted) and has no index. The table of contents is complete and the illustrations and tables are good.

The methods used by the Public Health Service in making dust surveys, the analyses of dust samples, their interpretation, and the use and appraisal of protective equipment are very well treated. The chapters on design of exhaust hoods and of local exhaust systems are probably the first that have appeared in book form. The chapter on the measurement of air flow is very good.

(3) Drinker, P. and Hatch, T.: **Industrial Dust. Hygienic Significance, Measurement, and Control.** Price $4.00. McGraw-Hill Book Company, New York, 1936, 316 pages with indices and alphabetically arranged bibliography of 260 references. This book is just out and includes chapters on physical properties of dusts, fumes and mists; effects of dusts and fumes upon man; physical and chemical factors in pneumoconiosis; permissible dustiness; the dust survey; dust determination; determination of particle size; chemical and mineralogical analyses; control of the dust hazard; design of local exhaust systems; air-cleaning apparatus; dust respirators and masks.

(4) **The Guide of the American Society of Heating and Ventilating Engineers.** Published by the Society, New York. Price $5.00. This is an annual which is constantly being revised and contains excellent advertising information as well as good chapters on various specialties in the general field of ventilating and heating. Until recently this society in common with others, such as the American Society of Mechanical Engineers, had not paid much attention to dust collection and had been far more interested in cleaning air entering buildings or in preventing the pollution of out-door air by smoke and fly-ash. Consequently, the data in the Guide are mostly on fans, friction in pipes, and the like, but such data are good.

(5) Harding L. A. and Willard, A. C.: **The Mechanical Equipment of Buildings.** Vol. 1. John Wiley & Sons. Price $6.00. This is much the best book on the subject but its usefulness in the field of dust control is more or less limited to the few

pages devoted to air flow in pipes, pressure losses through orifices, hoods, etc.

(6) American Blower Company, Detroit. **Air Conditioning Engineering, 1935.** Price $5.00. An excellent book published and sold by the above company. Considerable space is devoted to fans, blowers, pipe losses and the like.

(7) American Standards Association. Report Z9, January 28, 1936. 22 pages with short bibliography on **Fundamentals Relating to the Design of Exhaust Systems** by a committee of which Theodore Hatch is chairman. Everything in this report is of direct use to the man designing and operating dust exhaust systems. The design data, questions, rules, and practical suggestions are authoritative and can be applied with entire confidence.

There are various other pertinent codes sponsored by the American Standards Association, while studies now are in progress on exhaust hoods for grinders. A new code on this latter item would be a very welcome one and would give much-needed information.

(8) Approved Dust Respirators: One can obtain from the U. S. Bureau of Mines a list of protective devices of all sorts which have their approval. Such approval signifies that the equipment has met certain exacting specifications which the Bureau sets. Copies of the Bureau's test methods also are furnished on demand.

(9) Manufacturers: Obvious practical sources of information are firms specializing in the manufacture of any equipment used in this general field. Such firms include the makers of fans and blowers, cyclone separators, dust arrestors of all sorts and a rather small list of firms and individuals engaged in consulting practice in this particular field. The Office of Air Hygiene Foundation will always be glad to advise members as to these sources of information.

The Consultant vs. the Company's Engineers

There is a prevalent idea that dust control and appraisal of equipment for dust control must be carried out with the aid of outside consultants. Granting that a firm applying dust control for the first time is dealing with new matters, there is no excuse for not adding at once such equipment to the general production machinery and putting it under the direct responsibility of the company's engineers. We cannot emphasize too strongly that dust control is primarily a maintenance job rather than one of designing a new plant. Dust control should be made routine procedure as soon as possible.

The consultant brought in for some particular job has the advantage of bringing a fresh point of view and is presumably

an expert in his specialty. But he lacks and always will lack the production man's point of view. He cannot stay more or less *indefinitely on the job*, design and test each hood, and live with the problem as it may well demand. Large firms will gain by using the consultant on dust problems as a source of information and possibly as an appraiser of their own dust control work, having in mind the possible legal ramifications. Small firms may find it pays to let such a consultant, who lives nearby, have direct charge of the control and be held responsible for making frequent inspections just as larger firms use their own engineers.

Dust control equipment is usually written off at a depreciation rate of about 20% annually. The engineer, who is on the job, can keep well below this figure, but the purchaser who installs such equipment and neglects it will find his depreciation figures much higher. Whether or not the consultant can earn his fee by keeping down these depreciation losses or by his usefulness in the event of lawsuits will depend upon local conditions.

Several states now have on their staffs men specially trained in industrial hygiene problems. The bureaus to which these men are attached are glad to assist any firm in evaluating its health hazards. The list of states having such specialists is expanding rapidly.

Methods of Determining Dust

This committee does not feel that any useful purpose will be served by reviewing or describing the technic of making dust surveys and dust determinations. The required information is available in references 2 and 3. This report will be confined to asking and attempting to answer questions which experience has shown are troublesome.

If a dust can be determined by a simple chemical procedure, as in the case of lead, the concentrations in air are recorded gravimetrically as milligrams per cubic meter. But in the case of silica, results are given by count because it is easier to count the particles than to determine them chemically. The count method usually does not distinguish the substance particularly desired from the extraneous matter—that is, in a foundry dust one counts all the particles seen in the microscope, but makes no attempt to distinguish silica from coal, iron, or clay. The error thus introduced may be great, but is reduced by stating that the coarse dust and the 5 micron dust from which the fines come contains such and such a percentage of free silica, usually as quartz.

There is no doubt in the minds of anyone who is familiar

with present dust-sampling and dust-estimating methods that they will be amended and changed from time to time. At the present writing, we would advise the use of the simplest possible procedure where dust control alone is question. If one wishes to obtain values which can be compared with published data it is generally necessary to copy with considerable care the technic used in the original case. This is another way of admitting the annoying fact that results by one method are usually not comparable to those obtained by another method.

It is very doubtful if any useful purpose is served by determining accurately extremely dense dust concentrations—the only excuse for such data is to show the skeptic that the workplace is much dustier than it should be. In South Africa, Dr. Mavrogordato, a man with abundant experience, dismisses these dense dust samples with the laconic symbols T. M. C. (too many to count).

Copying the Public Health Service's technic for the sake of the alleged legal prestige it may have can easily be carried to absurd extremes. We know of an instance in which a very competent engineer, quite against his inclinations, needed a gasoline motor-driven generator and an electric pump mounted on a mine car hauled by a tractor, with three men in attendance, in order to get 4 impinger samples in one day.

It is probable that any sampling procedure which fixes concentrations in groups 100% apart is sufficient and that the results of any attempt to come closer to the concentration at the moment of sampling are simply misleading. Thus ranges such as 0-5, 5-10, 10-20, 20-40, etc., suffice for dust control.

Another well worn argument is that of sampling for silica dustiness by count as against weight. Obviously a few 10 micron particles will vastly outweigh many times as many 1 micron particles. But if one achieves a degree of air cleanliness which is satisfactory on a gravimetric basis, it will be even more satisfactory on a dust count basis. If dusts were uniform in size and composition it would be possible to convert dust counts to milligrams per cubic meter with accuracy. But the particles are never uniform in size and rarely in composition. The U. S. Bureau of Mines in its work in testing dust respirators has been sampling dustiness gravimetrically and finds that one milligram of a dust that has a geometric mean of 0.6 micron and a standard geometric deviation of 1.90 is equivalent to about 30 million particles which would be the equivalent counted by light field illumination. In these determinations the samples for particle size were collected by the Owens jet dust counter and measured by the Bureau of Mines microprojection technic.

It should be remembered that dust determinations have been taken and recorded routinely in South Africa for some 20-odd years and the figures are given, generally, by weight and not by count. There are no comparable data from anywhere else in the industrial world. It is unwise, therefore, to dismiss gravimetric records as being inadequate when the best data we have were obtained with their help.

Routine gravimetric or chemical analyses of dust requires no special equipment, as all the apparatus is at hand, and the chemist needs no special practice or training. He can take the samples by the impinger instrument if he wishes. On the other hand dust counts, at least by the light field method, require some experience and a good deal of care that conditions are just as they should be. Otherwise, very great errors can be made. We have many examples of large errors through inexperience in the counting technic but such errors are unlikely when the dust collected is determined by gravimetric methods.

Analysis of Dust.—It is difficult to analyze a mixed dust by microscopic methods unless the various constituents have special properties. The trouble is simply that the particles are too small to make possible the use of the accepted technics of petrographic analysis. This difficulty is well known and there has been developed a definite scheme for making such dust analyses, which method is really a combination of analytical chemistry and petrography. It is discussed in considerable detail in references 2 and 3.

A comparatively new analytical development is the quantitative analysis of mine dusts by x-ray diffraction, a technic described by G. L. Clark in Industrial & Engineering Chemistry, Vol. 8 page 36, 1936. See also Applied X-Rays by Clark, McGraw-Hill Book Co., 1932.

Dusts which are to be analyzed are collected, ordinarily, from rafters or other convenient places on which dust has been allowed to settle for some little time. Obviously the procedure is very convenient, but it has been shown that a larger error can be made by assuming that such settled material has the same composition as dust samples by the usual impinger method. The trouble is that mixed dusts contain at least two kinds of particles of which the specific gravity, hardness, and shape may be quite different. Let us assume a hypothetical case. If a piece of rock is made up of quartz grains held together by a clay-like substance and this rock is shattered by a rock drill or by blasting, the finest dust and the dust which remains in the air longest will be clay and not quartz. Another

common example can be seen in almost any foundry. The so-called sand used may contain as much as 50% quartz, but the dust in the air floating about the foundry may show much less quartz.

In order that errors may be avoided in analyzing air floated dusts, the samples had best be drawn from the air and then divided up into sized fractions such as 5-10 microns, 2-5 microns, 1-2 microns, etc. It is not hard to make these fractions if one has a sample of 50-100 grams, but it is almost impossible to make them on samples of a few milligrams such as one usually obtains by impinger. Obviously it is inconsistent to draw samples for dust counts from the air and then to take samples of analysis from rafters with entire disregard of particle size.

We know of occasions, however, when analyses of rafter dusts gave important information which would not have been obtained otherwise. Thus, in a certain plant it was possible to account for lead poisoning among the workmen because of lead in rafter dust although the usual impinger samples gave no lead—the process had been changed and there was no longer lead in the air.

A procedure such as this sizing followed by chemical analysis is slow. There is not the slightest occasion to make such analyses frequently, and we would not recommend them at all for control work. They may be useful in connection with the initial survey of some particular process.

The Size of Dust Particles

A great deal has been made of the fact that dust particles in autopsied lungs are of the order of 1 micron—about like the common bacteria. It is argued, therefore, that the human anatomy and physiology exercise some phenomenally accurate size grading which excludes larger particles. There is no reason whatever to look for any such mysterious explanation. The sizing is done in the air before the dust is breathed and not by man after it has been breathed.

It is unlikely that large particles (100-200 microns or 0.1-0.2 milligram) will penetrate into the minute air sacs (alveoli) of the lungs, but they can get there and have often been seen and measured at autopsy. An alveolus is plenty large enough to accommodate such large particles. But the rate of settlement in ordinary air of such dust particles is relatively rapid and they are not apt to be inhaled at all. If they are inhaled, they are likely to bump into the moist walls of the nose, the throat, or lower respiratory passages. Common sense shows that particles which have sufficient mass to acquire appreciable momentum on being moved are likely to be captured as they

turn various corners on the way to the lungs. Only those small enough to act as part of the transporting air stream are likely ever to reach the lungs.

In diseases such as silicosis and asbestosis, particles must reach the alveoli or no silicosis or asbestosis results. In maladies like hay fever, the harm is done by particles which may be 15-30 microns instead of 1 micron. It is not necessary for the hay fever-producing pollen grains to reach the lungs—they may very well be caught in the nose and initiate their harm there. Furthermore, it only requires a few grains to bother the sensitive individual. Fortunately, most of us are not sensitive to pollen but it is not at all uncommon to find workmen who are unfavorably affected by exposure to various organic *dusts such as wood flour and pollen.*

Toxic dusts such as lead and manganese are much more likely to produce ill effects if breathed than if swallowed. The reason for this difference is physiological and not physical, but it is established and should not be ignored in dust control problems. Again, common sense tells us that the fine particles of lead are vastly more apt to be breathed than the larger. Furthermore, elementary chemistry tells us that finely divided materials are more active than coarse. Such processes as solution are always more rapid with the fine than with the coarse substances.

It follows then that dust control for hygienic reasons should be aimed at the fine rather than the coarse particles. Continuing this argument to its logical conclusion, if one could avoid use of the 1 micron dusts or less, or exclude them from the dust which passes a 325-mesh screen, nearly all dust diseases would be eliminated. This is not at all an academic idea, for de-dusting processes are not new and are being applied in many industries. If some of the mechanical ingenuity which is now being applied unthinkingly to creating 1 micron dust were diverted to ways for avoiding it, probably it would be discovered that dusts which are too large to be breathed would serve many processes just as well as those which are around 1 micron in size.

Finally, if one admits that the tiny particles are those to be controlled, one then faces the fact that the problem is to direct air currents carrying dust particles through appropriate hoods and thence to the device which removes the dust particles from the transporting air stream.

Dust Collection

The dust collecting plant consists of four essential parts: (a) the exhaust hoods, (b) the piping, (c) the dust arrestor, and

(d) the fan or blower. Local conditions must govern the choice of each item such as the volumes of air to be handled, the precise design of the hoods, the kind of dust arrestor to be used and the kind of fan.

It is possible very often for a firm buying new equipment known to produce or to disseminate dust to demand that it be equipped with an exhaust hood and thus to avoid the troublesome job of putting a hood on a piece of apparatus not intended to be hooded. This precaution can be applied to practically all machinery which crushes rock, to bagging and packaging machinery of many types, to grinding and abrasive wheels, to many kinds of mixing machines, to most woodworking tools, and the like. It would be hard to give a complete list, but the object in view is to make the firm selling the dust producing machinery at least partly responsible for any damage which the machinery causes when used as intended. For instance, it does a respectable firm no good to have one of its tools known to the trade as a "widow maker", yet many firms seem to feel that responsibility for the apparatus ends when the sales guarantee is met and the account closed.

If dust collecting is to be installed in any plant, it usually is well worth while studying each process with the help of experimental hoods and a portable blower. The object is to enable the engineer to build each hood in the best manner possible and especially to use the minimum amount of air needed. The blower may have sufficient capacity to serve the full sized hood or a small blower and a small test hood may suffice. In such work it is not necessary to capture the dust, and the dusty air can be exhausted in any direction which will not interfere with the test. A series of such studies gives the engineer the data that he needs for his final design work, and permits him to select with confidence his piping, dust arrestors, and fans.

If a firm specializing in any of this equipment is asked to do the design work, such a firm must draw from the knowledge gained by its own practical experience in similar problems or else do this same test work. In general, it is to the interest of the purchaser to do his own testing, and that is the best way possible for the purchaser to train his own men to care for the equipment later.

We list herewith the comparatively meagre information which is available for scientific design of hoods. Lacking such data, hoods are constructed by trial or as the result of practical experience. By such rule of thumb procedure it is impossible to achieve the economy or precision one ordinarily expects in engineering.

Minimum Air Velocities Required to Capture Certain Industrial Dusts

Industry	Process	Required air velocity		Criterion
		At point of origin	At face of hood	
Granite cutting	Hand pneumatic tool	220 FPM		Reduced concentration to safe level.
	Surfacing machine	1500 FPM		Reduced concentration to safe level.
	All tools		1500 FPM	Reduced concentration to safe level.
Grain elevators	Elevator boot & head garner		500 FPM	Visual test.
Paint Spraying	Spraying booth		50-200 FPM	Reduced concentration to safe level.
Sand pulverizing	Bagging machine	400 FPM		Reduced concentration to safe level.
Electric welding		100-200 FPM		Visual test.
Quarrying and mining	Horizontal drilling with Kelly-Hatch trap	60*		Reduced concentration to safe level.
	Vertical drilling with Kelly-Hatch trap	200*		Reduced concentration to safe level.
Electric plating	Chromium plating	50**	1500 FPM	Reduced concentration to safe level.
	Steam to acid tanks	75-100 FPM		Reduced concentration to safe level.
Hatters' Fur	Brushing	200*		Usual Practice.
	Cutting machines	380*		Usual Practice.
	Blowers	2000*		Usual Practice.

*Cubic feet per min.
**Cubic feet per min. per foot of slot (common practice).

Recommendations as to hood design, requisition velocities, and the like, can now be obtained from the appropriate departments of many states, some of which embody these recommendations in codes.

Protective Equipment

The information available on this subject is very complete, largely because industry has demanded and received from the U. S. Bureau of Mines, the Bureau of Standards, and the American Standards Association, a series of specifications which must be met if the equipment is to be approved. The result has been the development of two classes of equipment, one which passes rigorous specifications and the other which competes with the approved equipment but is not claimed to pass. Often the less effective equipment is good enough and both kinds are being used today.

We refer, of course, to dust respirators, air supplied masks, sand blast helmets, goggles, gloves, boots, shoes, and the like. Not all the equipment is covered by these specifications, but enough is so that industry can see their advantage.

The role of protective equipment in industry is perfectly definite, although sometimes misunderstood and abused. In general, better results are obtained by controlling pollution or dustiness at its source than by equipping men with safeguards which they must wear or through which they must breathe. The use of such equipment should be the second step and not the first in the dust control project. But protective equipment always will have a place in industry.

We do not believe that much will be gained by having this Foundation sponsor research in the field of protective equipment. Competition between firms engaged in its manufacture, with the friendly interest of the Bureau of Mines in the results of this competition, insures progress and continued improvement in these goods.

Permissible Dustiness

Under one name or another this subject comes up whenever dust control is considered. If the breathing of dust causes disability of any sort—silicosis is only one manifestation—then it follows that there must be some degree of air cleanliness from which no disability will result to the average man during the average working period. The super-cautious person may claim that the permissible concentrations, commonly called thresholds, are not precise and generally have not been established. This is perfectly true, but emphasizing instead of answering the question, is merely passing the responsibility along to the engineer. Such an attitude is childish and indefensible.

In the conditioning of air for buildings or for railroad cars one demands and gets clean air. Often dustiness is reduced from 2 or 3 to less than 0.5 milligram per cubic meter, otherwise the occupants complain and the engineer is held responsible. There

is no hygienic reason whatever for exacting such extreme cleanliness; nevertheless, it has become customary to have it and the custom is favored by all and hence is likely to remain.

The South African figure for permissible dustiness in gold mining is 1 milligram per cubic meter. It is the result of engineering expediency rather than of medical requirement. That is, it was established or set up as an objective considerably before it was known what the desired figure was. We have ample precedent for doing the same thing in the United States. If one waits for figures of permissible dustiness which are medically sound, he probably will be disappointed.

Dr. A. J. Lanza, when in the U. S. Public Health Service in 1917, set a figure for the Joplin, Missouri, mining district of 1 milligram per 100 liters of air—not because he thought or claimed that such a concentration was safe, but because he and his colleagues found it attainable if good engineering practice were enforced. In the recent study in the anthracite district of Pennsylvania made by the U. S. Public Health Service, it was found that 50 million particles per cubic foot with 5% quartz in the coarse dust and 10 million with 35% quartz were apparently satisfactory hygienically and often were attained.

The figure of 10-20 million particles per cubic foot for granite dust derived from coarse material of 35% quartz content has often been quoted from the Vermont granite studies made by the Public Health Service. Some progressive metal-mining companies have set the maximum permissible dustiness at 5 million particles per cubic foot which is probably even more severe than the South African figure of 1 milligram per cubic meter. Thus we have 50 million particles with 5% and 5 million with pure quartz.

The absurdity of splitting hairs in order to achieve precisely the degree of cleanliness which fits medical knowledge is accentuated when the engineer begins his design work. He does not base his calculations on dust counts, but on the volumes of air to be handled, together with the best data he can get on the gross dust loading—cubic feet or thousands of cubic feet per hour and pounds of dust per day. If left to his own devices he will do his best to achieve a dust concentration substantially lower than any medical knowledge warrants. Why, then, wait for the mythical thresholds before installing the equipment?

We have neglected the processes in which dustiness is heavy but the dust of no proven harm. There are many such examples. For instance, pure gypsum, limestone, and dolomite are recommended by both the United States and British governments for the dusting of bituminous coal mines in order to re-

duce the explosion hazard. The reason these dusts are used is solely because they have been found to be relatively harmless if breathed. Other dusts, like quartz, might be just as satisfactory so far as reducing the explosion hazard is concerned. Following this line of reasoning to its obvious conclusion, one might presume that the plant having heavy concentrations of substantially pure gypsum needed no dust control. However, the Bureau of Mines recommends that persons applying rock dust in coal mines be supplied with respirators regardless of the kind of dust.

There is no satisfactory medical answer at present to this question, but the engineer is making a bad mistake if he lets men breathe heavy dust concentrations of any material. If no reason for dust control can be found, then one should read transcripts of some of the recent suits at common law in which fantastic damages for alleged silicosis were granted to men who breathed dust containing little or no silica. The defendant in such suits is always embarrassed to explain away heavy dust concentrations, while the proof of a clean workplace makes an excellent impression upon everyone. Incidentally, the clean place induces better work by all.

The engineer must remember that it is he and not the physician who must answer that dreadful question: "Was this place being operated according to the best modern practice?" The courts and the compensation boards are not impressed with subtle distinctions between dusts with 10% and 40% quartz, especially when the medical experts are reluctant to make definite statements as to the comparative significance of such differences.

It would be as well to realize that men working in dusty trades suffer far more from respiratory troubles of all kinds than do men who work in clean air. The evidence that excessive dustiness of any kind is harmful is beyond argument. In our opinion this Foundation would be making a grave mistake if it wastes time on futile attempts to refute this fact. The evidence is overwhelming and would be admitted by any disinterested person.

Investigations Needed

The handicap in this general field lies chiefly in the lack of fundamental data. The demand for dust control installations is bound to help clear up this situation, but this Foundation would contribute greatly to present needs if it would sponsor research along a few definite lines.

For example, we have design data for exhaust hoods on very

few processes. It would not be difficult to obtain very complete data on hood design for all of the various dust-producing processes involved in the crushing, grinding, powdering, and general handling of rock. Such studies make admirable thesis subjects for graduate students in engineering and can be carried out with the cooperation of firms who supply or use the machinery in question.

There are some fundamental data on solubility and toxicology of various dusts which can be obtained by careful work in the laboratory. There are a number of institutions well equipped to study such problems. At the risk of duplicating the recommendations of the Medical Committee of this Foundation, we suggest that the Foundation establish without delay a central agency for studying routinely and continuously the comparative toxicity or harmfulness of different dusts.

As was shown in the table, page 10, we have design data for exhaust hoods for only a few processes. It would be entirely practicable to study all of the important processes which create dust such as crushing, grinding, and general handling of rock and rock products. A very important source of dustiness in all plants handling finely powdered materials is the so-called transfer points in conveying systems of any kind. Thus, when one belt conveyor dumps crushed rock on to another or into a hopper, an exhaust hood is usually indicated but one looks in vain for fundamental data from which to design such a hood.

A very important source of dustiness is in the packaging of powdered materials. If one suggests to a plant manager that his process of putting fine material into cans or bags is too dusty he often answers that any suction device would carry off most of the powder but this is far from true. Again we have no fundamental data for designing exhausts for such systems yet no one could dispute the fact that packaging processes cause a great deal of dustiness.

There are no reliable data to indicate the difference in dustiness from blasting with and without dust control during the rock drilling. It seems to be the general opinion that dustiness from blasting is a necessary evil and the fact that such dustiness can be reduced greatly by preventing the accumulation of either wet or dry dust upon the rock is ignored. It would not be at all difficult to obtain figures which would be of use to any firm mining rock of any kind.

We have no data on the abrasive effects of transporting dust pneumatically. The problem is important in the design and maintenance of dust-collecting plants. It happens to be a problem which lends itself nicely to solution by research.

It is possible that a study of the dustiness created by drilling in different kinds of rock would be useful. Again that is a problem admirably suited to research.

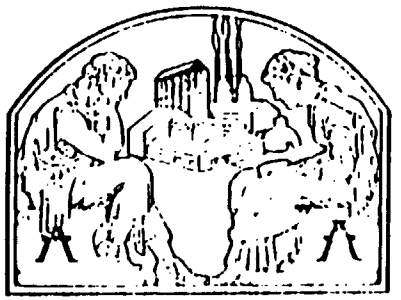
It is to be hoped that the results of any such research will be published in appropriate technical journals and thus made available to all. If the data are paid for by the Foundation but kept exclusively for its members, the impression which results will not be good.

We should consider the outlook of this Foundation poor indeed if it considers its objectives begin and end with silicosis. At the moment silicosis looms large in the public eye, but that is not a phase which is likely to last. On the other hand, the name of this organization implies that it has a broad outlook upon the hygienic problems arising from air pollution of all kinds. Such problems will always be present.

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Preventive Engineering Series, Bulletin No. 2, Part 1



The Determination of Benzol Vapor in the Atmosphere

PITTSBURGH, PENNSYLVANIA
JANUARY, 1938

"Our Committee proposes to issue a series of bulletins on such subjects as the following: Dust control in rock drilling; design and operation of paint-spray booths; design and installation of local exhaust hoods; routine dust sampling and control; design and care of dust arrestors; design of duct work for exhaust systems; bench marks in control of dusts and fumes; use and care of protective equipment; determination of gases, specifically benzol, chlorinated hydrocarbons, and probably an acid gas, such as sulphur dioxide; probably two bulletins on the identification of dusts, that is, combined microscopy and chemistry."

—Extract from report of Preventive Engineering Committee at Special Meeting of Members, November 30, 1937.

THE DETERMINATION OF BENZOL VAPOR IN THE ATMOSPHERE*

The air containing benzol vapor is passed slowly through nitrating acid which reacts with the benzol to form dinitrobenzene. This is determined by a volumetric or colorimetric method.

Taking of Sample

Apparatus required.

Absorber with flowmeter (see Figure 1).
Blower with one hole stopper to fit suction inlet.
Fifteen feet of 3/8" rubber tubing.
5 cc. pipette.
Wash bottle.

Reagents required.

Soda lime.
Nitrating acid (1 part fuming nitric acid; 1 part conc. sulfuric acid).
Distilled water.

Procedure.

Five cc. of nitrating acid are pipetted into the absorber A which must be dry. The pinchcock P is closed and the blower started. P is then opened gradually until the flowmeter reading indicates a flow of ¼ liter per minute. (The flowmeter orifice should be of such a size that the manometer reading is between 2" and 5" of water at that flow.) The sampling period should ordinarily continue for 30 minutes, but if necessary can be reduced to as low as 10 minutes. Shorter samples are not satisfactory except when very high concentrations of benzol vapor are present.

The contents of the absorber are poured through the side arm into a 30 cc. glass stoppered bottle and the absorber is rinsed out three times with about 5 cc. of distilled water. The absorber must be dried before being used again. It is usually advantageous to have two or three extra absorbers to use while the others are being dried out.

The samples will keep for several weeks.

Analysis of Samples

(1) Volumetric method

This method is preferable except when there are twelve or more samples to be done at once, or when it is desired to dis-

* This is part 1 of a series issued as Bulletin No. 2, under the auspices of the Preventive Engineering Committee. Part 2 will deal with the use and care of respirators.

tinguish benzol from toluol vapor which is present. Toluol, xylol, etc., interfere.

Special apparatus required.

One 50 cc. burette with glass stopcock and sidearm with glass stopcock.
Two Kipp gas generators (500 or 1000 cc.).
Special distilling flask (see Figure 3).
One micro gas burner.

Reagents required.

Sodium sulfate (anhydrous).
Calcium carbonate and hydrochloric acid (for CO_2 generator).
Zinc and hydrochloric acid (for hydrogen generator).
40% sodium hydroxide solution.
1% suspension of phenolphthalein in water.
Standard solution of m-dinitrobenzene. (1.088 gm. of pure m-dinitrobenzene dissolved in conc. sulfuric acid made up to exactly 500 cc. This contains the equivalent of 1 mg. benzol per cc.)
Standard solution (about 0.12 N) of titanium trichloride. (100 cc. of 20% $TiCl_3$ solution and 100 cc. of 12 N hydrochloric acid diluted to one liter with freshly boiled distilled water.)
This solution is mixed in a 1200 cc. bottle and the oxygen is immediately driven out by bubbling hydrogen through for several minutes. The bottle is then connected by a syphon to the side arm burette and the whole protected from the atmosphere by keeping it under a slight pressure of hydrogen (Figure 2).
Standard solution of ferric ammonium sulfate. (50 gm. of ferric alum $Fe(NH_4)(SO_4)_2 \cdot 12H_2O$ and 50 cc. of 6 N sulfuric acid diluted to one liter with distilled water.)
Potassium sulfocyanate solution (10 gm. KCNS in 100 cc. water).
Solid sodium bicarbonate.
Concentrated sulfuric acid.

Distillation of Dinitrobenzene

The unknown sample is placed in a bath of ice water and a few drops of phenolphthalein suspension added. Then 40% NaOH is run in slowly from a burette until the mixture just turns pink. The slightly alkaline solution is transferred to the distilling flask, 20 gm. of sodium sulfate are added, and

the mixture diluted to 150 cc. The distilling flask E is connected to the condenser and to the flask D (Figure 3) and heated over a micro burner. Steam is introduced by boiling the water in flask D, at such a rate that the volume of liquid in E does not change appreciably. Continue the distillation for one-half hour to one hour, when 100 cc. of distillate should have come over. This distillate is analyzed with titanium trichloride according to the directions given below.

Standardization of Titanium Trichloride

To 100 cc. of distilled water add 10 cc. of conc. sulfuric acid. Insert a 2-hole rubber stopper with a 2-inch length of glass tubing in one hole connected by two feet of rubber tubing to the carbon dioxide gas generator. Remove the stopper, add with a spatula about 1 gm. sodium bicarbonate, replace the rubber stopper, open the stopcock on the gas generator, then plug up the second opening in the rubber stopper with a cork or piece of glass rod. Place the flask in a hot water bath (90-100° C.) and leave it there, still connected to the gas generator, for five minutes. Then remove the flask, take the plug from the stopper, close the gas generator stopcock, and quickly run 10 cc. of titanium trichloride solution into the flask. Immediately replace the stopper, add sodium bicarbonate as before, connect to the gas generator and heat again in the hot water bath for 10 minutes. Remove the flask, shut off the CO_2 stopcock and add about ½ cc. of KCNS solution, then place the flask under the ferric alum burette, the tip of which projects through another 2-hole rubber stopper. Run in ferric alum until the pink color of the titanium trichloride disappears and is replaced by a faint yellow tinge of $Fe(CNS)_3$.

Divide the volume of ferric alum required by that of titanium trichloride used to obtain the ratio conc. Ti^{+++} / conc. Fe^{+++}.

To obtain the actual strength of the ferric alum, repeat the above process, starting with 5 cc. of the standard dinitrobenzene solution in 100 cc. of water, and add 15 cc. of titanium trichloride instead of 10 cc.

Analysis of Unknown

The unknown is determined in the same way, using the distillate obtained as described above.

The benzol vapor concentration is obtained in mg. per liter of air by dividing the number of mg. of benzol found by the volume of air sampled. This is converted to parts per mil-

lion by volume by multiplying by the factor $24.5 / 78 \times 10^3 = 314$, if the samples were taken at room temperature (20-30°C.).

Sample Calculation

Sample	I $TiCl_3$ Solution Added	II Ferric Alum Needed	Ratio cc. II/cc. I	Avg.
Water (1).....	10.00 cc.	11.25 cc.	1.125	
Water (2).....	10.23 cc.	11.51 cc.	1.123	1.124

5 cc. Dinitrobenzene sol = 5 mg. benzol		(a) Needed	(b) Calc.	(b)—(a)	
	(1)	15.00 cc.	11.24 cc.	16.88 cc.	5.64 cc.	
	(2)	14.61 cc.	11.11 cc.	16.77 cc.	5.66 cc.	5.65 cc.

5.00 / 5.65 = 0.885 mg. benzene / cc. ferric alum

Unknown sample	I $TiCl_3$ Soln.	II Ferric Alum (a) Needed	(b) Calc.	(b)—(a)	C_6H_6 Found
No. 1, 7.5 liters air.....	15.00 cc.	14.96 cc.	16.88 cc.	1.92 (x .885)	= 1.70 mg.
No. 2, 6 liters air.....	15.00 cc.	11.25 cc.	16.88 cc.	5.63 (x .885)	= 4.98 mg.

Conc. Benzol Vapor Found

			Mg. per liter		Parts per million parts air
Sample (1)	1.70 / 7.5	=	0.227 (x 314)	=	71
Sample (2)	4.98 / 6.0	=	0.830 (x 314)	=	260

Chemical Reactions Involved

(1) Absorption

$$C_6H_6 + 2HNO_3 = C_6H_4(NO_2)_2 + 2H_2O$$

(2) Reaction with $TiCl_3$

$$C_6H_4(NO_2)_2 + 12TiCl_3 + 12HCl = C_6H_4(NH_2)_2 + 12TiCl_4 + 4H_2O$$

(3) Titration

$$TiCl_3 + FeCl_3 = TiCl_4 + FeCl_2$$

(4) End point

$$FeCl_2 + 3KCNS = Fe(CNS)_3 \text{ (red)} + 3KCl$$

(2) *Colorimetric method*

Special apparatus required.

1 cc. pipette calibrated in 0.1 cc.

Nessler tubes.

Reagents required.

Methyl ethyl ketone (butanone).

The absorber is rinsed with 5 cc. of nitrating acid instead of distilled water. Enough more nitrating acid should be added to make the volume of the sample 10 cc. 0.10 cc. of this is taken and added to just 1.90 cc. of nitrating acid, and 5.0 cc. of water. 40% NaOH is run in slowly (cold) until the mixture is just alkaline to litmus, and one drop in excess is added. The flask is then put in a water bath at 25-30° C. and 10 cc. of butanone (methyl ethyl ketone) are added, and the mixture shaken occasionally for 10 minutes, care being taken that the temperature does not fall below 25° C. The mixture

is transferred to a 50 cc. separatory funnel and the aqueous layer drained off. The butanone layer is transferred to a 50 cc. Nessler tube and exactly 1.5 cc. of 40% NaOH added. The tube is shaken every 10 minutes for one to two hours, or until the color does not increase on further standing.

The color of the butanone layer is compared with that of known quantities of dinitrobenzene, ranging from 0.01 to 0.05 mg. of benzol. These are prepared by diluting 2.50 cc. of the standard solution of dinitrobenzene in sulfuric acid (1 mg. C_6H_6/cc.) to just 50 cc. with nitrating acid. One cc. of this solution will contain 0.05 mg. of benzol. To prepare a 0.05 mg. standard add 1 cc. of this solution to 1 cc. of nitrating acid, dilute with 5.0 cc. of water, neutralize and treat with butanone just as with the unknown sample. For a 0.01 mg. standard, combine 0.2 cc. of the solution with 1.8 cc. of nitrating acid, and so forth.

If the color of the unknown is too faint, a larger aliquot portion can be taken, and combined with just enough nitrating acid to make 2.00 cc. Similarly, if the color is too deep, a smaller portion can be taken.

Toluol and other common benzene derivatives do not interfere with the determination of benzene by this method.

References

(1) Volumetric Method

Smyth, H. F., Jr.—The Determination of Small Amounts of Benzene Vapors in Air.
J. Ind. Hygiene, 11, p. 335 (1929)

(2) Colorimetric Method

Schrenk, Pearce and Yant—A Microcolorimetric Method for the Determination of Benzene.
Bureau of Mines Report of Investigation 3287 (Oct., 1935)

Sources of Special Apparatus

Item	Source
Absorber	Macalister Bicknell Co. Cambridge, Mass.
Soda lime tube	
Flowmeter (1) Not calibrated	
(2) Calibrated	
Stand for mounting above	
Distilling flask	
Blower (1) Hand vacuum cleaner Mounting for above	
Blower (2) Special blower, mounted and with carrying case	Willson Products Co. Reading, Pa.

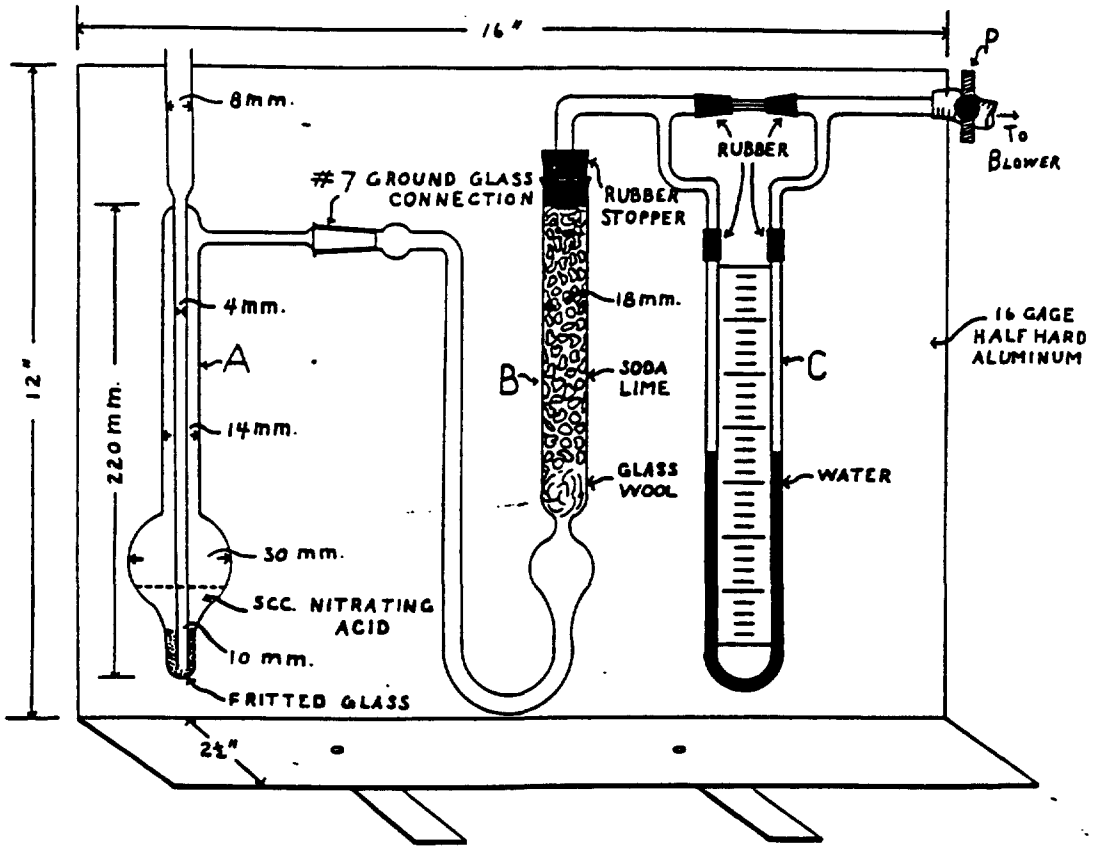


Figure 1. Apparatus for Taking Air Sample.

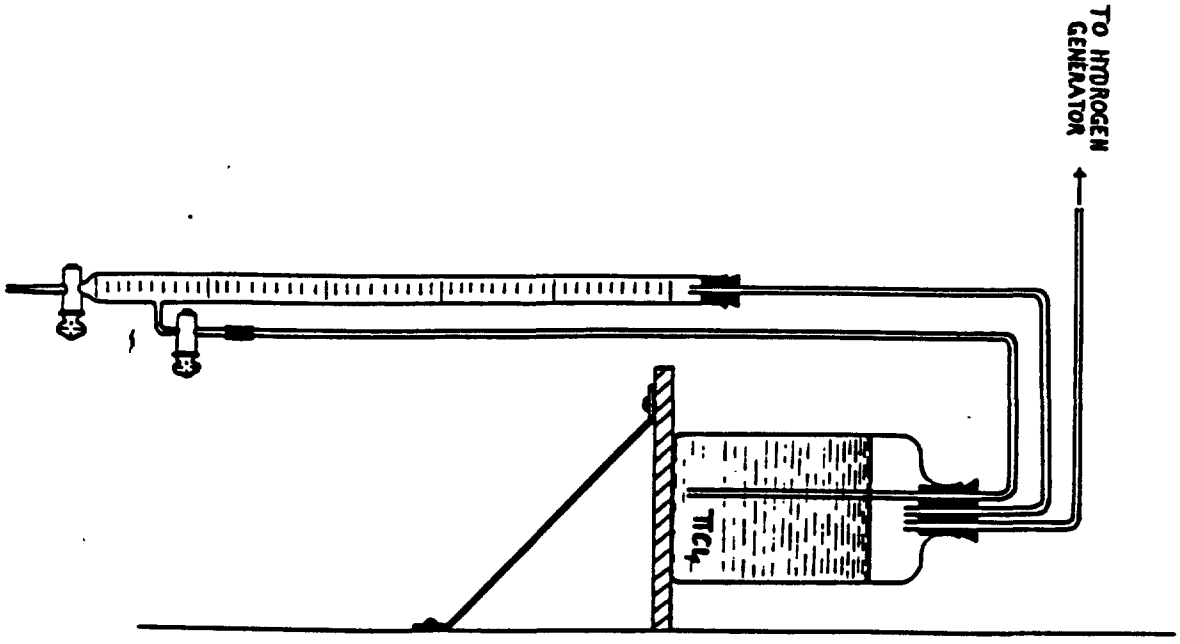


Figure 2. Storage Reservoir for Titanium Trichloride.

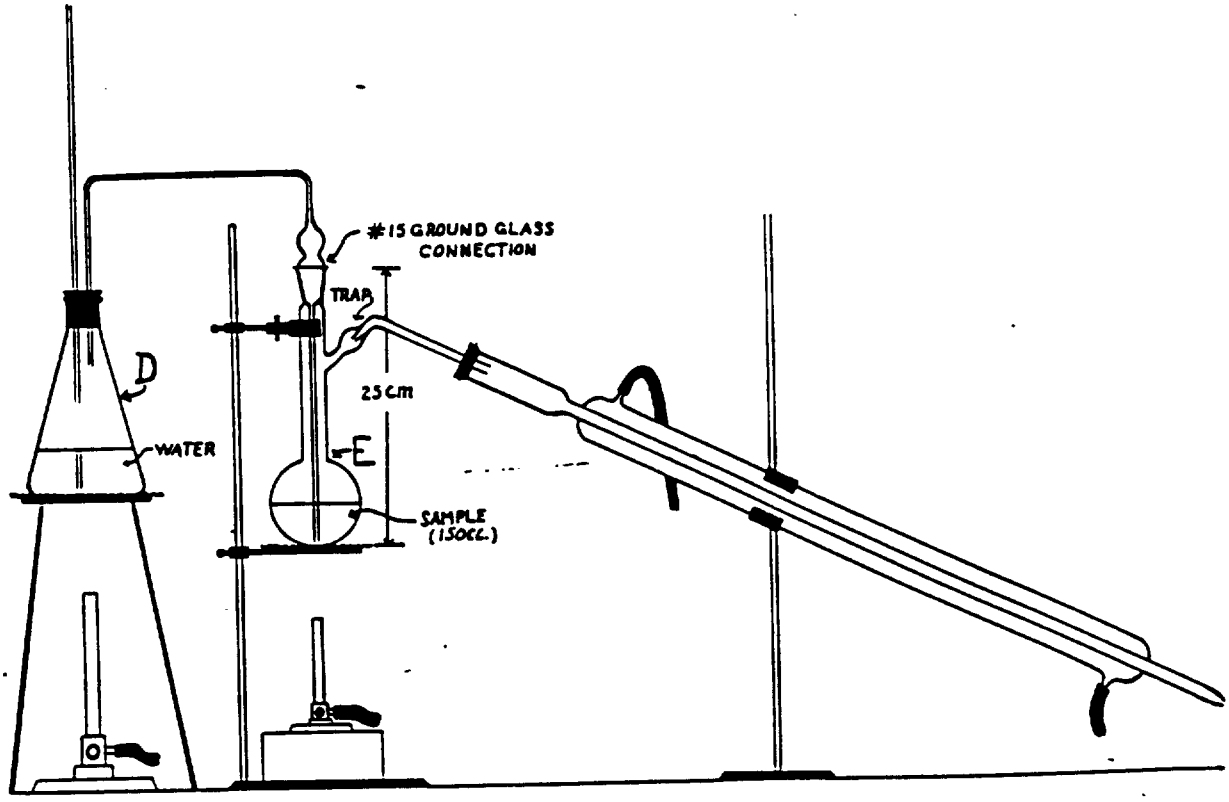


Figure 3. Apparatus for Distillation of Dinitrobenzene.

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AIR HYGIENE FOUNDATION OF AMERICA, Inc.

Preventive Engineering Series, Bulletin No. 2, Part 2



The Use and Care of Respirators

(Including List of Respiratory Protective Devices Approved by the U. S. Bureau of Mines)

PITTSBURGH, PENNSYLVANIA
FEBRUARY, 1938

THE USE AND CARE OF RESPIRATORS*

The term "respirators" or "respiratory protective devices" refers to a large and varied group of protectors worn on the face or over the head of the worker and designed to decrease or eliminate the amount of contaminant (dusts, fumes, mists, gases or vapors) in the inspired air. One type of respirator (the filter type) protects the wearer by filtering out some or all of the harmful material from the inspired air, and a second type (the supplied-air respirator) protects by supplying clean air from a convenient source.

Use of Respirators

Respirators are not a substitute for general dust or gas control, but are a helpful adjunct. They are used extensively on jobs such as abrasive blasting, paint chipping, handling used storage battery plates, cadmium oxide manufacture, welding operations, spraying of paints and glazes, the manufacture and use of pigments and dyes, and the like. Their most important use is under conditions where protection is required intermittently as in cleaning out operations, sweeping, after blasting, in removing cores from large foundry castings, shoveling, screening and handling of materials, and the operation and maintenance of processing equipment.

Respirators should not be considered part of the worker's wearing apparel. They are safety devices and should be supplied by the employer. The employer's duty does not stop with the purchase of respirators. He must see that they are distributed to all employees who need them. The workers must be told when to use respirators. They must be educated in their proper use—a difficult task which is accomplished only by incessant instruction.

Care and Maintenance of Respirators

Compared to other methods of dust and fume control, respirators are inexpensive. Consequently, little or no thought is sometimes given to their maintenance. Only too frequently good respirators are purchased, distributed carefully, and then forgotten. In a short time, they are very dirty and function ineffectively, if at all.

It is important that respirators be maintained in good working condition. Any respirator which is not properly kept

* This is part 2 in the series issued as Bulletin No. 2, under the auspices of the Preventive Engineering Committee. Part 3 will deal with the determination of chlorinated hydrocarbon vapors in the atmosphere.

will soon become very dirty and ineffective. The worker will object to wearing a dirty or unsightly respirator. Furthermore, if the respirator is not properly maintained, it will soon become defective and will not afford the necessary protection, even if worn correctly and continuously. A defective respirator is worse than none because the wearer is given a false feeling of security, and will not take the precaution which he would take if he had no respirator.

There are two general systems of respirator maintenance today. They are (1) individual maintenance and (2) central maintenance. In the individual maintenance system, the care and upkeep of the respirator is left to the user. He is supposed to wash, sterilize and repair the respirator. In the central maintenance system, all respirators are assembled at one central point for cleaning and repairing.

Usually the central maintenance system is worked out somewhat as follows. Each worker who needs respiratory protection is supplied with two respirators. The respirators are marked with the employment number of the user. Respirators may be marked by stamping the number on metal parts; riveting metal number plates on the rubber masks, and sewing laundry tabs on the headbands. When he goes to work in the morning, the worker passes by a row of pigeon holes in one of which (indicated by his employment number) he finds a clean and well-kept respirator. At the close of the shift, he again places the dirty respirator in the pigeon hole. The dirty respirators are all collected by one man who cleans and repairs them in a room laid out for this purpose. One respirator per worker is sufficient if the maintenance is carried out between shifts. Usually, however, two respirators are supplied and the repairs and cleaning done by one man on the regular shift. The worker in charge of the respirator maintenance need not be a new or special worker. It may be the man in charge of the stock room, or any individual whose work will permit. Frequently the maintenance of respirators can be combined with that of other protective equipment such as goggles and protective hats. In some industries where relatively few respirators are in use, the maintenance is one of the duties of the nurse.

The advantages of the central over the individual system are obvious. Each worker has a clean, well-kept respirator daily. He will object less to wearing it, and will get real protection at all times. The monetary saving effected by the increased life of the parts and decreased need for new respirators will usually more than offset the additional cost (if any) of setting up and maintaining the central system.

The idea of a central maintenance bureau is not a new one. Such bureaus have been in use in a score or more industries for several years. The results produced as evidenced by the condition of the respirators and the apparent satisfaction of the users are remarkable.

Respirator maintenance usually consists of cleaning, sterilizing and repairing. Effective methods of cleaning and sterilizing are as follows:

Cleaning:

Wash with a brush and soap in warm water.

Sterilizing:

(1) Immerse for ten minutes in a solution of formalin made by placing 1 part of 40 per cent formaldehyde solution into nine parts of water.

(2) Dip in a 3 per cent solution of carbolic acid, a 2 per cent solution of lysol, or a 70 per cent solution of denatured alcohol.

(3) Subjecting the respirator to sterilization by a moist atmosphere of antiseptic gas, preferably formaldehyde, for a period of ten minutes at room temperature.

After following any one of the outlined procedures, the respirator should be rinsed with water and hung up to dry. The filters, felt screens and head bands (if elastic) must be removed before cleaning or sterilizing the respirator.

Many dust respirators employ so-called "long life" filters which are intended to be used over and over. Such filters are cleaned by blowing the dirt or dust off with compressed air; by brushing the surface; or by tapping the filter. If the filters are moist, they must be dried before the dust can be removed effectively. To remove grease and the like, the filters may be dipped in a dry cleaning solution for a very short time. This process should be carried out only infrequently because it decreases the life of the filter.

Bureau of Mines Approval

At the present time, there are two schedules under which the Pittsburgh Experiment Station of the U. S. Bureau of Mines tests filter (dust, fume or mist) respirators and supplied-air respirators (hose masks, air line respirators, abrasive blasting helmets) for effectiveness. These schedules are as follows:

No. 21 (1934) - "Procedure for Testing Filter-Type Dust, Fume, and Mist Respirators for Permissibility."

No. 19A (1937) - "Procedure for Testing Supplied-Air Respirators for Permissibility."

Both of these schedules were put into effect after the Bureau had examined the needs of industry with great care and circulated the proposed schedules among interested persons. Details of the testing methods are described fully in the schedules which are obtainable through the Government Printing Office. The result has been that the various state agencies, insurance companies, mining and manufacturing establishments are apt to advise the use only of the Bureau of Mines approved devices on jobs with a recognized dust or fume risk.

At this writing, the following makes and types of respiratory protective devices have Bureau of Mines approval;*

SELF-CONTAINED OXYGEN BREATHING-APPARATUS APPROVED UNDER SCHEDULES 13 AND 13A

1. Gibbs mine rescue breathing-apparatus. Approval No. 1300, issued to Mine Safety Appliances Co., Braddock, Thomas, and Meade Streets, Pittsburgh, Pa., January 15, 1920.
2. Paul mine rescue breathing-apparatus. Approval No. 1301, originally issued to American Atmos Corporation, 909 Hay Street, Wilkinsburg, Pa., January 15, 1920. Later transferred to Mine Safety Appliances Company.
3. Fleuss-Davis Proto mine rescue breathing-apparatus. Approval No. 1302, issued to Siebe, Gorman & Co. (Ltd.), London, England, February 7, 1924.
4. McCaa mine rescue breathing-apparatus. Approval No. 1303, issued to Mine Safety Appliances Company, August 31, 1925.
5. Draeger mine rescue breathing-apparatus (1924 type). Approval No 1304, issued to Draegerwerk, Lübeck, Germany, August 1, 1929.
6. McCaa half-hour oxygen breathing-apparatus. Approval No. 1305, issued to Mine Safety Appliances Company, April 1, 1931.
7. McCaa one-hour oxygen breathing-apparatus. Approval No. 1306, issued to Mine Safety Appliances Company, July 28, 1937.

GAS MASKS APPROVED UNDER SCHEDULES 14, 14A, 14B, AND 14D

Type A: Acid Gas Masks

1. M. S. A. hydrocyanic acid gas mask. Approvals Nos. 1413, regular size canister, and 1414, supersize canister, issued to Mine Safety Appliances Company, December 9, 1933.

Type B: Organic Vapor Masks

1. M. S. A. organic vapor mask. Approval No. 1415, issued to Mine Safety Appliances Company, July 28, 1936.

* Reprinted from U. S. Bureau of Mines Information Circular 6952 and supplements.

Type AB: Acid Gas and Organic Vapor Masks

1. M. S. A. acid gas and organic vapor mask. Approval No. 1409, issued to Mine Safety Appliances Company, January 23, 1930.
2. M. S. A. Hydrogen sulphide and petroleum-vapor mask. Approval No. 1410, issued to Mine Safety Appliances Company, July 16, 1930.
3. Davis acid gas and organic vapor mask. Approval No. 1411, issued to Davis Emergency Equipment Co., Inc., 55 VanDam Street, New York, N. Y., January 19, 1931.
4. M. S. A. hydrogen sulphide and petroleum-vapor mask. Approval No. 1412, issued to Mine Safety Appliances Company, September 14, 1931.
5. M. S. A. hydrogen sulphide and petroleum-vapor mask. Approval No. 1416, issued to Mine Safety Appliances Company, June 16, 1937.

Type C: Ammonia Gas Masks

1. M. S. A. ammonia gas mask. Approval No. 1401, issued to Mine Safety Appliances Co., April 16, 1920.
2. G. M. D. ammonia gas mask. Approval No. 1404, issued to Mine Safety Appliances Co., March 10, 1926.
3. LaFrance ammonia gas mask. Approval No. 1401, issued to American-LaFrance and Foamite Industries, Inc., Elmira, New York, June 23, 1927.
4. G. M. D. ammonia gas mask. Approval No. 1406, issued to Mine Safety Appliances Co., February 14, 1928.
5. Davis ammonia gas mask. Approval No. 1408, originally issued to Bullard-Davis, Inc., December 19, 1928, later transferred to Davis Emergency Equipment Co., Inc.
6. LaFrance ammonia gas mask. Approval No. 1408, issued to American-LaFrance and Foamite Industries, Inc., Elmira, New York, November 18, 1930.

Type D: Carbon Monoxide

1. M. S. A. self-rescuer. Approval No. 1402, issued to Mine Safety Appliances Co., March 6, 1924.

Type N: Gas Masks for Protection Against Acid Gases, Organic Vapors, Carbon Monoxide, Ammonia, Smokes, Dusts, and Mists

1. All-Service gas mask. Approval No. 1403, issued to Mine Safety Appliances Co., July 1, 1925.
2. All-Service gas mask. Approval No. 1405, issued to Mine Safety Appliances Co., August 24, 1928.
3. All-Service gas mask. Approval No. 1405, issued to B. F. McDonald Company, 1248 South Hope Street, Los Angeles, Calif., October 2, 1937.

HOSE MASKS APPROVED UNDER SCHEDULE 19 AND SUPPLEMENT TO SCHEDULE 19

1. M. S. A. combination hose mask. Approval No. 1901, issued to Mine Safety Appliances Co., May 29, 1929.
2. Davis hose mask. Approval No. 1902, issued to Davis Emergency Equipment Co., Inc., March 30, 1931.
3. Bullard hose mask. Approval No. 1903, issued to E. D. Bullard Co., 275 Eighth Street, San Francisco, Calif., April 14, 1933.
4. Davis hose mask with Davis-Root positive pressure blower (approved for two lines of hose). Approval No. 1904, issued to Davis Emergency Equipment Co., Inc., October 29, 1934.
5. M. S. A. combination hose mask (approved for two lines of hose). Approval No. 1905, issued to Mine Safety Appliances Co., January 7, 1935.
6. Davis hose mask (approved for two lines of hose). Approval No. 1906, issued to Davis Emergency Equipment Co., Inc., August 2, 1935.
7. LaFrance hose mask (approved for two lines of hose). Approval No. 1905A, issued to the American-LaFrance and Foamite Industries, Inc., Elmira, New York, September 20, 1937.

MECHANICAL-FILTER DUST, FUME, AND MIST RESPIRATORS
APPROVED UNDER SCHEDULE 21

Type-A Mechanical-Filter Respirators: For Protection Against Pneumoconiosis-Producing or Nuisance Dusts, as Quartz, Asbestos, Iron Ores, Cement, Limestone, Gypsum, Coal, Coke, Charcoal, Wood, Cellulose, Flour, and Aluminum

1. M. S. A. *Comfo* Respirator. Approval No. 2101, issued to Mine Safety Appliances Co., January 7, 1935.
2. Willson Bag Respirator No. 300. Approval No. 2102, issued to Willson Products, Inc., Reading, Pa., January 21, 1935.
3. Willson Bag Respirator No. 400. Approval No. 2103, issued to Willson Products, Inc., January 21, 1935.
4. Pulmosan M-15 Pouch-Type Filter Respirator. Approval No. 2104, issued to Pulmosan Safety Equipment Corporation, 176 Johnson Street, Brooklyn, New York, February 9, 1935.
5. Biever Respirator. Approval No. 2105, issued to Standard *Safety Equipment Company*, 75 East Wacker Drive, Chicago, Ill., March 6, 1935.
6. Willson Bag Respirator No. 4. Approval No. 2106, issued to *Willson Products*, Inc., May 27, 1935.
7. Pulmosan *M-11* Pouch-Type Filter Respirator. Approval No. 2109, issued to Pulmosan Safety Equipment Corp., March 23, 1936.
8. *No. 24 Dupor Respirator. Approval No. 2111, issued to H. S. Cover, Station A, South Bend, Ind., September 15, 1936.*
9. Cesco No. 90 Healthguard Respirator. Approval No. 2112, issued to the Chicago Eye Shield Co., 2300 Warren Blvd., Chicago, Ill., December 16, 1936.
10. McDonald Dustfoe Respirator. Approval No. 2115, issued to the B. F. McDonald Co., 1248 South Hope Street, Los Angeles, Calif., October 8, 1937.
11. Dustfoe Respirator. Extension of Approval No. 2115, issued to Mine Safety Appliances Co., November 23, 1937.
12. Willson Bag Respirator No. 100. Approval No. 2117, issued to Willson Products, Inc., December 27, 1937.
13. Willson Rotiform Respirator No. 200. Approval No. 2118, issued to Willson Products, Inc., December 30, 1937.
14. Willson Respirator No. 750. Approval No. 2119, issued to Willson Products, Inc., January 3, 1938. The use of felt screens with the paper filters is optional.
15. Pulmosan D-4100 Duo-Filter Respirator. Approval No. 2120, issued to Pulmosan Safety Equipment Corp., January 12, 1938.
16. American Optical Co., Southbridge, Mass., R 1000 Respirator. Approval No. 2121, *issued to American Optical Co.*, February 3, 1938.

Type-A respirators are not approved for protection against *poisoning* by breathing dusts whose main harmful constituents are metals or their compounds, such as antimony, arsenic, cadmium, chromium, lead, manganese, mercury, selenium, tellurium, thallium, uranium, and vanadium; or protection against harmful smokes and fumes. Respirators for protection against these forms of particulate matter require special approval.

Type-B Mechanical-Filter Respirators: For Protection Against Fumes of Metal (Usually their Chemical Compounds, as Oxides or Carbonates) such as Lead, Mercury (except Mercury Vapor), Manganese, Magnesium, Aluminum, Antimony, Arsenic, Copper, Chromium, Iron, Cadmium, and Zinc Resulting from Sublimation or the Condensation of their Vapor, or from the Chemical Reactions between their Vapor and Gases

No Type-B mechanical-filter respirator has been submitted for approval.

Type-C Mechanical-Filter Respirators: For Protection Against the Mist of Chromic Acid as Produced in Chromium Plating, the Mist Produced by Spray-Coating with Paints Whose Main Harmful Constituent is Lead, and the Mist Produced by Spray-Coating with Vitreous Enamels

1. An extension of approval has been granted for the use of the M. S. A. Comfo Respirator (see 1. under approved Type A Mechanical Filter Respirator) Approval No. 2101 for protection against the inhalation of the mist of chromic acid as produced in chromium plating and the mist produced by spray-coating with vitreous enamels whose liquid vehicle does not produce harmful gases or vapors. This extension of approval does not cover the use of this respirator against any lead-containing mist.

Mechanically Generated Lead Dust Mechanical Filter Respirator: For Protection Against the Inhalation of Mechanically Generated Dusts Whose Main Harmful Constituent is Lead, such as Lead Dusts Generated in Manufacturing Storage Batteries; Enameling; Pottery Making; Rubber Compounding; Sandpapering and Chipping Painted Surfaces; Paint Making; Preparing Lithotransfers; and Mining, Milling and Processing Lead Ores

1. M. S. A. Comfo Respirator. Approval No. 2107, issued to Mine *Safety Appliances Co.*, August 9, 1935.
2. Willson Bag Respirator No. 400L. *Approval No. 2108*, issued to Willson Products, Inc., September 5, 1935. This respirator is also approved *for protection against Type A suspensions of* atmospheric particulate matter.
3. *Pulmosan L-2100* Pouch-Type Filter Respirator. Approval No. 2110, issued to Pulmosan Safety Equipment Corp., July 17, 1936.
4. Pulmosan ML-3100 Pouch-Type Filter Respirator. Approval *No. 2112, issued to Pulmosan Safety Equipment Corp.*, November 30, 1936. This respirator is also approved for protection against Type A suspensions of atmospheric particulate matter.
5. Cesco Healthguard No. 91 Respirator. Approval No. 2114, issued to the Chicago Eye Shield Co., August 6, 1937. An extension of Approval No. 2114 was issued to the Chicago Eye Shield Co., December 16, 1937, approving use of this respirator for protection against Type A suspensions of atmospheric particulate matter.
6. Cesco No. 92 Healthguard Respirator. Approval No. 2116, issued to the Chicago Eye Shield Co., November 8, 1937. This respirator is also approved for protection against Type A suspensions of atmospheric particulate matter.

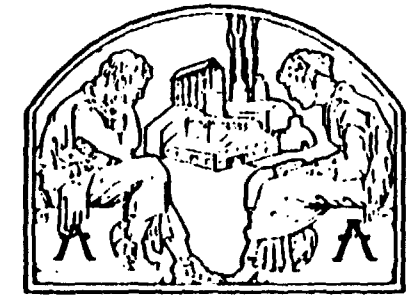
These respirators are not approved for protection against the inhalation of lead fumes generated by heating and volatilizing lead, such as the fumes generated in lead burning and soldering, smelting, type founding, and fusing lead glaze and enamel; or protection against dusts of other poisonous metals or their compounds, or harmful smokes, fumes or mists.

IDENTIFICATION OF APPROVED DEVICES

All devices marketed under the provisions of the United States Bureau of Mines approval system must bear, either on the package or affixed to the device, an approval label, on which is reproduced the seal of the Bureau of Mines, the approval number, and the name of the manufacturer to whom the approval is issued. The approval label also states the conditions for which approval is granted. Self-contained oxygen breathing apparatuses bear a plate affixed to the apparatus. Canister-type gas masks bear a label on the case and on each canister, and the approval number is stamped on the facepiece and harness, such as BM-1400. Hose mask cases bear an approval label, and the approval number is stamped on the facepiece, harness, and individual lengths of hose. The cases of mechanical filter respirators and containers for replacement filter units bear the approval label, and the approval number is stamped on the facepiece and each filter unit. These filter units also bear a marking that designates the class of particulate matter for which they are approved, as Type A, Type B, and Type C.

AIR HYGIENE FOUNDATION OF AMERICA, Inc.

Preventive Engineering Series. Bulletin No. 2. Part 1



The Determination of Chlorinated Hydrocarbon Vapors in the Atmosphere

PITTSBURGH, PENNSYLVANIA
MARCH, 1937

THE DETERMINATION OF CHLORINATED HYDROCARBON VAPORS IN THE ATMOSPHERE*

The air containing the chlorinated hydrocarbon vapor is passed through a quartz tube heated in a portable electric furnace. The compound is decomposed with the formation of hydrochloric acid, which is absorbed in sodium carbonate solution. The chlorine content of this solution is determined by a standard method.

Taking of Sample

Apparatus required.

Small electric furnace.

An alundum tube ½" inside diameter and 12" long is wound with 22 feet of #21 Chromel A wire. This is coated with a 3/10" layer of alundum cement and then with several layers of sheet asbestos cemented together with sodium silicate solution. To improve the appearance of the furnace the asbestos is coated with a liquid porcelain cement.

Electric resistance.

An outside resistance of 10 ohms is prepared by winding 12 feet of the Chromel wire on a piece of asbestos board.

Three way switch.

A three way electric switch (10 amp capacity) is attached to the resistance and furnace as follows: Position (1) through furnace only; (2) through half of resistance and furnace in series; (3) through entire resistance and furnace.

Combustion tube.

A 5 mm. I. D. silica tube 16" long, one end ground to fit a #7 ground glass joint.

Platinum foil.

2 pieces of 0.001" platinum foil, each 5" long and 1" wide, rolled up to just fit inside the central portion of the combustion tube.

Absorber.

As shown in diagram, with #7 ground connection to fit combustion tube.

* This is part 3 in the series issued as Bulletin No. 2, under the auspices of the Preventive Engineering Committee. Part 4 will deal with the design of exhaust hoods, and part 5 with the design of duct work for exhaust systems.

Flowmeter.

Calibrated for air flow of 1 liter per minute.

The above equipment is mounted on a piece of asbestos board as shown in Figure 1.

Blower.

Suction end attached to 15 feet of ⅜" rubber tubing.

Reagents required.

2% solution of sodium carbonate.

Dissolve 20 gm. of anhydrous C. P. sodium carbonate in one liter of water, add 2 gm. of arsenic trioxide, mix thoroughly and filter.

Procedure.

Place the combustion apparatus on a table or tripod in the room where the air analysis is to be made. Attach to a 110 volt electric circuit, and turn the switch to position 1. As soon as the inside of the furnace has reached a bright red heat, turn the switch to position 3 and leave it there as long as the temperature does not fall below a red heat. It may be necessary to use position 2 to maintain the proper temperature. (800-900° C.)

While the furnace is heating, pour 2 cc. of the sodium carbonate solution through the right arm of the absorber, and allow the excess to drain out through the open stopcock. Then close the stopcock and introduce about 10 cc. of solution into the left arm of the absorber. Place the glass plug in the right arm, and connect the left arm to the flowmeter. As soon as the desired temperature is reached in the furnace, start the blower, and open the pinchcock slowly until the flowmeter reading shows a flow of 1 liter per minute.

Continue sampling for 5 minutes to an hour. As a rule, a 30 minute sample should be taken. If the process involving chlorinated compounds covers a definite cycle of operation, the entire cycle should be covered, either by one sample or by a series of samples.

When the sample is completed, shut off the blower, open the stopcock and drain the liquid into a 50 cc. sample bottle. Rinse out each arm of the absorber twice, using 5 cc. each time, or a total of 20 cc. of distilled water.

Analysis of Sample

Special apparatus required.

One 10 cc. burette.

Reagents required.

0.02 N sodium chloride solution.

0.05 N silver nitrate solution (8 to 9 gm. $AgNO_3$ in 1 liter distilled water).

0.05 N potassium thiocyanate solution (5 gm. KCNS in 1 liter distilled water).

Ferric sulfate solution (5 gm. of ferric sulfate, 1 cc. H_2SO_4 in 100 cc.).

6 N nitric acid.

Standardization of solutions.

Dry about 7 gm. of C. P. sodium chloride at 150° C. overnight. Weigh out exactly 5.845 gm., dissolve in distilled water and dilute to just 500 cc. Take just 50 cc. of this solution and dilute to exactly 500 cc. with distilled water. The resulting solution is 0.0200 N, and contains 0.709 mg. of chlorine per cc.

Measure out 10.00 cc. of the silver nitrate solution with a pipette and dilute with 25 cc. of water to which 2 cc. of 6 N nitric acid has been added. Add 1 cc. of the ferric sulfate solution, and run in potassium thiocyanate solution from a burette until the mixture acquires a permanent yellow or reddish tinge. Note the volume of KCNS required.

Measure out just 10.00 cc. of the standard sodium chloride solution, dilute with 20 cc. of water, add 2 cc. of nitric acid and just 10.00 cc. of standard silver nitrate solution. Let stand one hour in the dark, then filter into a 50 cc. erlenmeyer flask and carefully wash the precipitate and filter paper three times, allowing the washings to drain into the flask. Then add ferric sulfate and titrate with thiocyanate solution as before.

Sample Calculation

	NaCl Solution	$AgNO_3$ Solution	KCNS Solution	Avg.
(1)	None	10.00 cc.	10.42 cc.	
(2)	None	10.00 cc.	10.39 cc.	10.40 cc.

conc. $AgNO_3$ / conc. KCNS = 10.40 / 10.00 = 1.040

(3)	10.00 cc.	10.00 cc.	6.21 cc.	
(4)	10.00 cc.	10.00 cc.	6.24 cc.	6.22 cc

KCNS used up = 10.40 — 6.22 = 4.18 cc.

conc. KCNS / conc. NaCl = 10.00 / 4.18 = 2.49

KCNS = 2.49 x 0.0200 = 0.0498 N

$AgNO_3$ = 1.040 x 0.0498 = 0.0518 N

Analysis of sample.

Add one drop of phenolphthalein solution to the sample, then add nitric acid until the solution is colorless, and 2 cc. in excess. Then add 10.00 cc. of standard $AgNO_3$ solution,

let stand one hour, filter, and titrate the filtrate with thiocyanate solution as described above. The concentration of the chlorinated compound may be calculated directly as follows. For room temperatures (20-30° C.) 24.5 liters can be taken as the molecular volume of gases (except at high altitudes).

Sample		Substance	.0518 N. $AgNO_3$ (a)	Calc. (b)	0.0498 N. KCNS Needed (b)-(a)		Mols Cl Present
(1)	$\frac{30\ l.}{24.5\ l.} = 1.22$ mols air	CCl_4	10.00 cc.	10.40 cc.	8.35 cc.	2.05 $(\frac{\times .0498}{10^3})$	$= 1.02 \times 10^{-4}$

$$\text{Conc. } CCl_4 = \frac{1.02 \times 10^{-4} \times 10^6}{4^* \times 1.22} = 21 \text{ parts per million parts of air}$$

(2)	10 l. = 0.408 mols air	CH_2Cl	10.00 cc.	10.40 cc.	7.60 cc.	2.80 $(\frac{\times .0498}{10^3})$	$= 1.395 \times 10^{-4}$

$$\text{Conc. } CH_2Cl = \frac{1.39 \times 10^{-4}}{1 \times 0.408} = 340 \text{ ppm.}$$

Chloronaphthalenes and Chlorodiphenyls

The method as outlined above is suitable for determining the chlorinated hydrocarbons used as solvents and refrigerants in concentrations well below their thresholds of toxicity. Some solid substances used industrially, however, such as the chlorinated naphthalenes and diphenyls, are toxic in much lower concentrations—of the order of 1 mg. per cubic meter of air.

For determining the above substances in low concentrations the sample is taken in the same way, but at least 30 and preferably 60 liters of air should be sampled. In addition the reagents must be specially purified to remove the last traces of chlorine. The chloride is determined by adding an excess of silver nitrate in an 80% alcohol solution to the acidified sample, and comparing the cloudiness of the sample with that caused by known amounts of chloride. The comparison is best done in a nephelometer. (Described in reference 2.)

Very small quantities of chlorinated solvents such as trichlorethylene and carbon tetrachloride interfere with the determination of chloronaphthalenes, etc. It is possible to distinguish between slightly volatile substances (chloronaphthalenes, etc.) and volatile compounds (carbon tetrachloride, etc.) by using an altogether different method described in reference 3.

Brominated Compounds

The method as above described can be used for substances such as methyl bromide, ethyl bromide, and so forth.

* Since there are 4 chlorine atoms in CCl_4.

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(3) Elkins, Hobby and Fuller—The Determination of Atmospheric Contaminants: I. Organic Halogen Compounds. J. Ind. Hygiene, 19, p. 474 (November, 1937).

Sources of Special Apparatus

Item	Source
Silica tube	
Platinum foil	
Alundum tube	Norton Co. Worcester, Mass.
10 lb. alundum cement RA 162	Norton Co. Worcester, Mass.
Glass absorber	Macalister Bicknell Co. Cambridge, Mass.
Calibrated flowmeter	Macalister Bicknell Co. Cambridge, Mass.
Asbestos paper, porcelain cement, etc.	
Flexboard—4' x 8' x ⅛"	Johns Manville Corp.
Fiber carrying case	
1 lb. #21 Chromel A wire	Hoskins Mfg. Co. Detroit, Mich.
Combustion apparatus, complete with carrying case	Wilson Products Co. Reading, Pa.
Blower (1) Special blower, mounted and with carrying case	Wilson Products Co. Reading, Pa.
Blower (2) Hand vacuum cleaner	
Combustion apparatus, complete	Macalister Bicknell Co. Cambridge, Mass.

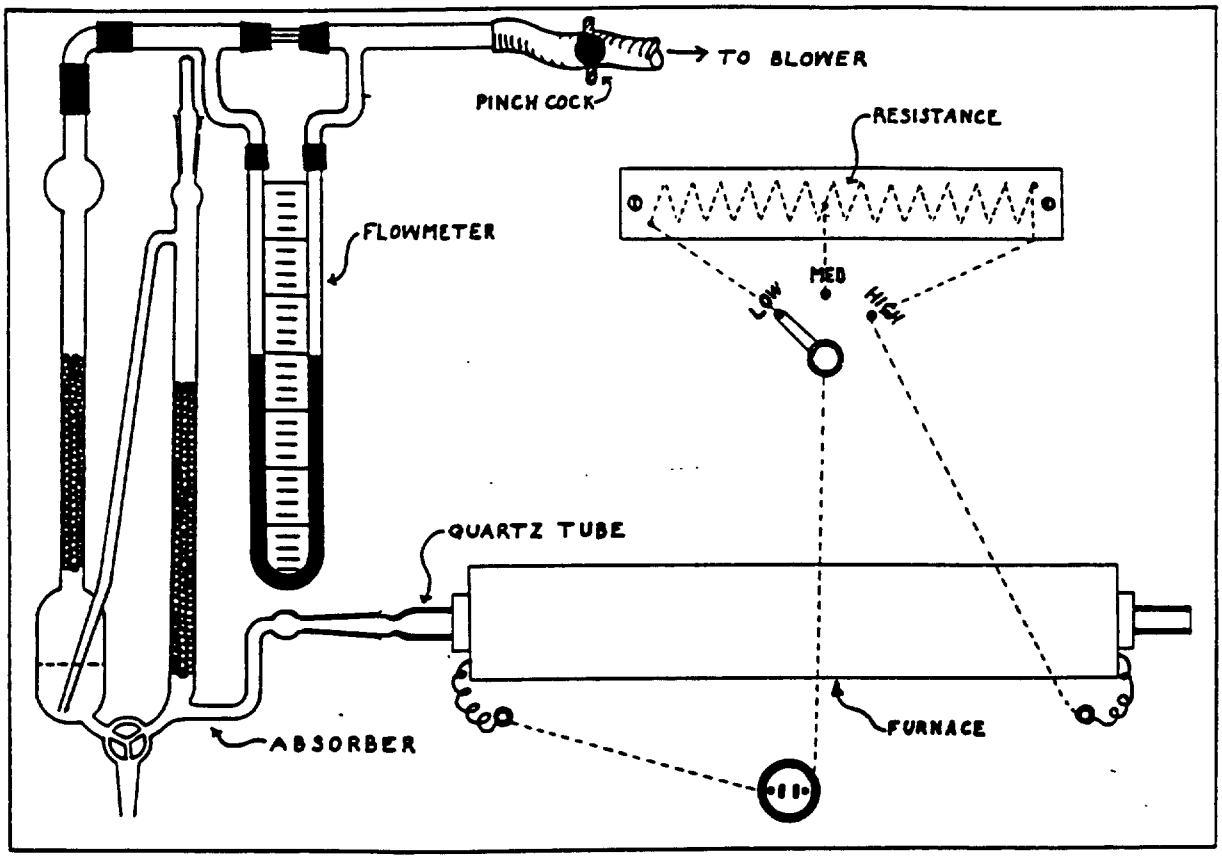
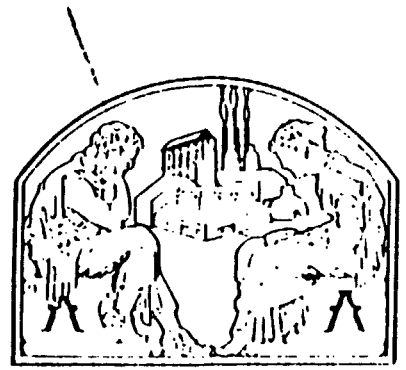


Figure 1. Combustion Apparatus for Taking Air Sample

b.

AIR HYGIENE FOUNDATION OF AMERICA, Inc.

Preventive Engineering Series, Bulletin No. 2, Part 1



Design of Exhaust Hoods

PITTSBURGH, PENNSYLVANIA
APRIL, 19[illegible]

DESIGN OF EXHAUST HOODS*

Exhaust systems may be classified according to the means employed to collect dust or other material handled. The dust or refuse may be collected and controlled by enclosing hoods, open hoods, inward air leakage, or by exhausting the general air of the room.

Hoods should be placed as close to the source of dust or fumes as possible, with due regard to the movements of the operator. When the hood must be placed at some distance above the machine, it should be built large enough to take care of the diffusion of the material which is usually quite rapid. For those substances which are lighter than air, the hood should be over or above the machine, and where a heavy vapor or dust-laden air at ordinary temperature is to be removed, horizontal or down-flow-type hoods should be used. The objective to keep in mind in all cases is to take advantage of the natural tendency of the material to move upward or downward.

Suction and Velocity Requirements for Hoods

The removal of dusts or fumes by means of exhaust hoods requires a movement of air at the point of origin sufficient to carry them to a collecting system. The air velocities necessary to accomplish this depend upon the physical properties of the material to be eliminated and the direction and speed with which it is thrown off. If the dust to be removed is already in motion, as is the case with high-speed grinding wheels, the hood should be installed in the path of the particles so that a minimum air volume may be used effectively. It is always desirable to design and locate a hood so that the volume of air necessary to produce results is as small as possible.

The static suction at the throat of a hood is frequently used in practice as a measure of the effectiveness of control. This is of considerable value where exhaust systems adapted to particular operations have been standardized by practice. It must be remembered, however, that the suction is only a rough measure of the air volume handled and consequently of the air velocity at the opening of the hood. The elimination of any dusty condition requires added information concerning the shape, size, and location of the hood used with regard to the operation in question.

In some states, grinding, polishing, and buffing wheels are

* This is part 4 in the series issued as Bulletin No. 2, under the auspices of the Preventive Engineering Committee. Part 5 will deal with the design of duct work for exhaust systems

subject to regulation by codes. The static suction requirements, which range from 1½ to 5 inches water displacement in a U-tube, should be followed although in several instances they may appear to be very high. Frequently, in these operations, a large part of the wheel must be exposed and the dust-laden air within the hood is thrown outward by the centrifugal action of the wheel, thus counteracting useful inward draft. This tendency may be diminished by locating the connecting duct so as to create an air flow of not less than 200 fpm about the lower rim of the wheel.

Exact determinations of hood control velocities are not available, but it is safe to assume that for most dusty operations they should not be less than 200 fpm at the point of dust origin. The method for approximately determining these velocities in terms of the velocity at the hood opening is given below.

Hoods

No set rule can be given regarding the shape of a hood for a particular operation, but it is well to remember that its essential function is to create an adequate velocity distribution. The fact that the zone of greatest effectiveness does not extend laterally from the edges of the opening may frequently be utilized in estimating the size of hood required. Where complete enclosure of a dusty operation is contemplated, it is desirable to leave enough free space to equal the area of the connecting duct. Hoods for grinding, polishing, and buffing should fit closely, but at the same time should provide an easy means for changing the wheels. It is advisable to design these hoods with a removable hopper at the base to capture the heavy dusts and articles dropped by the operator. Such provisions are of assistance in keeping the ducts clear. Air volumes used to control many dust discharges may often be reduced by effective baffling or partial enclosure of an operation. This procedure is strongly urged where dusts are directed beyond the zone of influence of the hood.

Axial Velocity Formula for Hoods

When the normal flow of air into a hood is unobstructed, the following formula may be used to determine the air velocity at any point along the axis:

$$V = \frac{0.1\ Q}{x^2 + 0.1\ A} \qquad (1)$$

where

- V = velocity at point, feet per minute.
- A = area of opening, square feet.
- x = distance along axis, feet.
- Q = volume of air handled, cubic feet per minute.

Velocity Contours

The air velocity distribution in front of a hood can be expressed in terms of the velocity at the opening. Curves of equal velocity are called velocity contours and these curves are identical for similar hood shapes when the hoods are reduced to the same basis of comparison. These facts apply to all hoods so that when the velocity distribution is known, the air flow required at a given point can be determined. Figure 1 shows the contour distribution in two axial planes perpendicular to the sides of a rectangular hood with a side ratio of one-half. The distribution shown is identical for all openings with a similar side ratio provided the mapping is as shown in Figure 1, page 9. The contours, of course are expressed as percentages of the velocity at the opening.

Air Flow from Static Readings

The volume of air flow through any hood may be determined from the following equation:

$$Q = 4005\ f\ a\ \sqrt{h_t} \qquad (2)$$

where

- Q = volume of air flow, cubic feet per minute.
- a = area of connecting duct, square feet.
- h_t = static suction at throat of hood, inches of water.
- f = orifice or restriction coefficient which varies from 0.6 to 0.9 depending on the shape of the hood.

An average value of f is 0.71, although for a shaped opening a value of 0.8 may be used.

Static suction is not a good measure of the effectiveness of a hood unless the area of the opening and the location of the operation with respect to the hood are known. This is clearly indicated by Equation 1 which shows that the velocity at any point along the axis varies inversely as the area of the opening plus the square of the distance. However, this formula coupled with Equation 2 should serve to indicate the velocity conditions to be expected when operations are conducted external to the hood opening.

Control Velocities

Little is known of the velocities required for the control of a nuisance. Many factors, such as the manner of nuisance production, material to be controlled, and the velocity and direction with which the material is projected from the source, influence the determination of these velocities. Tables 1 and 2 give the air velocities generally used for control purposes in several industries.

Table 1.—Minimum air velocities required to capture certain industrial dusts

INDUSTRY	PROCESS	REQUIRED AIR VELOCITY		CRITERION
		At point of origin	At face of hood	
Granite cutting	Hand pneumatic tool	200 FPM		Reduced concentration to safe level
	Surfacing machine	1500 FPM		Reduced concentration to safe level
	All tools		1500	Reduced concentration to safe level
Grain elevators	Elevator boot and head, garner		500	Visual test
Paint spraying	Spraying booth		50-200	Reduced concentration to safe level
Sand pulverizing	Bagging machine	400 FPM		Reduced concentration to safe level
Quarrying and mining	Horizontal drilling with Kelly trap	60*		Reduced concentration to safe level
	Vertical drilling with Kelly trap	200*		Reduced concentration to safe level
Electroplating	Chromium plating	50**	1500	Reduced concentration to safe level
	Steam and acid tanks	75-100		Reduced concentration to safe level
Hatters fur	Brushing	200*		Usual practice
	Cutting machines	380*		Usual practice
	Blowers	2000*		Usual practice
Electric welding	Welding	200		Visual test
Metal spraying***	Lead Zinc	200 125		Effective removal of all fumes

* Cubic feet per minute.

** Cubic feet per minute per foot of slot (common practice).

*** At opening of booth.

Table 2.—Minimum air velocities required to capture certain foundry dusts*

PROCESS	AIR VOLUMES	REMARKS
Foundry shakeout		
Overhead hood	300 cfm/sq. ft. of working openings	Hot castings
Overhead hood	200 cfm/sq. ft. of gross grate area	Hot castings
Overhead hood	200 cfm/sq. ft. of working openings	Warm or cold castings
Overhead hood	150 cfm/sq. ft. of gross grate area	Warm or cold castings
Side Hood	400 cfm/sq. ft. of gross grate area	Hot castings
Side Hood	300 cfm/sq. ft. of gross grate area	Warm or cold castings
Down draft	200 cfm/sq. ft. of gross grate area	Warm or cold castings
Sand Screens		
Flat deck type	75 cubic feet/minute per square foot of screen area, but not less than 200 feet per minute through inspection openings	
Cylindrical	1500 cfm	30" diam.
	2000 cfm	30-48" diam.
	3000 cfm	48-60" diam.
	4000 cfm	60-72" diam.
	5000 cfm	Over 72" diam.

* From article by John M. Kane, in The Foundry, January-February, 1938.

Large Open Hoods

Large hoods, such as are used for electroplating and pickling tanks, should be subdivided so the area of the connecting duct is not less than one-fifteenth of the open area of the hood. Frequently, it will be found necessary to branch the main duct in order to obtain a uniform distribution of flow. Canopy hoods should extend six inches laterally from the tank for every twelve-inch elevation, and wherever possible they should have side and rear aprons so as to prevent short-circuiting of air from spaces not directly over the vats or tanks. In most cases, hoods of this type take advantage of the natural tendency of the vapors to rise, and air velocities may be kept low. Cross drafts from open doors or windows disturb the rise of the vapors and therefore provision must be made for them. The air velocities required also depend upon the character of the vapors given off, cyanide fumes, for example, requiring

an air velocity of approximately 75 fpm on the surface of the tank, and acid and steam vapors requiring velocities as low as 25 to 50 fpm. The total volume of air flow necessary to obtain these velocities may be approximately determined from the following simple formula:

$$Q = 1.4\,P\,D\,V \qquad (3)$$

where

Q = total volume of air handled by hood, cfm.
P = perimeter of the tank, feet.
D = distance between tank and hood opening, feet.
V = air velocity desired along edges and surface of tank, fpm.

Lateral Exhaust System

The lateral exhaust method, as used for chromium plating tanks, is often preferred to the canopy-type hoods. This method draws air and fumes laterally across the top of vats or tanks into slotted ducts at the top and extends fully along one or more sides of the tanks. The slots are two inches wide and for effective ventilation a 2,000 fpm exhaust air velocity at the slot face is advisable. In addition, the duct should not be required to draw the air laterally for a distance of more than eighteen inches and the level of the solution should be kept six to eight inches below the top of the tanks.

Flexible Exhaust System

The flexible exhaust tube method may be advantageously used for removing dust or fumes. Flexible tubes having one end connected to an exhaust system and a slotted hood attached to the other end may be shaped at will to fit in with industrial processes without affecting the ease of operation. Efficient dust or fume removal may be had with use of relatively small exhaust volumes. This type of system may be used on swing grinders, portable grinding wheels, soldering operations, stone cutting, rock drilling, etc.

Spray Booths

In the design of an efficient spray booth, it is essential to maintain an even distribution of air flow through the opening and about the object being sprayed. While in many instances spraying operations can be performed mechanically in wholly enclosed booths, the volatile vapors may reach injurious or explosive concentrations. At all times the concentrations of these vapors, and particularly those containing benzol, should be kept below 100 parts per million. Spray booth vapors are dangerous to the health of the worker and care should be taken to minimize exposure to them.

The exhaust duct for a spray booth should be located in a

horizontal position slightly below the object sprayed. Stagnant regions within the booth should be carefully avoided or should be provided with exhaust. The air volume should be sufficient to maintain a velocity of 150 to 200 fpm over the open area of the booth, and the vapors may be discharged through a suitable stack to permit dilution, but it is better practice to pass the fumes or vapors through baffle-type washers or scrubbers designed for efficient spray fume removal.

Hoods for Chemical Laboratories

Hoods used in chemical laboratories are generally provided with sliding windows which permit positive control of the fumes and vapors evolved by the apparatus. Their design should offer easy access for the installation of chemical equipment and should be well lighted. Air velocities should exceed 75 fpm when the window is opened to its maximum height.

Protection Against Corrosion

The removal of gases and fumes in many chemical plants requires that metals used in the construction of the exhaust system be resistant to chemical corrosion. A list of the materials which may be used to resist the action of certain fumes is given in table 3. Hoods and ducts when short may frequently be constructed of wood and be quite effective. Rubberized paints are available and may be applied as protective coatings in handling such gases and fumes as chlorine and hydrochloric acid.

Table 3.—Materials to be used for the protection of exhaust systems against corrosion*

Type of fume conveyed	Protective material to be used
Chlorine	Rubber lining or chrome-nickel alloys
Hydrogen sulphide	Aluminum-coated iron, aluminum, high chrome-nickel alloys
Ammonia	Iron or steel
Sulphurous gases	High chrome-nickel alloys
Hydrochloric acid	Rubber lining, chrome-nickel alloys
Nitrous gases	Nickel-chrome alloys

* Condensed from data given by Chilton and Huey. Industrial and Engineering Chemistry, vol. 24, 1932.

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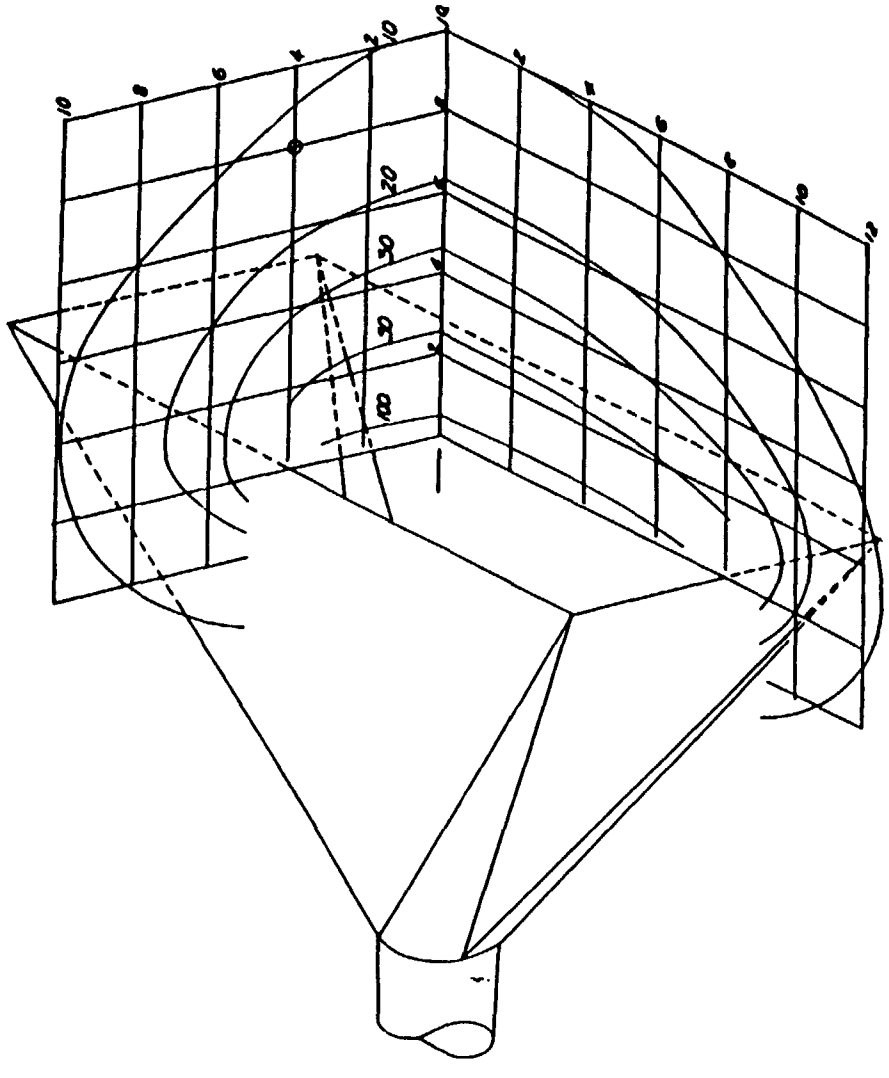
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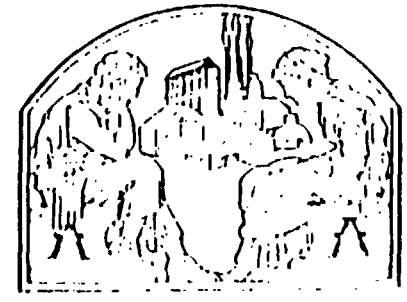
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AIR HYGIENE FOUNDATION OF AMERICA, Inc.

Preventive Engineering Series, Bulletin No. [illegible] Part [illegible]



Design of Duct Work for Exhaust Systems

PITTSBURGH, PENNSYLVANIA
[illegible]

DESIGN OF DUCT WORK FOR EXHAUST SYSTEMS*

Where the plant layout will permit, the fan and dust collector should be located at a central point, with main and branch ducts radiating to the various sections served. Equipment to be exhausted should be so arranged that in so far as possible, short or large diameter branches are at the extremities of the duct system, while long or small diameter branches are near the exhaust fan.

With scattered processes it is often advisable to separate the equipment to be cared for into several compact sections and provide a separate exhaust fan and duct system for each section. This arrangement of individual systems usually reduces the full load power consumption and also increases the flexibility of the plant. Processes that are normally operated in conjunction with each other should be included in a single group, and if there are a few machines which are much in use they can be tied into two separate duct systems with blast gates arranged to throw the load to either one as dictated by the plant operations. Multiple exhaust systems may be served by individual dust collectors or one large collector may take care of several systems. In the latter case back pressure valves (Figure 1) must be provided in each duct system to prevent back flow of air when one or more systems of the group are shut down.

Ducts should be located so that they are readily accessible, do not interfere with free access to the equipment served, or the operation of cranes, conveyors, elevators, trucks, etc., and where they will not be subject to injury by cranes, trucks, or other moving equipment. Locations conducive to the condensation of moisture inside the ducts are to be avoided. Underground duct locations are also to be avoided. Ducts should be spaced at least six inches above floors, where possible, and overhead ducts should be located close to the ceiling above.

Where large chips or heavy pieces of solid material may be carried along with the air stream into the duct system, it is advisable to install chip traps in the branch ducts, or such traps may be combined with the suction hoods. Chip traps which depend on expansion only for their effectiveness should have a cross sectional area of at least eight times the area of

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* This is part 5 in the series issued as Bulletin No. 2, under the auspices of the Preventive Engineering Committee.

the ducts served. The automatic dumping type of trap is not recommended due to danger of excessive air leakage. (See Figures 2, 3, 4 for illustrations of various types of chip traps.)

Ducts supplying return or replacement air should be located so that they do not cause excessive air motion near hooded processes. Return air ducts should also be arranged so that the workmen are not subjected to drafts of cold air.

Buffing and grinding wheel duct systems should be segregated, as sparks from the grinding wheels may set fire to the lint and grease from the buffing operation if both are carried through the same duct system.

The duct layout should be arranged so as to avoid passing through fire walls or important floors. This can sometimes be accomplished by placing the main duct on the outside walls of the building. Frequently vertical risers can be located in stair wells. Insurance regulations require that where ducts do pass through fire walls they be provided with automatic fire dampers on both sides of the wall. (For construction details of fire dampers see regulations published by National Fire Protective Association.)

Duct systems for the removal of explosive or readily ignitible materials should be kept independent of other duct systems. The ducts should be as straight as possible, should lead directly to the outside of the building and never through other rooms. Automatic sprinkler heads should be provided near the inlet and outlet of the duct system. If installed inside the ducts they should be placed in an offset and not in the direct path of the air flow. Explosion relief vents are usually required on duct systems handling explosive or readily flammable materials.

Duct Sizes

Common practice in determining duct sizes is to make the branches the same size as the throat openings at the hoods, with the main ducts so sized that their areas at any point are between 20% and 25% greater than the sum of the areas of the hood connections served between the point in question and the dead ends of the mains.

The sum of the areas of the hood connections is known as "load area" and on the basis of the above rule branches are made equal in area to the load area which they serve. Sub mains and mains are sized so that at all points their areas are between 20% and 25% greater than the load area served.

Since floor sweep ducts are used occasionally and for a

few minutes at a time, they are not included in computing the load area or the size of the main ducts.

The method described of sizing the branches and mains in accordance with the load area is a development from certain state codes which specify the size hood connections and the minimum static suction at the hood connections for a given condition. These codes also limit the minimum duct sizes so that their area shall be not less than the connected load area, and for certain conditions they require areas 20% greater than the connected load area (New York State code requires 20% excess area in main ducts on systems used for removal of dust created by grinding, polishing, and buffing wheels). Usually the minimum static suction required at the hood connections is two inches of water. On the usual exhaust system where the average restriction coefficient at the hood connections is taken as 0.7 and the ducts are sized on the basis of branches equal in area to the hood connections, with mains 25% greater area than the load area, the air velocity in the branches is 3960 ft. per minute and in the mains 3170 ft. per minute. These velocities are sufficiently high properly to transport the dust and small particles collected by the exhaust hoods in metal grinding, buffing, and similar applications.

Improved operating efficiency and lower power consumption can be obtained by sizing the branch and main ducts so that they comply with the following basic requirements:

(1) Area at each duct section should be such that the air velocity is not less than the minimum velocity required to carry the material exhausted from the hoods.

(2) Maximum air velocities in branch and main ducts should exceed the minimum transport velocities only by the amount required to obtain even pipe sizes, with the exception that they should be increased in certain branches to obtain balanced suction at the hoods as stated in paragraph 3.

(3) In order to obtain balanced suction at the hoods the pressure drop produced by the air flowing in any branch line should equal that obtained in that part of the main duct and branches which lies up-stream to the branch under consideration.

Method of Determining Pressure Drop in Ducts

The flow of air in a duct gives rise to friction which results in a pressure drop which is dependent upon the straightness of the duct, its smoothness, and perimeter. The pressure drop in straight round galvanized iron exhaust ducts, as

usually constructed, and when handling air at standard density, can be determined with sufficient accuracy by means of the following empirical formula:

$$P = \frac{L \times V^2}{66.6\, d\, (1000)^2}$$

P = Pressure drop in inches of water
L = Length of straight duct in feet
d = Duct diameter in inches
V = Velocity of air flow in feet per minute

Experience has shown that this simple formula works well in practice and that, ordinarily, there is no advantage in using more refined and complicated formulas, as any possible gain in accuracy is offset by the effect of unknown variables, such as, variations in dimensions and smoothness of the ducts, air leakage, etc.

For rectangular ducts the pressure drop is increased by the ratio of the perimeter of the rectangular duct to the perimeter of a round duct of equal area.

Pressure drop in elbows is most easily allowed for by adding to the straight duct, before figuring the friction in same, an additional length to cover loss in the elbows.

For each elbow having a center line radius equal to one half the pipe diameter, add to the straight pipe a length equal to 38 diameters of length. For radius equal to pipe diameter add 13 diameters of length and for radius twice the duct diameter 8 diameters of length.

Abrupt expansion at chip traps introduces pressure losses ranging from ½ to 1 velocity head in value.

The velocity head corresponding to any given velocity can be derived from the basic equation for the flow of fluids which states that

$$v = \sqrt{2gh}$$

Where v = Velocity in feet per sec.
g = Acceleration of gravity, or 32.16.
h = Head of fluid in feet.

A simplified form of the above equation is:

$$I = \frac{V^2}{16\,(1000)^2}$$

Where I = Velocity head in inches of water.
V = Air velocity in duct, in feet per minute.

Transport Velocities

General practice is to design ducts for conveying dust from grinding and buffing wheels, tumbling barrels, sand-blast rooms, stone plants, and similar applications on a basis of a velocity of about 3000 feet per minute. This velocity will also take care of dry sawdust, light wood chips, shavings, sander dust, etc. Grain dust, lint, cotton dust, and similar light materials are conveyed with 2000 foot velocity. At the other end of the scale we have velocities of 4000 to 4500 feet per minute for wet sawdust, heavy wood chips, and of 5000 feet per minute for lead dust.

Exact values of minimum transport velocities based on test data are meager and there are usually unknown factors such as size and shape of particles, density, and lowered operating velocities under part load operating conditions. It can be stated as a general rule, however, that the required transport velocity increases with any increase in density of the material and it also increases with any increase in particle size. DallaValle has expressed this relation in the following equation:

$$V = 54{,}700 \left(\frac{S}{S + 1} \right) p^{0.57}$$

V = Velocity, feet per minute, for vertical transport of material
S = Specific gravity of the material
p = Particle diameter, in feet

For practical purposes this formula may be written:

$$V = 54{,}700 \left(\frac{S}{S + 1} \right) \sqrt{p}$$

DallaValle's formula for horizontal transport shows considerably lower values than for vertical transport; however, the usual practice is to make no distinction between vertical and horizontal transport.

As vapors and gases mixed with air may be moved at any convenient velocity, pipe sizes for such applications are determined by consideration of economy, of size, and power consumption.

Conveying Capacity of Ducts

The quantity of solid material which can be conveyed in suspension in an air stream flowing in a duct is dependent upon the physical characteristics of the material, size of particles, density, and the volume of air flowing. Fine materials require more air than coarse materials. Heavy materials are

moved with less air than low density materials. Experience has shown that with air velocities from 25% to 50% above the minimum transport velocities it requires 50 to 100 cubic feet of air to convey one pound of material.

Dust concentrations in exhaust ducts are usually much below the maximum and ordinarily it is not necessary to check the duct size against the quantity of material to be conveyed. However, in unusual cases, where the concentrations are high for any reason, as is the case where materials from several collectors are discharged into a separate exhaust system for transport to final destination, it is necessary to provide a duct of sufficient size to obtain an air flow of from 50 to 100 cubic feet of air per pound of material conveyed.

Construction

Duct work for exhaust systems is usually fabricated from galvanized sheet iron, the gauges of which vary with the diameter of the duct and the suction at the fan. For low suction systems (up to 10 inches of water at the fan intake) the following gauges are recommended:

Small size ducts, 22 gauge
Ducts 16" to 24" diameter, 20 gauge
Ducts 25" to 34" diameter, 18 gauge
Ducts above 34" diameter, 16 gauge

Exhaust ducts which handle large quantities of highly abrasive materials require heavier gauges.

High suction systems also require heavier gauges or the ducts may be reinforced with band or angle iron.

Heavy welded black iron ducts with flanged and gasketed joints are recommended for extremely abrasive conditions such as granite dust, etc., or where the ducts are subject to external injury or have to be taken down occasionally.

For corrosive conditions ducts may be of cast iron, lead, copper, stainless steel, monel metal, aluminum, tile, or other special material. Ducts may be lined with lead or rubber or painted with acid resisting paints. Tile ducts are to be avoided due to danger of breakage and leakage.

Sheet metal elbows should be two gauges heavier than the ducts to which they are attached.

The main trunks and branch ducts should be as short and as straight as possible. They should be strongly supported and protected against possibility of damage by moving equipment. The dead ends should be capped to permit inspection and, unless space will not permit, elbows should be long turn

with a center line radius equal to one and one-half times the diameter.

Where a movable section of duct is required flexible metal hose, ball or slip joints may be used.

Floor sweeps should always be connected to vertical risers so that all material passing through them will be lifted from the floor by suction, thereby avoiding the possibility of large pieces being swept into them and blocking the system. They should also be equipped with tight fitting blast gates. (For typical floor sweep see Figure 5.)

Ducts installed outside of buildings and which carry moist hot air should be insulated with roofing paper to prevent condensation in cold weather. Very long runs of outside ducts should also be provided with expansion joints.

All ducts passing through roofs require weather caps to prevent water leaking into the building.

Branch ducts should lead out of the hoods at the point where the materials to be conveyed are directed naturally by the operation of the apparatus.

All branches should join the main at an acute angle with the incline in the direction of the air flow (see Figure 6). The junctions should be at the side or top and never at the bottom of the main; nor should two branch connections be placed directly opposite each other. Branch ducts should not project into the main.

All permanent circular joints should be lap jointed, riveted, and soldered, and all longitudinal joints either grooved and locked or riveted and soldered. Circular laps should be in the direction of the air flow, and piping installed out-of-doors should have the longitudinal laps at the bottom.

Cleanout openings having suitable covers should be placed near the bottom of all risers and at other points in the mains and branches so that every part of the system can be reached easily in case the system clogs. Either a large cleanout door should be placed in the main suction pipe near the fan inlet or, preferably, a detachable section of duct held in place by lug bands should be provided. Tight fitting blast gates should be installed at each hood connection.

Increase in duct size should be made on a taper and not by an abrupt change in size. Branches should enter the main at or near the point where the size changes in order to avoid the possibility of an oversize section and too low an air velocity.

All ducts should be smooth on the inside and free from pro-

jections, fins, or rough spots. No screens or other obstructions should be placed in the branches or main ducts, with the exception that cones or other adjustable devices for equalizing the air flow may be placed in the branch ducts close to the points where the ducts join the exhaust hoods. Where such equalizing devices are used they should be of substantial construction securely fastened in place and should not have any projections on which material may catch.

Equalizing devices should not be used where the materials conveyed are extremely abrasive.

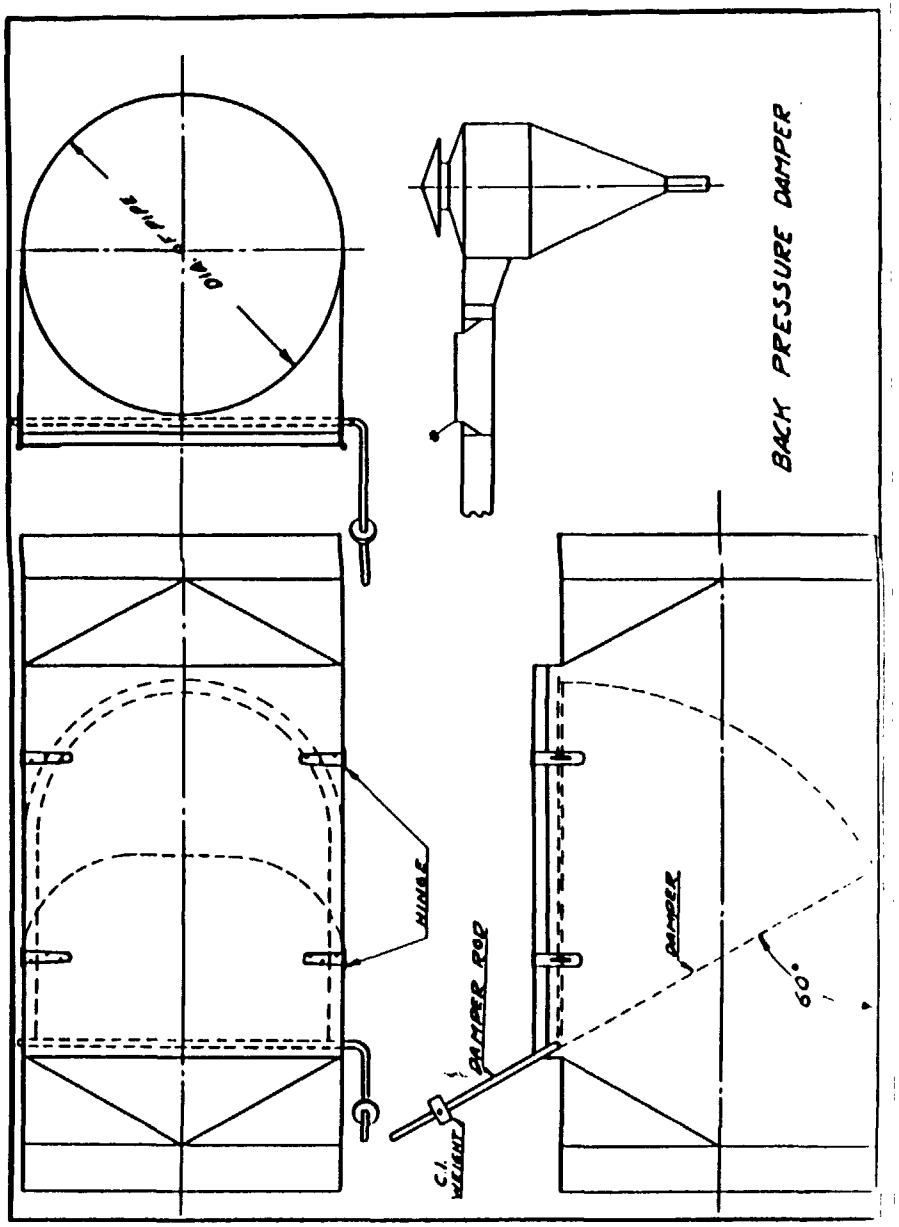
Codes

The duct design should be checked to see that it complies with any state or insurance codes effective for the location and type of exhaust system under consideration. The more important codes to be considered are:

(1) State codes covering the design and installation of exhaust systems—obtainable from state industrial or labor departments.

(2) Fire underwriters regulation for the installation of blower and exhaust systems, published by the National Fire Protection Association, 60 Batterymarch Street, Boston, Mass.

(3) Safety codes for the prevention of dust explosions—published by the American Standards Association, 29 West 39th Street, New York City.



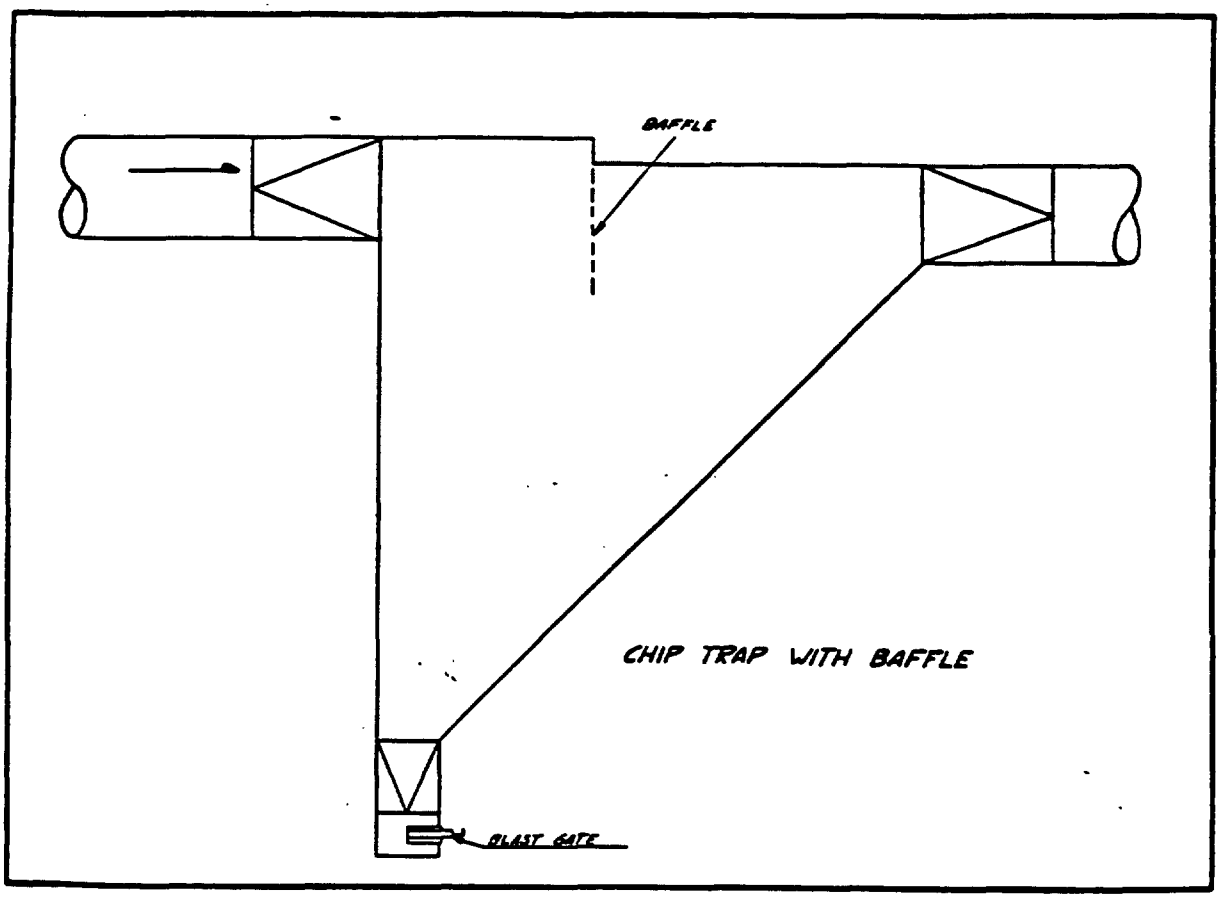
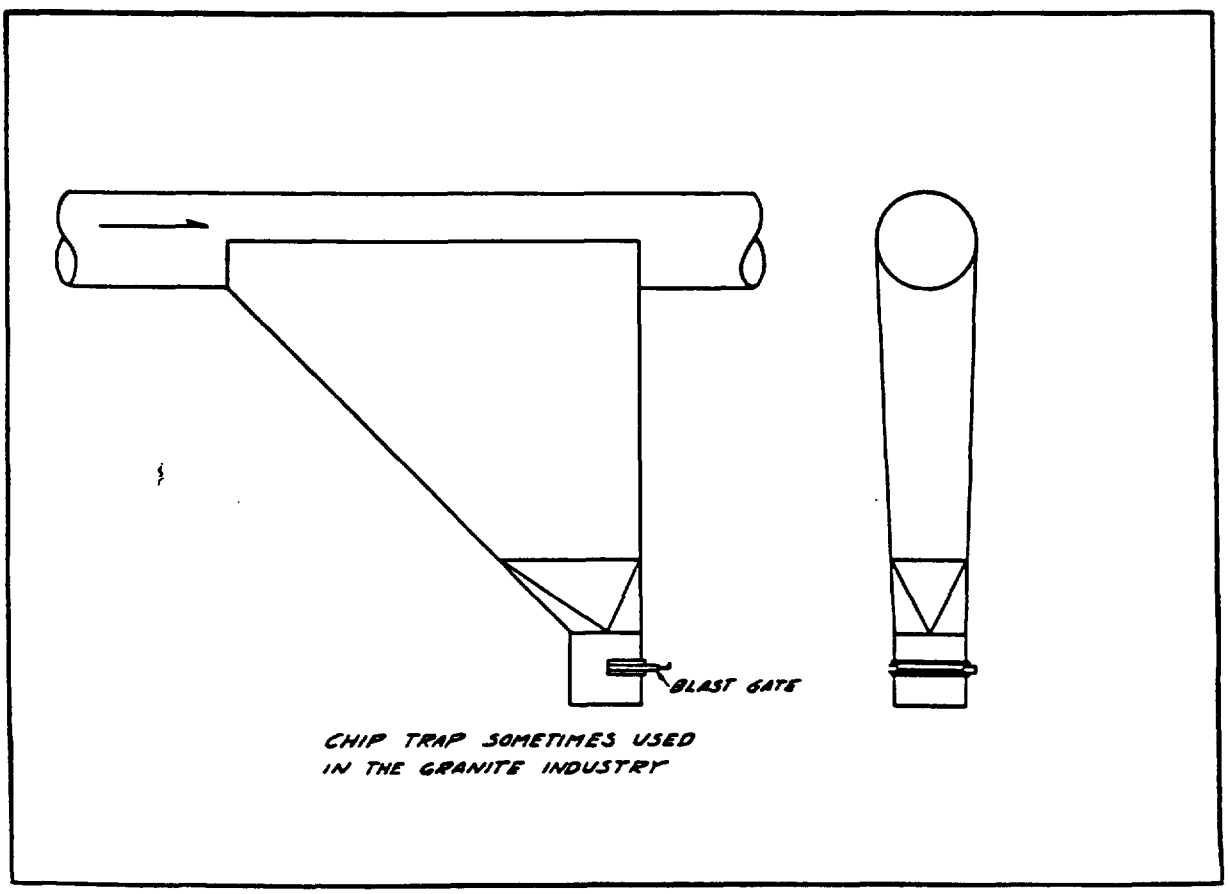

BAFFLE
CHIP TRAP WITH BAFFLE
BLAST GATE

Figure 2.


BLAST GATE
CHIP TRAP SOMETIMES USED
IN THE GRANITE INDUSTRY

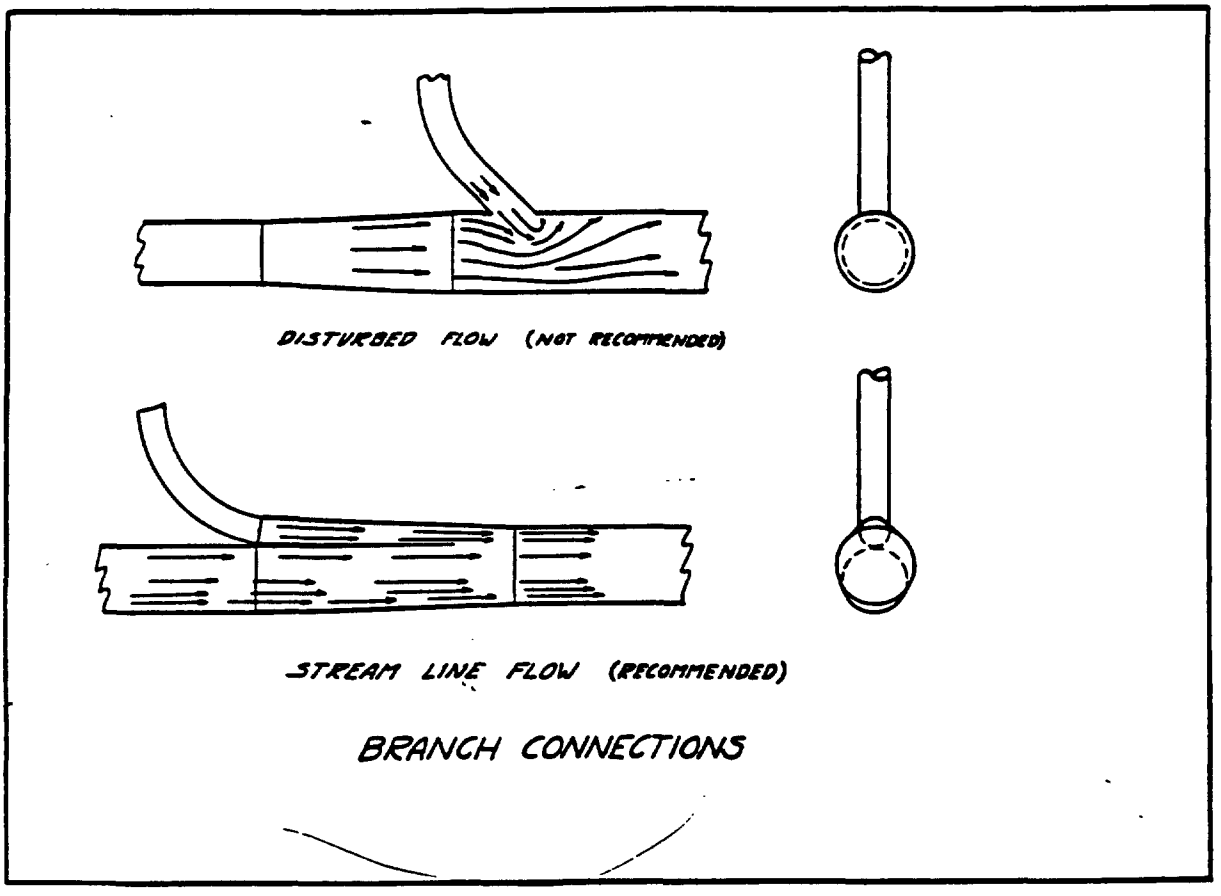
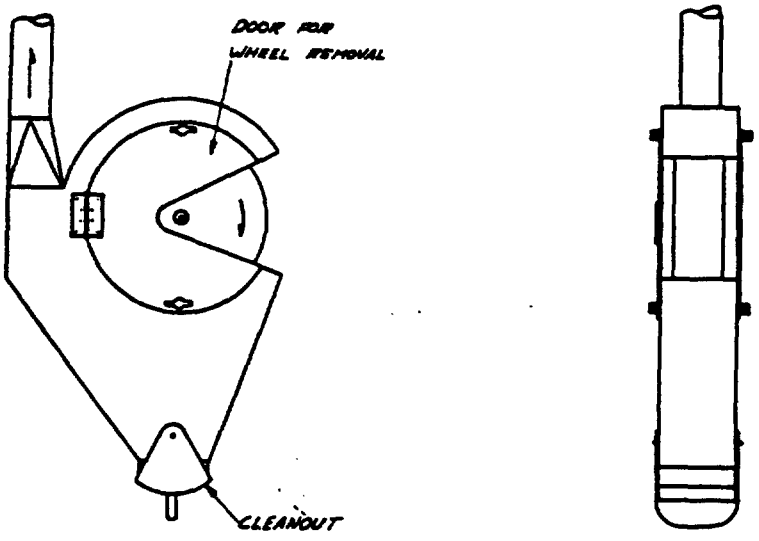
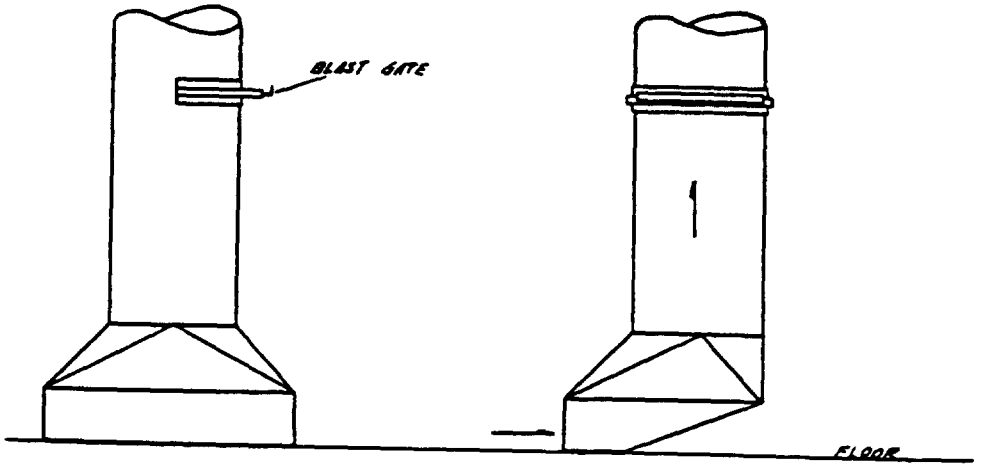

DISTURBED FLOW (NOT RECOMMENDED)
STREAM LINE FLOW (RECOMMENDED)
BRANCH CONNECTIONS

Figure 6.



CHIP TRAP COMBINED WITH SUCTION HOOD

Figure 4.



FLOOR SWEEP

AIR HYGIENE FOUNDATION OF AMERICA, Inc.

Preventive Engineering Series, Bulletin No. 7, Part 1



Determination of Lead in the Air

DETERMINATION OF LEAD IN THE AIR*

Lead dusts, fumes, and mists may be dispersed in air when using or processing lead, its alloys, or compounds. Some commonly-recognized sources of lead contamination are spray painting or enameling, battery making, rubber compounding, the preparation and use of lead pigments, the smelting of lead ores, and other processes requiring the agitation of molten lead surfaces. Other sources exist, and wherever lead is used in any form, the possibility of air contamination by its dusts or fume should be considered.

I. Collection of Dust Sample from the Air

Several dust-collecting methods are available whereby suitable volumes of air may be sampled. For convenience in the later text, it will be assumed that for lead dusts and mists (as in spray coating) an impinger is used to collect the sample from one cubic foot of air per minute in about 75 cc. of distilled water (1 to 10 nitric acid may be used also as the collecting medium). For lead fumes, the electric precipitator is preferred.

Since minute quantities of lead are sufficient to contaminate air, a large enough sample must be taken to provide a quantity of lead within the effective range of the microchemical method used for analysis. Usually, the lead from 30 to 45 cubic feet of air is sufficient. This is not a fixed quantity, however, and the volume of the sample may be adjusted to provide lead as the analyst sees fit after experience has taught him what concentration to expect from a particular operation.

Necessarily, glassware, reagents, and distilled water used throughout the methods discussed must be free of lead and otherwise chemically pure. Pyrex glassware is required. Blank samples should be run in lead-free air from time to time as a check on purity of reagents, etc.

II. Analysis of Sample

The following analytical procedures have been found to be satisfactory for routine determinations of lead in collected air samples.

(a) Volumetric Method - Fairhall's Chromate

By this method, lead is freed of interfering materials and precipitated as chromate. Indirect determination of lead is made by solution and iodometric estimation of the chromate

* This is part 6 in the series issued as Bulletin No. 2, under the auspices of the Preventive Engineering Committee. Part 7 will deal with the identification of industrial dusts.

ion. It is best to have 0.1 mg. or more of lead in the sample. This amount will be present in 30 cubic feet of air when the concentration is about 1.5 mg. per 10 cubic meters. For concentrations considerably above that, smaller samples may be taken, and larger samples are necessary for lower concentrations.

A. Apparatus

Besides common laboratory equipment, an accurate burette of 5 cc. capacity, graduated in 0.02 cc. divisions, is required.

B. Reagents and Solutions

1. Nitric acid, concentrated
2. Hydrogen sulfide
3. Sodium hydroxide, 10%, prepared by adding 10 g. to 95 cc. water
4. Acetic acid, glacial
5. Phenolphthalein, 1% suspension in water
6. Hydrochloric acid, 1:1, prepared by mixing equal volumes of concentrated acid and water
7. Potassium chromate solution prepared by saturating 10 cc. water with the salt and filtering
8. Potassium iodide solution prepared by dissolving 5 g. in 50 cc. water
9. Starch indicator prepared by adding about 0.1 g. powdered starch, suspended in 5 cc. water, to 25 cc. boiling water
10. 0.005 N sodium thiosulphate ($Na_2S_2O_3$) solution prepared by dissolving 0.7910 g. of the freshly dried anhydrous powder in 1 liter of freshly distilled water. This is standardized against an 0.005 N solution of iodine freshly prepared by dissolving in a volumetric flask exactly 0.0635 g. *of freshly sublimed iodine in 100 cc. of dilute* potassium iodide solution. The $Na_2S_2O_3$ solution tends to decompose unless protected from the air and should be stored in tightly stoppered bottle whose volume is only slightly greater than that of the solution. Its concentration should be checked every two weeks or before use as below. Run exactly 10 cc. iodine solution into a flask from ordinary burette (iodine solution must be made fresh for each standardization). Add 20 cc. water and a few drops of starch solution. Add $Na_2S_2O_3$ solution from another burette until blue

color just disappears. Repeat twice or until results check. Then:

$$\text{Normality (N) of } Na_2S_2O_3 = \frac{0.05}{\text{Volume } Na_2S_2O_3}$$

and since

1 cc. of 0.005 N $Na_2S_2O_3$ = 0.345 mg. of lead

$$\text{1 cc. of } Na_2S_2O_3 \text{ of normality N} = \frac{N \times 0.345}{0.005} \text{ mg. of lead}$$

C. Procedure

1. Wash contents of impinger collecting flask (or other sampling container) into 250 cc. beaker with water and 5 cc. nitric acid
2. Evaporate slowly to dryness and repeat with a few drops of nitric acid if much organic matter is present
3. Evaporate twice to dryness with one cc. hydrochloric acid
4. Dissolve residue by heating in 25 cc. water plus 5 drops of nitric acid
5. Filter into Erlenmeyer flask, washing well with warm water
6. Neutralize with sodium hydroxide and make just acid with hydrochloric acid, adding 2 drops in excess. (Phenolphthalein indicator.)
7. Saturate with hydrogen sulfide. (If such interfering salts as those of calcium, iron, and phosphorus, or silicate dusts were not present in the original air sampled, steps 5, 6, 7, and 8 may be eliminated)
8. When precipitate of lead sulfide has flocculated, filter and wash on an acid-resisting paper, such as Whatman #50
9. Dissolve precipitate through filter with a few cc. of warm concentrated nitric acid and wash well with warm dilute nitric acid
10. Just neutralize filtrate with sodium hydroxide. *(Phenolphthalein indicator.)*
11. Add 5 or 6 drops acetic acid and warm the solution
12. Add 10 drops potassium chromate solution and let stand for 2 to 12 hours until yellow precipitate of lead chromate has coagulated. This may

be hastened by heating solution just to boiling for 5 minutes

13. Filter and wash well with warm water. The final wash water must not produce a precipitate when a drop of lead acetate solution is added to it. (Whatman's #42 paper, 7 cm., is best suited for this filtration.)
14. Dissolve precipitate through filter into Erlenmeyer flask with about 2 cc. hydrochloric acid and wash well with warm water. This should remove all yellow color from the filter.
15. Add 2 cc. potassium iodide solution to filtrate, together with several drops starch indicator
16. Titrate immediately with measured volume of sodium thiosulfate from 5 cc. burette until blue color disappears.

D. Calculations and Reactions

$$Pb(NO_3)_2 + K_2CrO_4 = PbCrO_4 + 2KNO_3$$

$$2PbCrO_4 + 16HCl + 6KI = 2PbCl_2 + 2CrCl_3 + 6KCl + 3I_2 + 8H_2O$$

$$6Na_2S_2O_3 + 3I_2 = 6NaI + 3Na_2S_4O_6$$

wherefrom: $3Na_2S_2O_3 = PbCrO_4$

Typical examples:	1.	2.
a. Total air sample	30 cu. ft.	60 cu. ft.
b. $Na_2S_2O_3$ used (0.005N)	2.305 cc.	0.32 cc.
c. Total mg. lead = b × 0.345	0.795 mg.	0.110 mg.
d. Mg. lead/cu. ft. = $\frac{c}{a}$	0.0265	0.0018
e. Mg. lead/10 cu. meters air = d × 353	9.3	0.6

f. Condensed calculation (1)

$$2.305 \times 0.345 \times \frac{353}{30} = 9.3 \text{ mg./10 cu. m.}$$

(b) Colorimetric - Dithizone

By this method, lead is extracted from a solution of controlled alkalinity with a chloroform solution of dithizone (diphenyl-thiocarbazone). Dithizone forms colored metallo-organic compounds with several heavy metal ions. By proper control of alkalinity, and cyanide concentration, interfering ions are eliminated, and the cherry-red lead compound is segregated in solution. the intensity of color depending on the amount of lead present. For quantitation, the color is compared with that of dithizone solutions containing known amounts of lead.

The quantity of lead in the portion of the sample taken for analysis should be less than 0.1 mg. and preferably not over half that much. This allows sampling of smaller quantities of air than 30 cu. ft., particularly if the lead concentration is suspected of being above 1.5 mg. per cu. m.

A. Apparatus

Besides common laboratory glassware, there are required several 100 cc. volumetric flasks, six or eight Squibb separatory funnels, and a set of 12 color-comparison tubes (50 cc. Nessler tubes).

B. Reagents and Special Solutions

1. Nitric acid, concentrated
2. Extractive solution A. To 15 cc. of 10% potassium cyanide solution (10 g. KCN dissolved in 95 cc. water) add 20 cc. of 5% ammonium citrate solution (5 g. ammonium citrate in 95 cc. water and made just alkaline with ammonium hydroxide). Then add 53 cc. concentrated ammonium hydroxide of sp. g. 0.9 and 450 cc. water
3. Extractive solution B. To 500 cc. water add 5 cc. 10% potassium cyanide solution and 15 cc. concentrated ammonium hydroxide
4. Chloroform
5. Dithizone solution. Dissolve 5 mg. dithizone in 200 cc. chloroform. Dithizone may be obtained in 1 gram lots from Eastman Kodak Company, Rochester, New York, or through a laboratory supply house. (If a yellow or brown color appears in the blanks, the purity of the dithizone is questionable.)
6. Lead nitrate standard solution. Dissolve exactly 1.598 g. of purified lead nitrate in water plus 1 cc. nitric acid, bringing total volume up to exactly 1,000 cc.

   To a 10 cc. portion of this solution, which contains 1 mg. lead per cc., add 990 cc. water to obtain a solution containing 0.01 mg. lead per cc.

C. Procedure

1. To the sample contained in sampling flask, add just 10 cc. nitric acid and boil until the volume

is less than 90 cc. or until solution has boiled for several minutes. Cool and wash sample into 100 cc. volumetric flask, bringing volume to 100 cc. Note that the sample contains exactly 10% nitric acid by volume.

2. Mix sample and remove 5 cc. to a Squibb separatory funnel containing 15 cc. of extractive solution A. (Reagent 2.)
3. Add dithizone solution from a burette, 0.3 cc. at a time, shaking after each addition until cherry-red color in the bottom layer just becomes tinged with purple
4. Add chloroform from another burette in such amount that the total of dithizone solution plus chloroform equals 10 cc.
5. Shake funnel for 10 seconds
6. Run bottom chloroform layer into second separatory funnel containing 20 cc. of extractive solution B (reagent 3), and shake well. If chloroform layer is not now a clear red color repeat *step six*
7. Run chloroform layer into color comparison tube and stopper with cork
8. At same time prepare color comparison standards containing 0.005, 0.010, 0.015, 0.025, and 0.04 mg. lead from nitrate of lead solution (diluted, reagent 6). For 0.005 mg. standard take 5 cc. of lead solution, add exactly 40 cc. water and 5 cc. nitric acid. Treat 5 cc. of this thoroughly mixed solution as outlined above (steps 1 through 7). For other standards use proportionately larger amounts of lead solution but always make up to 50 cc. including 5 cc. of nitric acid. For example, 0.015 mg. standard includes 15 cc. lead solution, 30 cc. water, and 5 cc. nitric acid.

   If aliquot portion of the sample (1/20) is expected to contain more than 0.04 mg. lead, higher standards up to 0.1 mg. may be prepared from the concentrated stock lead solution (reagent 6), by the same procedure and with the same precautions as to the amount of acid.
9. Match unknown air sample with standards, interpolating between as near as judgment allows

D. Calculations

	1.	2.
a. Total air sample	30 cu. ft.	20 cu. ft.
b. Color matches	0.008 mg.	0.025 mg.
c. Estimated total lead = b × 20	0.16 mg.	0.5 mg.
d. Mg. lead/cu. ft. = $\frac{c}{a}$	0.0053 mg.	0.025 mg.
e. Mg. lead/10 cu. m. = d × 353	1.9	6.7

f. Condensed calculation (1)

$$0.008 \times 20 \times \frac{353}{30} = 1.9 \text{ mg. lead per 10 cu. m.}$$

Microscopic Detection of Lead

It is often important to determine qualitatively the presence or absence of lead in dust samples, in raw materials, such as paint pigments, glazes, enamels, etc., or in excreta. This may be accomplished quickly by a microscopic method in which the lead iodide is precipitated from a drop of solution and identified microscopically by its form and color. Antimony, bismuth, and silver will interfere with the determination, and if present must be eliminated by special methods.

A. Apparatus
   1. Microscope and accessories including 10 x eyepiece and 10 x objective for total magnification of 100 diameters
   2. Microscope slides
   3. Small alcohol lamp or hot plate
   4. Several capillary tubes made by drawing out 5 mm. glass tubing to about 0.5 mm. diameter

B. Reagents and Solutions
   1. Nitric acid, 1:7, prepared by diluting 10 cc. concentrated acid with 70 cc. water
   2. Acetic acid, 1%, prepared by diluting 1 cc. glacial acetic acid with 99 cc. water. These solutions may be conveniently kept in glass-stoppered 2 oz. bottles, equipped with glass dropping-rod
   3. Potassium iodide crystals

C. Procedure
   1. Place small amount of material to be analyzed, about the size of the head of a pin, near one end of microscope slide
   2. Place one drop of nitric acid on the material

3. Slowly evaporate liquid to dryness over alcohol flame by repeatedly introducing the slide to and withdrawing it from the flame. If hot plate is used, it should be just moderately hot
4. Add second drop of nitric acid to material and repeat evaporation. If lead is present, characteristic dendritic crystals of lead nitrate should now be visible microscopically. See Figure 1.
5. Add one drop of acetic acid to the material and warm
6. Touch end of capillary tube to drop, drawing up most of the liquid by capillary action but leaving behind any undissolved solids
7. Place end of capillary tube on clean end of slide and deposit liquid by gently blowing on other end
8. With the sharpened end of a match stick, slightly moistened, or a fine glass needle, introduce a small crystal of potassium iodide, no larger than a common salt crystal, into the edge of the drop and immediately focus microscope on edge of drop
9. The appearance of yellow hexagonal plates, precipitated within the drop, indicates the presence of lead. See Figure 2. With considerable amounts of lead, these plates will appear immediately and be large. With smaller amounts, their appearance may be delayed until the drop has partially evaporated. If crystals do not appear in two or three minutes, add another crystal of iodide and continue watching. If very minute crystals are formed, they should be viewed under higher magnification to identify their form
10. When excreta are to be examined, the hexanitrite test should be used (See reference 4).

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Figure 1. Lead Nitrate Crystals (100X)

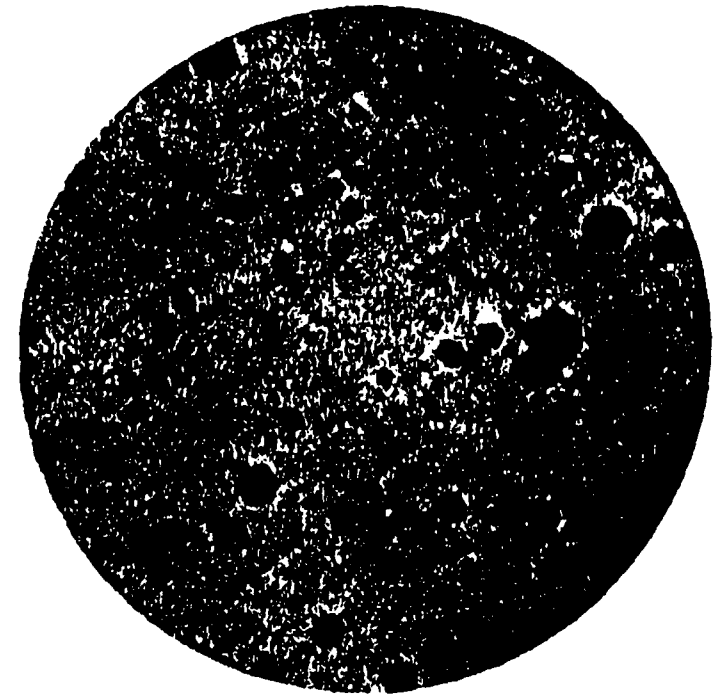
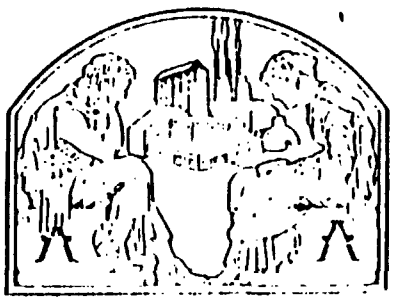


Figure 2. Lead Iodide Crystals (100X)
Yellow hexagonal plates are characteristic of lead iodide

box

AIR HYGIENE FOUNDATION OF AMERICA, Inc.

Preventive Engineering Series, Bulletin No. 2, Part 1



Identification of Industrial Duct

PITTSBURGH, PENNSYLVANIA
JULY, 1939

IDENTIFICATION OF INDUSTRIAL DUSTS*

The inorganic materials found in industrial dusts are largely minerals, although many artificial substances are also encountered. Chemical analyses of mixtures of such materials will seldom reveal the percentages of the various minerals present. In the determination of silica, for example, if a dust contains free silica plus silicates, the silica determined chemically will be "total silica," that is, all of the free silica plus the silica combined with other elements to form silicates, with no indication as to the amount which is uncombined or the amount to be allotted to each silicate. However, each mineral has characteristic optical properties, that can be determined microscopically with the aid of polarized light. This method of identifying minerals by means of their optical properties is known as optical mineralogy. The identification of industrial dusts is accomplished best by using petrography as the basis of analytical work and supplementing it wherever necessary with chemical determinations.† Any information relative to raw materials and processes will facilitate the analysis.

For purposes of identification, dusts may be classified in general into four groups:

(a) those composed chiefly of soluble materials (limestones, fertilizer, parting compounds, etc.).

(b) those composed chiefly of organic materials (wood, brewery and distillery, tobacco, leather, grain, etc.).

(c) those composed chiefly of insoluble and inorganic materials (granite, foundry, tile and brick, abrasives, etc.).

(d) those composed chiefly of metals or their compounds (lead, manganese, etc.). The dusts in this group are the easiest to identify and will not be discussed in this bulletin. Under the microscope they are generally opaque.

Chemical Examination

If a sample belongs either to group (a) or (b), the amount

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* This is part 7 in the series issued as Bulletin No. 2, under the auspices of the Preventive Engineering Committee. Part 8 will deal with routine sampling for control of atmospheric impurities.

† It is assumed throughout that those undertaking dust analysis have had some training in quantitative analysis.

of soluble and combustible material can be determined as follows:

I. Soluble material (type a) determined by treating a one-gram sample with warm 1:10 HCl.

II. Combustible (organic) material (type b) determined by igniting a one-half to one-gram sample.

Total silica may be determined by the sodium carbonate fusion method[1]. The filtrate can be tested chemically for other elements. This test may also be applied to the filtrate from the determination of soluble material (see I. above). For example, if $CaCO_3$ is believed to be present, the filtrate can be tested for calcium, or if tricalcium phosphate parting compound is being analyzed, the presence of the phosphate can be confirmed chemically.

Petrographic Examination

Although chemical methods may be used to determine the presence of specific elements, petrographic technique is necessary for identifying minerals.

There are certain optical constants of minerals which are determined in identifying them by means of optical mineralogy. Those which are applicable to the fine-grained components of industrial dusts are index of refraction, which is a measure of the amount of refraction or bending of light rays which pass through the particles; birefringence, which is a measure of the amount of separation of light rays emerging from the particle (i. e., the difference between maximum and minimum indices of refraction); pleochroism, which is differential color absorption; extinction angle, and elongation sign, which measure the relation between crystallographic and optical orientations. In addition, such physical constants as crystal form and cleavage (which govern shape), color, magnetic properties, etc., may be of value.

The method requires the use of a polarizing microscope, microscope lamp, a set of liquids of known index of refraction, microscope slides, and cover glasses.

Microscope:

A polarizing microscope differs from the ordinary microscope chiefly in that the former has two "Nicol prisms," which produce plane-polarized light, i. e., light vibrating in a single plane. One, the polarizer, is located below the condenser; the other, the analyzer, is located in the microscope tube above the objective. Either, or both, can be removed from the path of light through the instrument. When both are in the instrument with planes of polarization at right angles to each other,

they are said to be in a "crossed" position (field is dark). Observations are made with crossed Nicols and with one prism removed from the path of light. The newer type polarizing materials, such as Polaroid, or Zeiss Bernauer polarizers, may be used on an ordinary microscope, but they are not satisfactory at high magnifications, since they do not completely cut out all of the light when in the "crossed" position. Because of the small size of the particles being studied, the microscope should be equipped with at least high-dry (x50) and oil-immersion (x90) objectives and eyepieces with magnifications of 10 and 30 diameters.

Index Liquids:

The liquids of known indices of refraction are used to determine the indices of dust particles. A set of these liquids with indices ranging from 1.420 to 1.770, with intervals of one in the second decimal place, are satisfactory for dust analyses. The liquids up to 1.700 can be made with the aid of an Abbé refractometer. Above 1.700 the method of measuring minimum deviation with a prism on a goniometer is used. Mixtures of amyl alcohol 1.409, kerosene 1.448, petroleum oil 1.477, monochlornaphthalene 1.626, monobromnaphthaline 1.658, methylene iodide 1.737-1.741, methylene iodide saturated with sulfur 1.778 are used. Each liquid is miscible with those with indices immediately above and below it. (These liquids are quite susceptible to temperature changes—index decreases as temperature increases .0004 to .0007 for each degree centigrade.) Such liquids are used routinely in all petrographic work and, therefore, can be obtained from the geology departments of many universities, as well as from the following dealers in scientific supplies: Eastman Kodak Company, Rochester, New York; Fisher Scientific Company, Pittsburgh, Pennsylvania; Eimer and Amend Company, New York City; and Arthur H. Thomas Company, Philadelphia, Pennsylvania.

Index of refraction is determined, with the analyzer out, by immersing portions of the sample in liquids of known index of refraction until the indices of the mineral are matched with those of the liquids. When a non-opaque particle has an index of refraction exactly the same as the liquid in which it is immersed, it disappears. Individual mineral particles behave as imperfect lenses if they have a different index from that of the liquid. If a grain has a higher index than the liquid, it will tend to focus the light from the condenser at a plane above its own (Figure 1). If the microscope is focused on the grain and the tube is then raised slightly, the center of the grain will become lighter because of a tiny halo of light sur-

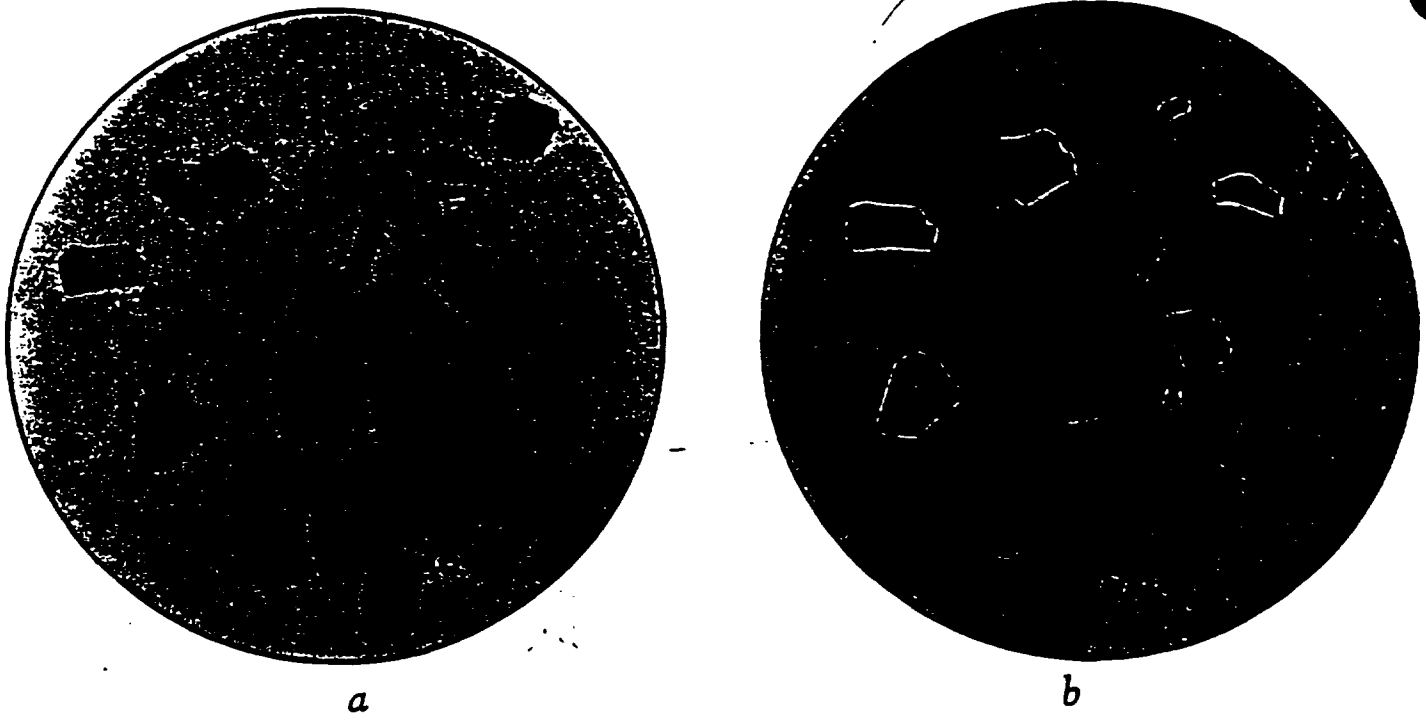


Figure 1

FIGURE 1

Index of Refraction

(a) grains of quartz (Q) and feldspar (F) in focus in a 1.540 liquid.

(b) quartz (Q) and feldspar (F) in 1.540 liquid with microscope tube raised slightly. The halo of light has moved in toward the grain in (Q) indicating that its index is higher than that of the liquid, while in (F) the halo has moved away from the grain toward the liquid, showing the grain to have an index of refraction lower than that of the liquid.

rounding the mineral which moves in toward the center of the grain as the tube is raised. This halo always moves in the direction of the higher medium when the microscope tube is raised. Thus, if the mineral particle has an index lower than the liquid, the halo will move away from the particle toward the liquid. For example, if a mineral with an index of 1.600 is placed in liquids with indices of 1.580 and 1.620, the halo will move toward the mineral in the first and away from the mineral in the second. By placing portions of the sample in different liquids, the indices of the various constituents can be determined. Indices of unknown minerals are determined by trial and error, with different liquids being used, until the closest possible one is found. On the other hand, if a known substance is being sought, its index can be found in tables[2] and the proper liquid used.

Since most crystalline materials have more than one index (uniaxial have two: ω and ϵ; biaxial have three: α, β, γ), it is desirable to measure as many as possible. Under crossed Nicols, as the stage is rotated through 360°, a crystalline substance will be seen to become dark at four positions 90° apart. These are known as "extinction positions." They result from the coincidence of the principal vibration planes of the crystal and the vibration planes of the two Nicol prisms. These represent principal optical directions. Indices of uniaxial and biaxial substances should be determined at extinction positions. The Nicols are "crossed" and an extinction position located by rotating the stage; the upper Nicol is removed and index of the mineral checked against the liquid in which it is immersed; the Nicols are crossed again, the stage rotated 90° to the next extinction position, the upper Nicol removed, and this index checked against the liquid. Several grains should be measured so that the highest and lowest indices may be found. For example, if calcite, which is uniaxial ($\omega = 1.658$, $\epsilon = 1.486$) is immersed in a 1.540 liquid, it will be found that at one extinction position the index of the mineral is higher than the liquid and at 90° the index of the mineral is lower than the liquid. In a 1.490 liquid, the mineral will be practically matched with the liquid in one direction and considerably higher at 90°. To determine the highest and lowest indices, particles having maximum birefringence should be used (orientation of the grains is one factor in birefringence—see next section).

Biaxial minerals have a third index (β), which is intermediate between the maximum and minimum (α and γ). In materials below 10 microns in size, it is practically impossible to locate the third index. However, in most cases, the two

extreme indices together with other properties will be sufficient to distinguish the mineral.

Birefringence:

When the Nicol prisms (or polaroid discs) are in a "crossed" position, the field or background is dark and the particles are light (except amorphous substances like glass and isometric crystalline substances which are dark under crossed Nicols). They may be light gray or have a definite color, known as an "interference color." The color produced depends upon the difference between the maximum and minimum indices of refraction, the thickness of the grain, and its orientation on the microscope stage. The scale of interference colors includes light gray (which is characteristic of minerals of low birefringence) and four orders of colors—each order consisting of a complete visible spectrum. First order colors are bright, second and third order increasingly lighter, and the fourth order (highest birefringence) are pastel shades. Thus, with grains of uniform thickness, the lighter the colors (except gray), the higher the birefringence (Figure 2).

Pleochroism:

Some crystalline materials may remove certain wave lengths of light passing through them. This phenomenon may be differential with respect to various crystal directions, so that when using one polarizing element a pleochroic crystal will change color when rotated 90°. The iron mica biotite, for example, is dark brown in one position and straw colored at 90° from that position.

Extinction angle:

When it is possible to compare the principal optical directions of a mineral, located by extinction positions, to crystallographic directions, a clue may be obtained as to the crystallographic orientation of the directions of vibration corresponding to the indices of refraction. For example, talc has good cleavage parallel to the C-crystal axis; when this cleavage is parallel to the direction of vibration of a Nicol prism and the mineral is at extinction, the extinction is said to be parallel (Figure 3). Thus, the optical and crystallographic directions coincide. In the case of tremolite, which has cleavage parallel to the C-crystal axis, when a needle is at extinction there is an angle of 17° (or less) between the cleavage and direction of vibration of a Nicol prism. Thus, tremolite is said to have an extinction angle of 17° (Figure 3).

Elongation sign:

When crystals (such as talc, tremolite, etc.), have a definite

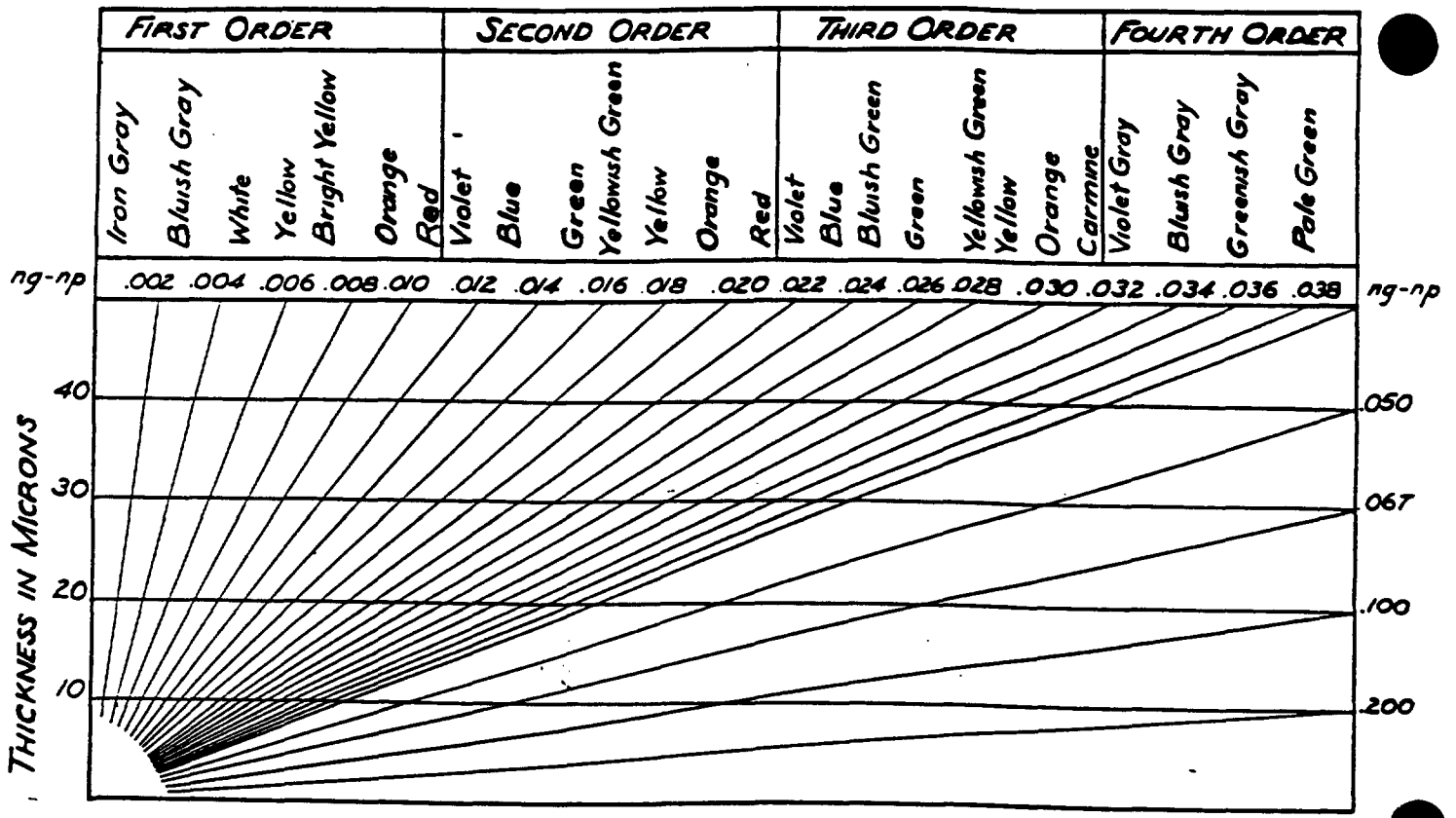


Figure 2

FIGURE 2

Diagram Showing Relation Between Birefringence (ng-np), Thickness of Grain and Interference Color

A grain of quartz (birefringence .009) 20 microns thick will have an interference color between bluish-gray and white. This is determined by following the diagonal line from .009 to the lower left-hand corner of the diagram until it intersects the horizontal line representing 20 microns; then projecting a vertical line from the point of intersection to the interference color scale above. (Adapted from Winchell's Derivation of Newton's Color Scale, 8 p. 112.)

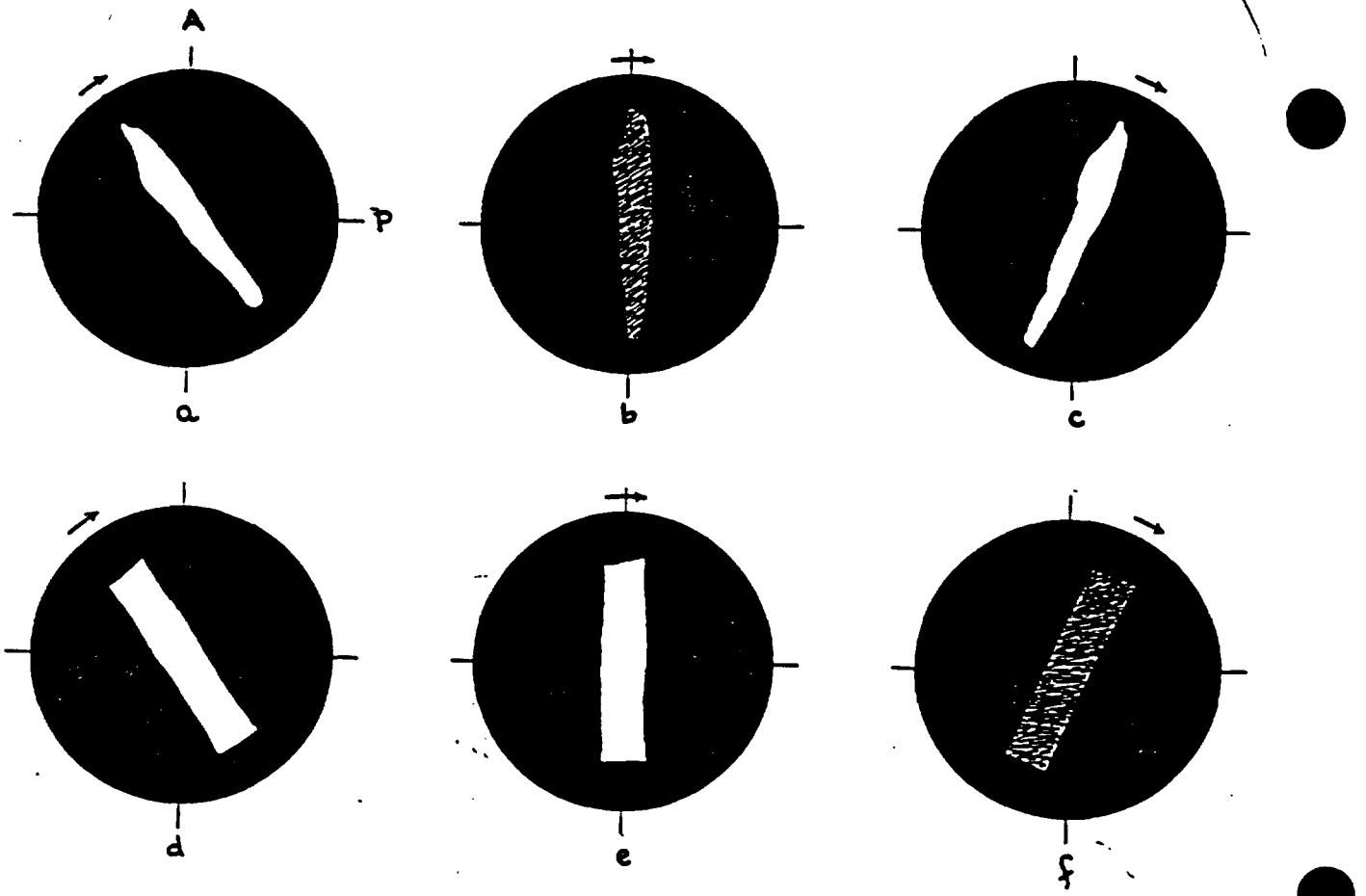


Figure 3

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FIGURE 3

Parallel Extinction and Extinction Angle

A shows the direction of vibration of light emerging from the analyzer; P the direction of vibration of light emerging from the polarizer; (a), (b), and (c) represent the rotation of a grain of talc under crossed Nicols. As the long axis of the grain becomes parallel to the direction of one Nicol prism, the grain becomes dark. Thus, the mineral has parallel extinction. In (d), (e), (f), a grain of tremolite rotated does not become extinct in the parallel position, but does so 17° beyond. Tremolite has an extinction angle of 17°.

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direction of elongation, the relation between this direction and the vibration directions of the rays passing through it may be used as a factor in their identification. A crystal having the direction of vibration corresponding to its highest index (slow ray) parallel (or nearly parallel) to its direction of elongation, is said to have positive elongation. If the direction of elongation is more nearly parallel to the direction of vibration corresponding to the lowest index of refraction, a crystal has negative elongation.

Shape:

Certain minerals have characteristic shapes which may help in their identification. Asbestos, for example, occurs in characteristic long fibers, the micas in plates and needles, calcite as rhombs, etc.

Color:

Color may be helpful, but it is not always diagnostic because small amounts of impurities may cause color changes.

Technique

A small amount of the dust taken on a pointed match is immersed in the liquid chosen (start with 1.560). A drop of liquid is placed on a clean microscope slide, the dust placed in the drop, and a cover glass applied. The indices of the various minerals present are determined by the method described above (Table II, which is appended, gives the optical characteristics of a few minerals commonly found in dusts. For a complete table of all minerals, see Larsen and Berman's Bulletin[2]). The quantities of the various minerals present are expressed by particle count in the sizes below 10 microns. One hundred particles in each of three to five fields are identified and counted to determine percentage of each mineral present. For example, if 500 particles are counted with the following result—quartz 100, feldspar 200, mica 50, opaque (metal or metallic oxide) 25, others (material which may not be identified or in which you are not interested) 125—this would mean that quartz forms 20%, feldspar 40%, mica 10%, opaque 5%, others 25% by particle count. Confirmation of any doubtful mineral may be made chemically by testing for some of the elements present in that mineral.

Size limitations:

In his report on the determination of free silica, Knopf[3] made the statement that ". . . . petrographic examination of the material must be supplemented by other methods, because the minimum grain size that can be conclusively identified under the petrographic microscope is about 0.010 mm. (10 microns) in diameter." Considerable work has been done

since this statement was made and it has been found that the lower limit on the size of particle which can be seen and identified depends on many factors, including wave length of light used, magnification, birefringence of the material, and the difference between the index of refraction of the mineral particle and that of the liquid in which it is immersed. In a recent report of the Sub-Committee on Dust Procedures in Air Analysis of the American Public Health Association, the lower limit given for the identification of free silica is about two microns[4]. For materials of high birefringence, such as the carbonates, this limit is even lower.

Examples of Application

Because of the wide differences in composition of industrial dusts, it is necessary to use considerable judgment in their analysis. A few examples of ways in which these methods may be applied are given below.

1. A granite dust contains quartz (1.544, 1.553), potash feldspar (1.519, 1.523, 1.525), mica (biotite) (1.616, 1.670, 1.670), magnetite (opaque) and some zircon (1.926, 1.985) as accessories. If this dust is immersed in a 1.540 liquid, quartz, biotite, and zircon will be higher than the liquid and feldspar lower. Thus, all the material below the liquid is feldspar; the biotite is distinguished from quartz and feldspar by its higher indices and birefringence; magnetite is opaque and affected by a magnet, while zircon has extremely high indices and birefringence.
2. Foundry dusts are composed of quartz, potash, feldspar, clay, carbon (opaque), iron oxide (red), micas, calcite, etc. In a 1.540 liquid, feldspar is below, calcite has one index below and one considerably above, iron oxide has a red color in both ordinary and polarized light, all other minerals have indices above 1.540. The calcite can be distinguished by its high birefringence and quartz, clay, and feldspar separated by their indices (Table II). In addition, carbon is combustible and calcite and iron oxide are soluble in HCl.
3. In a mine dust containing dolomite, sulfides, quartz, tremolite, diopside ($CaMgSi_2O_6$) and traces of talc, etc., the problem of determining free silica (quartz) arose. Dolomite and sulfides are acid soluble and could be removed in this way. The residue containing quartz and silicates was

treated with hydrofluosilicic acid to remove the silicates. It was found, however, that the residue consisted of a mixture of quartz and diopside (tremolite and talc had dissolved, but diopside had not). Since diopside has indices of 1.671, 1.678, 1.699, and quartz 1.544, 1.550, they could be separated easily in a 1.600 liquid. All of the minerals in the original sample can be determined optically, however, for the sulfides are opaque, dolomite has high birefringence, diopside high indices of refraction (see above), tremolite indices 1.599, 1.613, 1.624, and quartz has the lowest indices. Thus, by using liquids with indices of 1.560, 1.620, and 1.660, it is possible to identify all of the minerals in this dust.

Variations in Composition with Size

The distribution of minerals in different size ranges is quite variable. The minerals present in one size range are generally present in all size ranges, but their proportions vary. For example, it has been shown that in foundry dusts, the amount of free silica decreases, while carbon and iron oxide increase, as particle size decreases.

TABLE I.

DUST FROM SHAKE-OUT*

	Size of Fraction in Microns				Calculated Composition of the total sample	
	> 10	5-10	2-5	< 2	% by wt.	% by count
Combustible.....	3.2	7.9	10.2	30.2	5.2	27.2
HCl Soluble.....	9.5	27.2	34.1	45.8	14.0	48.6
Silicates.....	22.0	31.8	47.4	23.0	24.5	26.0
Quartz.....	65.3	33.1	8.3	1.0	56.3	3.2

*See reference (5).

These changes are characteristic of industrial dusts in general and manifest themselves in many ways. Some glass batch house dusts from operations where coarse washed silica sand is used have such a sharp demarcation in grain size that in a mixture of 50% quartz and 50% soda ash, the quartz is all above 50 microns and 90% of the soda ash is below 50 microns. In this case, screening with a 270-mesh screen

(about 60 microns) gives a fraction retained having a composition of nearly 100% free silica and the portion passed practically pure soda ash. Such a mixture is probably of low, if any, hygienic significance, because the sand grains are so large. In many talc dusts, the calcium carbonate present is practically all below ten microns in size. In such a case, the sample may show 50% soluble in dilute HCl (representing the calcium carbonate in the whole sample), while the carbonate particles will form 80% of the grains below ten microns, by particle count. (An analyst should be wary of trade names, for they are often misleading. The term "talc" as used commercially may include material containing as low as 6% of the mineral talc and as high as 85% of calcium carbonate[6].)

These examples are given to stress the importance of defining the size range of the material analyzed. In some cases, it may even be advisable to fractionate the material by elutriation and analyze each fraction. A method for such fractionation developed by Cummings[7] is as follows:

> "The dust to be separated is thoroughly dried in the drying oven and is then passed through screens suitable for separating particles larger than the upper limit of the size desired. Dust passing through a 270-mesh screen has been used for the separations illustrated.
>
> "Twenty-five grams of this screened material are spread evenly over the bottom of a large, flat, glass culture dish 22 cm. in diameter and 8 cm. deep. Dilute 125 cc. of 95% alcohol to 250 cc. and pour this mixture slowly into the dish, and at the same time work the dust to a smooth paste with a rubber 'policeman.' Add to this suspension a liter of water, stir constantly, and continue the agitation until a homogeneous suspension is obtained.
>
> "Just as the agitation is stopped, the time is observed and the dust is allowed to settle for one-half minute. The supernatant suspension is carefully, but quickly decanted into a second container of the same size. The time is noted at the end of the decantation, and this suspension is now allowed to settle for one minute. The supernatant fluid is decanted as before into a third container, where it is allowed to settle for two minutes. This process is continued, using twice the length of time for each succeeding sedimentation until after the eighth, or sixty-four-minute sedimentation. It is then decanted into a dish in which it is allowed to settle for twenty-four hours. From this,

it is decanted into another dish and allowed to settle for two days, and finally into a dish in which it settles for four days. The dust is roughly classified by this first process; the largest particles are found in the sediment of the first container, and the finest in the last. Dust remaining in suspension after four days of settling is in such violent Brownian movement that it will remain suspended practically indefinitely.

"In order to clean these fractions, the 'fines' must be removed by further washings. Therefore, the sediment in the first dish is again brought into suspension in a liter of the water-alcohol mixture by rapid agitation, and is allowed to settle again for one-half minute. The supernatant suspension, which contains a mixture of 'fines,' is decanted as before into the dish containing the sediment which settled out in one minute in the first classification. All the dust in this dish is then brought into suspension, allowed to settle for one minute, and then decanted into the following dish. This process is continued through the series and the whole operation repeated as often as is necessary to obtain a clear, supernatant fluid in the settling interval. Beginning with the third sedimentation, water is used rather than the water-alcohol mixture.

"When the supernatant fluid is clear at the end of a washing, it is discarded, and the sediment is carefully transferred to a watch glass with the aid of a rubber 'policeman.' The sediment is then dried in the oven and finally transferred to glass-stoppered weighing bottles."

Summary

Examine the sample under a microscope to find roughly the size distribution and the type into which the dust falls.

If sample contains much material above 100 microns, it should be passed through a 270- or 325-mesh screen. A weighed sample (about 5 grams) is screened and the percentage which passes the screen is determined. This portion is then studied further.

The amount of HCl-soluble material and the organic matter are determined in the customary way. The original material and the residues are then examined in suitable immersion media under ordinary and polarized light to identify the minerals present.

Chemical determinations may then be necessary in order to confirm the presence of any doubtful minerals.

TABLE II.

CHARACTERISTICS OF A FEW MINERALS COMMONLY FOUND IN DUSTS

Mineral	Composition	Indices of Refraction			Birefringence	Shape and Remarks
Calcite*	$CaCO_3$	1.486		1.668	.172 pastel colors—very high	Rhombohedral
Dolomite* . . .	$Ca,Mg(CO_3)_2$	1.503		1.681	.178 pastel colors—very high	Rhombohedral
Magnesite* . .	$MgCO_3$	1.515		1.717	.202 pastel colors—very high	Rhombohedral
Quartz	SiO_2	1.544		1.553	.009 light gray—low	Irregular
Corundum . . .	Al_2O_3	1.760		1.768	.008 light gray—low	Irregular
Carborundum	SiC	2.654		2.697	.043 light colors—strong	Irregular
Orthoclase . .	$KAlSi_3O_8$	1.519	1.523	1.525	.006 light gray—low	Prismatic to irregular
Gypsum* . .	$CaSO_4.2H_2O$	1.521	1.523	1.530	.009 light gray—low	Prismatic
Albite	$NaAlSi_3O_8$	1.525	1.529	1.536	.011 light gray—low	Prismatic to irregular
Talc	$H_2Mg_3(SiO_3)_4$	1.539	1.589	1.589	.050 light colors—strong	Plates or needles—parallel extinction
Asbestos . . . (chrysotile)	$H_4Mg_3Si_2O_9$	1.542	?	1.555	.013 light gray—low	Fibrous
Muscovite . .	$H_4K_2(Al,Fe)_6Si_6O_{24}$	1.552	1.582	1.588	.036 bright colors—medium	Plates & needles—parallel extinction
Clay (kaolin)	$H_4Al_2Si_2O_9$	1.561	1.565	1.567	.006 light gray—low	Platy to irregular
Anorthite . .	$CaAl_2Si_2O_8$	1.575	1.583	1.588	.013 light gray—low	Prismatic to irregular
Tremolite . .	$H_2Ca_2Mg_5Si_8O_{24}$	1.599	1.613	1.624	.025 bright colors—medium	Prisms & needles—extinct'n angle 17°
Biotite	$H_4K_2(Fe,Mg)_3Al_2Si_3O_{24}$	1.616	1.670	1.670	.054 light colors—strong	Plates & needles—parallel extinction —pleochroic

*Soluble in hydrochloric acid.

The Department of Industrial Hygiene, Harvard School of Public Health, Boston, will supply half-gram samples

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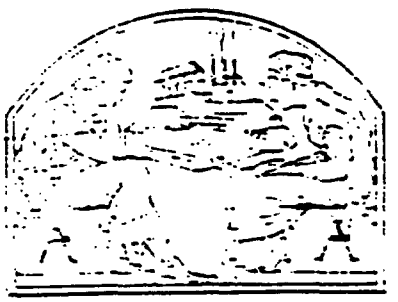
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INDUSTRIAL HYGIENE FOUNDATION OF AMERICA, Inc.

Research Engineering Series, Bulletin No. 3, Part 1



Air Flow Measurement by the Diffuser Method

FOREWORD

Upon recommendation of its Preventive Engineering Committee, Industrial Hygiene Foundation authorized a comprehensive study of exhaust ventilation. A grant was made to the University of Pennsylvania, where work is now being carried on under supervision of Professor Theodore Hatch, ably assisted by Robert H. Walpole, Jr.

Reports will be issued from time to time, so that members of the Foundation may benefit while the study is in progress. The reports will be in the form of bulletins in the Preventive Engineering Series; the first is on AIR FLOW MEASUREMENTS.

The fundamental factor which determines the rate of exhaust ventilation for certain industrial processes is the rate of air displacement produced by the process itself. As a starting point, therefore, in the development of a basic approach to the design of exhaust systems, it is desirable to measure the rate of air displacement produced by the process which is to be ventilated.

In general, the air displacement occurring in a given process takes place in such a way that the ordinary air flow meters are not applicable. It becomes necessary, therefore, to utilize a different method of measuring air flow.

The method described in this bulletin was developed to meet these needs, and is capable of measuring the rate of air flow in a complex system which has multiple air inlets and outlets. A major advantage of the method is that it is not necessary to measure the amount of air escaping from every opening.

Practical field tests have indicated that the technique offers a useful and practical approach to the determination of basic exhaust ventilation requirements for those industrial processes which by their operation cause air displacement.

H. B. MELLER,
Managing Director.

4400 Fifth Avenue,
Pittsburgh, Pa.
June 1, 1942.

AIR FLOW MEASUREMENT BY THE DILUTION METHOD

By

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and

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Problems in air flow measurement are encountered in which it is not possible to confine the air stream entirely and force it through a meter or past a definite velocity-measuring station. Under these conditions, the rate of air flow may be determined by the dilution method wherein a test gas is fed into the air stream at a known rate and, after uniform mixing is established, its concentration is determined in a unit volume of air. The rate of feed of the gas divided by its resulting concentration equals the rate of air flow.

The test gas must be one that is not absorbed either chemically or physically in the system and, for general use, it must not be toxic or explosive. It should lend itself to collection and measurement by means of simple sampling apparatus and analysis. Carbon dioxide meets these requirements. It is readily available in pressure cylinders and may be fed at a constant rate through a standard pressure-reducing valve and flow-meter. It is easily absorbed in an alkaline solution and is quickly determined by simple titration with as high an accuracy as may be desired. For approximate tests, a portable CO_2 analysis apparatus of the volumetric type may be employed. It is, of course, necessary to subtract from the total amount of CO_2 in the sample that amount which is normally present in the air in order to determine the concentrations of the added gas.

The basic apparatus required for air flow measurement by the dilution method is shown in Figure 1 and the various parts are enumerated below:

1. Cylinder of CO_2.
2. Constant pressure valve.
3. Flow-meter, calibrated in grams of CO_2 per minute at 760 mm. Hg and 0° C. Correction values for other pressures and temperatures are arranged in a convenient table.
4. Gas-feeding tube, arranged to insure uniform mixing of the test gas with the air stream.
5. Sampling tube.
6. Dust filter (when required).
7. Sampling apparatus, including absorption flask and flow-meter.
8. Source of suction.

Many combinations of feeding and sampling equipment will suggest themselves. The apparatus should be simple, rugged, and positive in opera-

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tion. The flow-meter for feeding the CO_2, for example, may be built into the pressure-regulating valve while a hand-operated, constant-flow pump may be employed with the sampling apparatus.

Accuracy

The accuracy of the dilution method, using CO_2 as the test gas, depends upon the following:

1. Uniformity of mixing of the CO_2 with the air stream.
2. Accuracy of flow-meter in the feeding apparatus.
3. Accuracy of the analytical procedure employed for determining the CO_2 concentration in the air stream.
4. Ratio of the concentration of added CO_2 to the normal atmospheric content of this gas.

Complete mixing of the test gas with the air stream is obviously essential. It is readily obtained in a simple air stream in which the air enters through a single inlet and the sampling point can be located a considerable distance downstream. In a complex flow system, however, with numerous inlet and discharge openings and with opportunities for short-circuiting of the test gas, considerable care must be exercised to insure thorough mixing. In certain cases we have found it necessary to introduce the CO_2 into two or more of the secondary air streams before they join to form the main stream. Proof of uniform mixing is demonstrated when the concentration of the CO_2 is found to be the same at the several points of discharge.

The accuracy of rate of feed of the test gas depends upon the design and calibration of the flow-meter, the corrections that are applied for the effects of temperature and pressure and the constancy of flow during the test. These are subject to direct control and the error may be fixed to meet the demands of the problem. This is also largely true with respect to the analytical procedure employed to determine the CO_2 concentration. A number of methods for measuring this gas are described in standard textbooks on gas analysis. The volumetric method, in which the change in volume of the sample resulting from absorption of the CO_2 is measured directly, is perhaps the simplest. It requires no separate sampling device nor is chemical titration involved. The standard instrument, however, does not measure the concentration more closely than to 1 part in 10,000 and, since the amount of gas added may not exceed 6 to 8 parts in 10,000, the accuracy of the air flow measurement will be ±15 to 20 percent. More accurate methods depend upon the absorption of the CO_2 in an alkaline solution of known strength and determination of the amount collected by acid titration. This requires an accurate flow-meter, an efficient absorption device, protection of the absorption liquid from contamination with CO_2 from the air before and after sampling, and careful chemical analysis. It is capable, however, of measuring the CO_2 concentration with a high degree of accuracy. With simple apparatus and analytical procedures which are adaptable to field conditions an accuracy of ±5% is readily obtained.*

The ratio of the concentration of added gas to the normal atmospheric content is, next to uniformity of mixing, the most important factor in determining the accuracy of air flow measurement by the dilution method. The error in air flow measurement increases as the ratio of added to normal CO_2 decreases, as indicated by the following equation:

$$1 \pm \frac{E_Q}{100} = \frac{R}{\left[\left(1 \mp \frac{Eco_2}{100}\right)(R+1)\right] - 1}$$

Where E_Q = Percent error in air flow measurement.
Eco_2 = Percent error in CO_2 concentration.
R = Ratio of added to normal CO_2 concentration.

The relation between E_Q and R is plotted for three values of Eco_2 in Figure 2. These curves exhibit sharp breaks at certain values of R below which the accuracy of air flow measurement decreases rapidly. For an error of ±5% in the CO_2 determination, the critical ratio is approximately 1.5 and this value has been selected for practical field work, thus giving an accuracy of air flow measurement of ±10%. This requires a rate of CO_2 feed of at least 36 grams per 1,000 cu. ft. of air, at sea level. The feeding apparatus should be provided with several interchangeable flow-meters to cover the range of air flow rates to be measured and in a particular problem it is necessary to select the proper rate of CO_2 feed from an initial estimate of the air flow and subsequent trial.*

Application

The dilution method has been found particularly useful in studies of the exhaust ventilation requirements for certain industrial processes in which the principal factor controlling the ventilation needs is the rate of air displacement established by the process itself. As an example, the discharge of crushed rock through a chute onto a belt sets up a flow of air with the falling material and the air escaping from the point of feed onto the belt disperses dust into the surrounding atmosphere. The rate of exhaust ventilation at this point must be in excess of the rate of air displacement. The latter can be measured by the dilution method, thus providing a basis for the design of the exhaust hood. The convenience of this method of measuring air flow rates is well illustrated by the example shown in Figure 3. As indicated in the sketch, crushed ore was fed into the boot of an elevator through two chutes, one from primary screens and the other from a crusher. The material discharged from the elevator into a closed bin from which it was fed to screens, the oversize from which dropped through a bin and chute to the crusher. The problem was to determine the rate of air displacement in the elevator. Smoke tests revealed that air was entering the boot of the elevator with the ore discharging from the primary screens and from the crusher as well. Above the elevator boot the housing was found to be under pressure with air escaping at the elevator head and at intermediate openings. Four air flow measurements were made at the locations shown in Figure 3. By means of tests 1 and 2 the rates of air flow induced by the

* Conductivity methods are also available.

* High rates of CO_2 feed (75 gms. per minute and more) through the pressure-reducing valve causes freezing in the valve. The use of a heating element near the reducing valve helps.

discharge of ore from the primary screens and the crusher respectively into the elevator were determined whereas tests 3 and 4 were designed to measure the total rate of air displacement in the elevator. Since the major air inflow occurred in the screen and crusher discharge chutes, it was expected that the sum of the rates of air flow determined in tests 1 and 2 would approximately equal that obtained in test 3. The results from tests 3 and 4 would be in substantial agreement provided there was no leakage in the elevator housing below the point of CO_2 feed in the latter test. The rates of air flow were found to be as follows:

Test	Rate of air flow, cfm.
1	1810
2	2750
1 + 2	4560
3	5000
4	4600

In view of the fact that the rate of flow of ore was not constant during these tests, the agreement among the results is excellent.

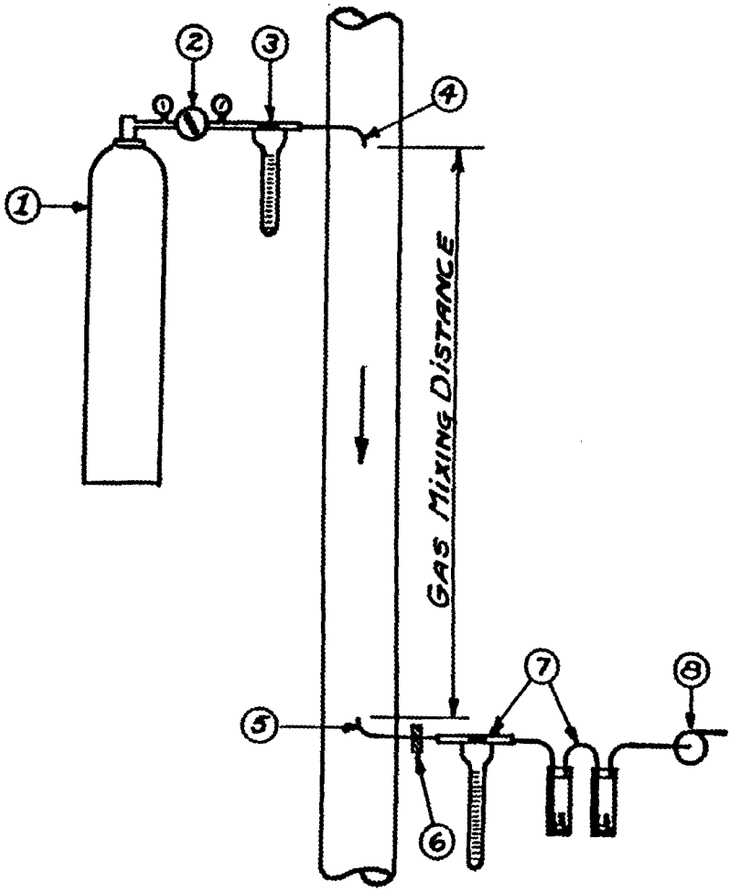


Figure 1.
Diagrammatic layout of apparatus employed for air flow measurement by the dilution method.

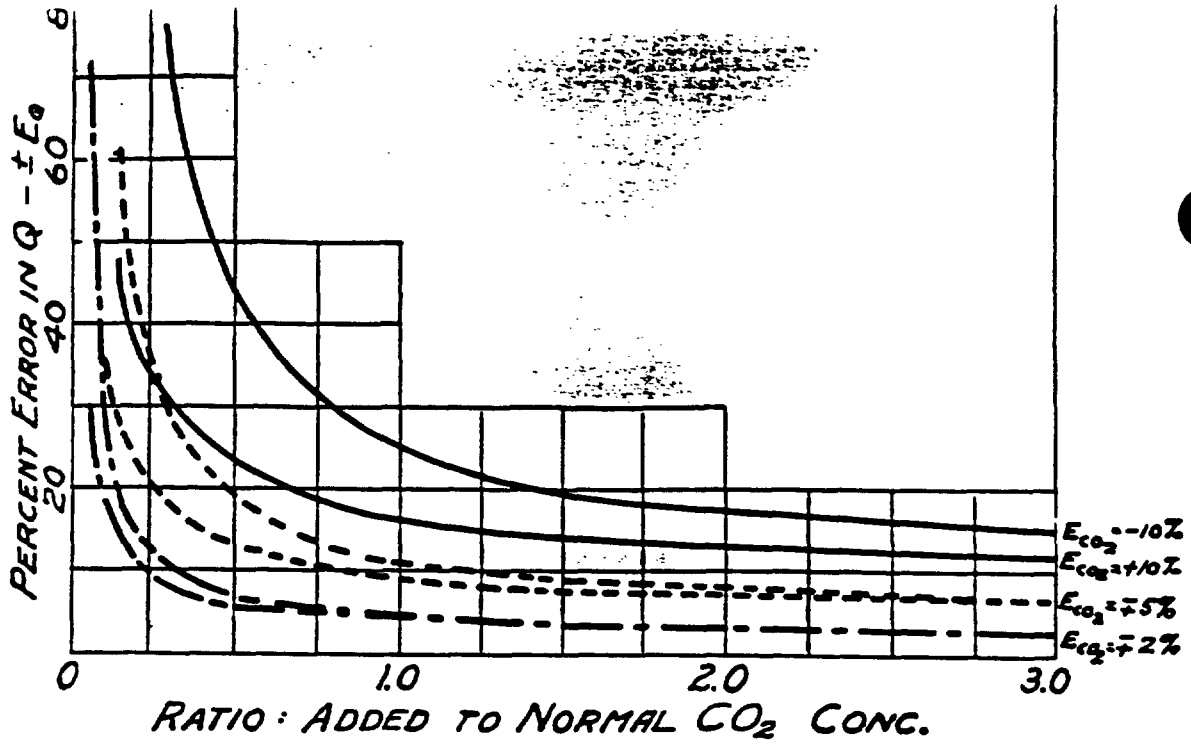


Figure 2.
Error in air flow measurement in relation to the ratio of added to normal CO_2 concentration in the air.

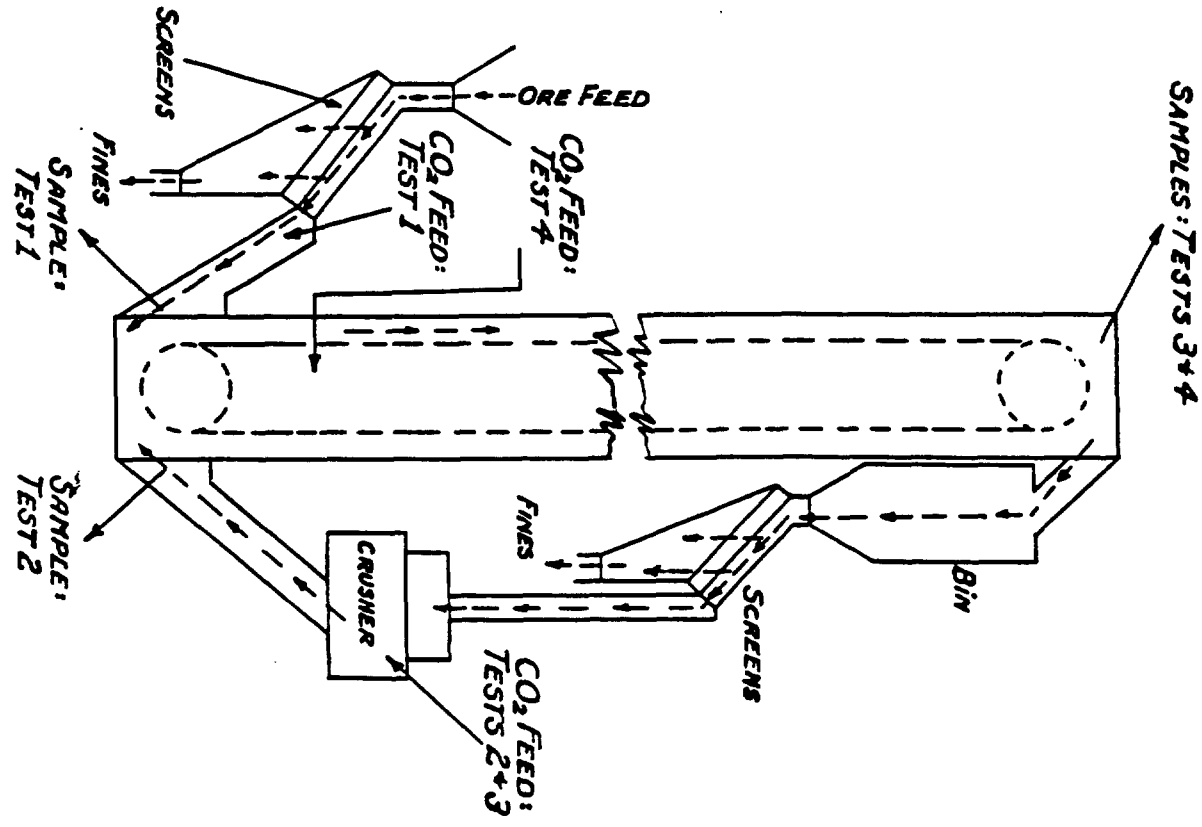


Figure 3.
Measurement of air flow in an elevator by the dilution method.

INDUSTRIAL HYGIENE FOUNDATION OF AMERICA, Inc.

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(REVISED EDITION)



MEASUREMENT OF AIR-FLOW RATE IN INDUSTRIAL VENTILATION

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PITTSBURGH, PENNSYLVANIA
1946

INDUSTRIAL HYGIENE FOUNDATION

An Association of Industries
for the
Advancement of Healthful Working Conditions

MEASUREMENT OF AIR-FLOW RATE IN INDUSTRIAL VENTILATION *

The control of industrial health hazards commonly involves the application of ventilation either in the form of an exhaust system or a system of general ventilation. The most important element of a ventilation system is the rate of air flow, commonly expressed in cubic feet per minute, a factor which plant engineers and industrial hygienists should be able to measure quickly and with facility.

Instruments for measuring air flow in the plant are simple, and the technique involved in their use need not be over meticulous. Of prime importance is the exercise of good judgment in deciding when to use any given instrument and when to check a result by a different technique.

It is important to realize at the outset that great accuracy in measuring air flows in plant ventilation equipment is seldom necessary for industrial hygiene purposes. Generally, it may be said that from this point of view, an error of 5 percent is insignificant; an error of 10 percent is permissible for most such purposes and is well within the bounds of practicality. An error of 15 percent may be permissible but is seldom necessary with ordinary care with the techniques described in this bulletin.

Air Flow and Static Suction

The notion is widespread that measurements of static suction are of little value for estimating air flow through hoods.† This is contrary to fact. Air flow measurement by this technique is generally the most valuable of all because it is so simple, so quickly performed and so widely applicable. However, other factors are involved in addition to the actual static suction reading and these must be given proper consideration if this reading is to be a reliable indication of the air velocity.

This technique consists in measuring the static suction or static head at one or more small holes in the wall of the pipe a little beyond the hood entrance, as shown in Figure 1.

The reading in inches of water is a measure of the velocity in the pipe plus suction loss at the entrance, i. e., through the hood. This reading of static head (h_s) taken in conjunction with the cross-sectional area of the pipe (A) and a factor called coefficient of entry (C_e) that is dependent on the shape and proportions of the hood, enable a direct calculation of the air flow quantity (Q) in cubic feet per minute (c. f. m.) by means of the following formula:

$$Q = 4000\ A\ C_e\sqrt{h_s}$$

Q = cubic feet air per minute.
A = cross-sectional area of pipe, in square feet.
C_e = coefficient of entry (values for different types of hoods are given below).
h_s = height of water column obtained in U-tube, in inches.

* This is part 2 in the series issued originally in 1942 as Bulletin No. 3, under the auspices of the Preventive Engineering Committee of Industrial Hygiene Foundation.

† Hood in this Bulletin is employed in the general sense of suction opening, whether it be the end of a pipe, tapered or untapered, a canopy, a slot, etc.

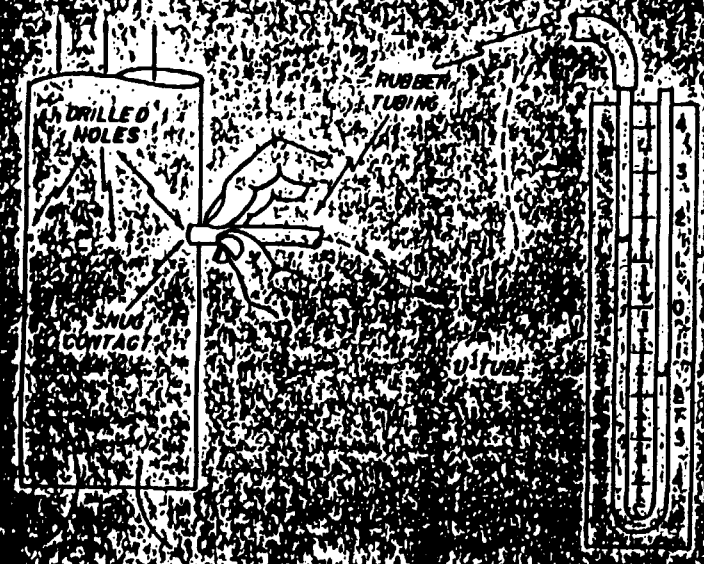


Figure 1. Measuring static head at a hood (plain end of a pipe in illustration) for determination of air flow.

Technique of Measurement

In measuring the static head, h_s, at a hood, a small hole is drilled in the wall of the pipe a distance of 1 to 2 diameters away from the neck of the hood, or end of the pipe if there is no taper.

The free end of the rubber tubing, connected at the other end to a glass tube or manometer, is held with the fingers tightly against the wall of the pipe, covering the drilled hole; and the difference in height of the water columns in the manometer, in inches and tenths, measured and recorded. The contact between the end of the rubber tubing and the wall of the pipe must be snug. Rubber tubing having a fairly thick wall is more convenient for this purpose than light-wall tubing.

A hole approximately 1/16 inch in diameter is convenient, although the size of hole is not of critical importance. The hole should not be punched, since the inwardly projecting jagged edges of metal disturb the air stream, and the true value of the static suction is not obtained. In drilling the hole, the small burrs sometimes formed have a similar effect, although much less serious. To insure most accurate results, such small metal turnings should be broken off. This is easily done after penetrating the pipe wall by revolving the axis of the drill in a spiral while rotating the drill itself.

Accuracy of reading is further improved by taking readings at more than one hole at different locations around the circumference of the pipe. This is especially important where it is necessary to make a measurement following an elbow or other pipe fitting causing excess turbulence. The average of such readings is to be taken unless, for example, one out of three or four readings is widely different from the others, when it may be discarded.

Manometers. Any U-tube, even though crudely constructed, will serve these purposes. It may readily be made by bending glass tubing into the shape of a U and attaching it to a strip of wood or metal having a scale marked in inches and tenths. (See Figure 1.)

Although not necessary, some engineers prefer manometers with adjustable scales to facilitate easy and rapid reading of the net difference in height of the two columns of liquid. One of these forms made from a cheap wooden slide rule has been described. Other forms may be purchased from Ellison Draft Gage Company and the Trimount Instrument Company. Ordinary U-tube manometers may be purchased from scientific apparatus suppliers, although any chemical laboratory has facilities for making them.

The Alnor velometer, which is a direct reading instrument actuated by the impact of air upon a swinging vane in the meter, can be used for measuring the static head by use of a jet (#2460) provided with a suction cup to be placed over a hole in the pipe. The drilled hole, preferably of 1/8 inch in diameter, should be free from burrs as mentioned above. It is essential that this hole be larger than the orifice at the end of the jet. The jet and scale can be calibrated for any convenient range, zero to two inches being the standard scale, but a range of zero to eight inches is recommended for industrial work. Unlike the U-tube manometer, operation of this instrument is dependent on a positive flow of air through the dial-indicating mechanism. It is therefore necessary that frictional losses through the tube and instrument be constant, and periodic checks on its accuracy should be made.

Hood Entry Coefficient

The entry coefficient (C_e) to be used in the formula is dependent on the shape of the hood entrance because of the effect of that shape on the manner in which the air stream enters the pipe. The more the shape minimizes sharp corners at the small-area passages of the hood, the higher the coefficient. Coefficients are given for the fundamental shapes of hoods in Figures 2 to 17 and in Table I.

Those for cones may be applied also to the more common rectangular-shaped hoods which taper to a round pipe (See Example 1 below). Where such a rectangular hood has different angles for each opposite pair of sides, the larger of the two included angles should be the one considered.

In Table II is a table of cotangents enabling quick estimation of included angles from the hood dimensions given in the accompanying diagram.

Accuracy. It will be noted that the range of coefficients for straight hoods with flaring inlets where there is no air passage less in area than the connecting pipe is from 0.82 to 0.95. If, therefore, one were careless in identifying the hood shape and its proportions and arbitrarily used a coefficient midway in this range, say 0.85, the maximum possible error would still permit a reasonably good approximation of the air flow. However, by selecting the proper coefficient from among those given in the table, an accuracy of 5 to 10 percent may be safely assumed. The accuracy is probably better for the straight connected hood (no intervening elbow) than for those where close proximity to an elbow necessitates taking the suction reading after the elbow.



Fig. 2: Tapered cone, or rectangular to round.

C_e = 0.8 to 0.95

See Table I.

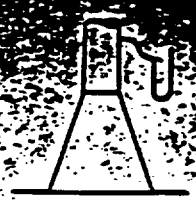


Fig. 3: Flanged tapered cone, or rectangular to round.

C_e = 0.82 to 0.96

See Table I.

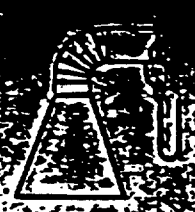


Fig. 4: Same as Fig. 1 except close elbow.

C_e = deduct 0.06 from value found in Table I.



Fig. 5: Same as Fig. 2 except close elbow.

C_e = deduct 0.08 from value found in Table I.



Fig. 6: Plain end of pipe.

C_e = 0.72



Fig. 7: Flanged end of pipe.

C_e = 0.82

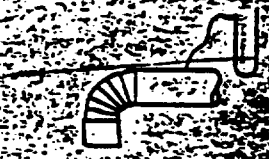


Fig. 8: Plain end of pipe plus close elbow.

C_e = 0.62



Fig. 9: Flanged end of pipe plus close elbow.

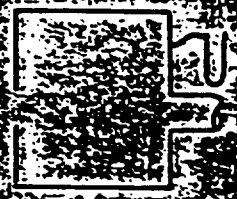


Fig. 10: Sharp-edge orifice.

C_e = 0.60

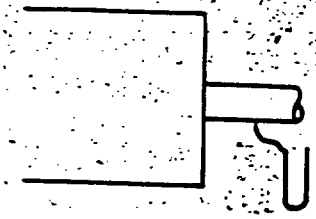


Fig. 11: Exhaust booth, fundamentally same as Fig. 7.

C_e = 0.82

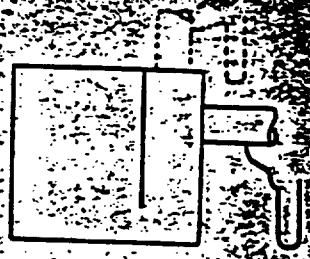


Fig. 12: Enclosed chamber, and negligible pressure inside.

C_e = 0.82

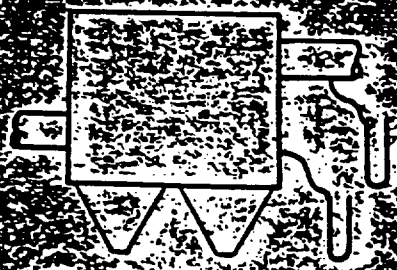


Fig. 13: Enclosed chamber, and under measurable negative pressure. Net h_s = difference of 2 readings.

C_e = 0.82



Fig. 14: Hood as over lead pot, low face velocity, low stack temperature.

C_e = same as Fig. 2

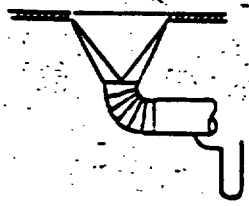


Fig. 15: Bench exhaust grill with taper connections.

C_e = same as Fig. 5

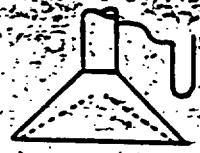


Fig. 16: Double hood with inner cone.

C_e = 0.70 (approx.)

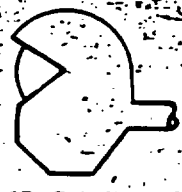


Fig. 17: Grinding wheel hood.

C_e = 0.80

Figures 2 to 17.
Coefficients of entry (C_e) for various hood shapes.
Use in formula: $Q = 4000 \times \text{Area} \times C_e \sqrt{h_s}$

TABLE I.

ENT[illegible]OEFFICIENTS (C_e) FOR TAPERING HOODS OF DIFFERENT PROPORTIONS

Included Angle	Ratio $\frac{\text{Area Face}}{\text{Area Pipe}}$					
	8:1 or greater	4:1	2:1	1:1		
Unflanged Tapering Hoods (Figure 2)						
10°	0.95	0.94	0.93	0.89	No angle; Plain pipe end	0.72
20°	0.92	0.91	0.90	0.87		
30°	0.89	0.88	0.87	0.86		
40°	0.87	0.86	0.85	0.85		
60° or more	0.82	0.82	0.82			
Flanged Tapering Hoods (Figure 3)						
10°	0.96	0.96	0.95	0.93	No angle; Flanged pipe end	0.82
20°	0.93	0.93	0.92	0.91		
30°	0.90	0.90	0.90	0.90		
40°	0.89	0.89	0.89	0.88		
60° or more	0.82	0.82	0.82			

For hoods followed closely by an elbow, necessitating measurement after elbow: Deduct 0.08 from C_e values shown here.

TABLE II.

TABLE OF COTANGENTS FOR ESTIMATING APPROXIMATE INCLUDED ANGLE OF HOODS



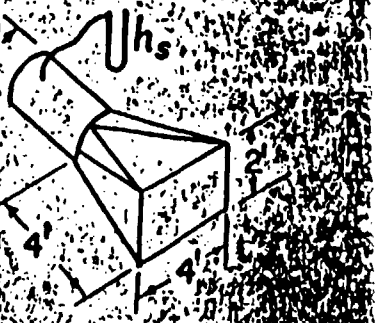
See Table II.

Ratio L/a	Included Angle
11.4	10°
5.7	20°
3.7	30°
2.7	40°
2.1	50°
1.7	60°

Example:

L = 24"
a = 6"
L/a = 24/6 = 4
angle = 30° approx.

Examples



Example 1. An unflanged rectangular hood whose face is 2 ft. by 4 ft. is connected to a round pipe 12 inches in diameter. The axial length of the hood is 4 ft. Two small holes are drilled in the pipe between 1 and 2 ft. from the junction of hood and pipe, and measurements of static suction (h_s) made with a U-tube manometer. The readings obtained are 0.8 inches and 1.0 inches. What is the air flow through the hood?

Solution. We note that the larger angle of the hood is 40° (L/a = approximately 2.7, Table II) and that the ratio of the face area to pipe area is $4 \times 2/0.78$, or about 10 to 1. Reference to Table I shows that the expected coefficient of entry for a hood like this one is 0.87.

The average static suction is 0.9 inches. Substituting these values in the formula,

$$Q = 4000 \times \text{Area} \times C_e \sqrt{h_s}$$
$$= 4000 \times (0.7854) \times 0.87 \sqrt{0.9}$$
$$= 2600 \text{ c. f. m.}$$

Example 2. A hood identical with that of Example 1 is followed so closely by an elbow in the connecting pipe that it is impossible to get a fair reading at a distance of 1 diameter from the hood junction. The reading must therefore be made following the elbow. Several readings so taken average 0.75 inches. What is the air flow through the hood?

Solution. Note from Table I that 0.08 is to be deducted from the normal coefficient when the reading is taken after a close elbow, which gives a coefficient for present circumstances of

$$C_e = 0.87 - 0.08 = 0.79$$

Substituting in the formula,

$$Q = 4000 \times (0.7854) \times 0.79 \sqrt{0.75}$$
$$= 2150 \text{ c. f. m.}$$

The engineer interested in air flow measurements of the type under discussion will soon learn to judge in what category such a hood belongs without making actual measurements for included angle and area ratio. Seldom are conical or rectangular flaring hoods constructed in practice with included angles smaller than 60°-60°, and therefore a coefficient of 0.82 will be found to apply most frequently.

Exhaust from Chambers

The foregoing methods of determining air flow by measurement of static suction are also applicable where a duct exhausts from a large chamber, provided only that the size of the chamber is great relative to the pipe diameter, thus resulting in no abnormal constriction to free flow in the

vicinity of the pipe entrance. In this case it is necessary to correct for negative pressure prevailing in the chamber by subtracting the measured static suction in the chamber from the static suction in the pipe. (Figure 18.) Net h_s for use in formula is obtained by subtracting h_1 from h_2.

The commonest example of this case is where a pipe leads from a cloth dust collector under negative pressure. The method described is not applicable, however, where, as often occurs, the length of pipe from chamber to exhaust fan is less than about one diameter.

A fair approximation of the air flow entering some part of an exhaust system through a sharp-edged orifice or a fitting resembling such an orifice may also be obtained by static pressure measurements. As indicated in Figure 18, the coefficient of entry for such an orifice is 0.60. Seldom will one encounter the laboratory sharp-edged orifice in industry but occasionally there are similar pieces such as exhaust slots or bench grilles in the form of relatively small holes in steel plate. In practice the accuracy of results in many cases of this type is likely to be poorer than with ordinary cases of the type previously discussed.

Example. There is a rectangular hole 8 inches by 2 inches in the side of a large duct. The static suction in the pipe at this point is 2 inches. How much air is passing through the hole into the duct?

Solution. Substitute the above data in the general formula, using the entry coefficient of 0.60.

$$Q = 4000 \times \text{Area} \times C_e \sqrt{h_s}$$

$$= 4000 \times \frac{8 \times 2}{144} \times 0.60 \sqrt{2}$$

$$= 140 \text{ c. f. m.}$$

Velocity Pressure Measurements

Where the pressure exerted by a stream of air of known area can be conveniently measured, it affords the most direct measure of air flow. Such measurement may be made conveniently, for example, at the end of a pipe where air discharges into the atmosphere by holding the end of a simple bent tube or, if more convenient, a Pitot tube in the stream, pointing parallel and opposite to the flow. The other end of the tube, connected to a water manometer, registers the velocity pressure directly, in inches of water (Figure 18 B). The velocity of the air stream at this point may then be calculated by the formula:

$$V = 4000 \sqrt{h_v}$$

where V = velocity in feet per minute.

h_v = velocity pressure in inches of water.

The total air flow, cubic feet per minute, is then given by the average velocity in feet per minute over the whole area multiplied by the area in square feet.

$$Q = VA$$

The accuracy of such a measurement depends largely on the time and care devoted to it. Thus one may make a careful twelve point or six point

Appended to this bulletin is a table of velocities (V) corresponding to all commonly encountered velocity pressures (h_v).

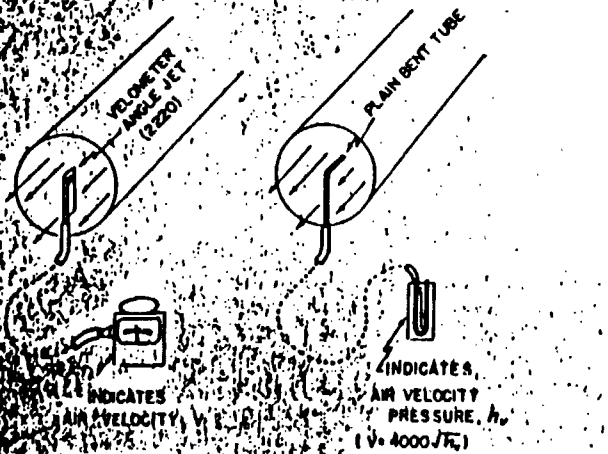


Figure 18 A. Figure 18 B.

Use of the Alnor Velometer and the U-tube manometer for measuring velocity of an air stream issuing from a pipe or other like orifice, from which the rate of air flow (c. f. m.) may be calculated by obtaining the product of average velocity and orifice area; Q = A V.

traverse (traverses are described later under Pitot tubes) with an inclined gage and get accurate results (less than 5 percent error); or, as is more likely to be indicated for ordinary industrial work, one may be satisfied with a less exact result where measurements are less time-consuming.

In its simplest form, an approximate measurement would be made with a tube (glass or metal) bent at a right angle, connected at one end to a U-tube manometer. If a preliminary exploration of pressures along one diameter of the pipe indicates them to be distributed reasonably symmetrically, one then measures the center line velocity to the nearest half-tenth of an inch. (If the velocity pressure is less than about one-half inch, an inclined gage should be used.) The air flow for the pipe of area A square feet and center line velocity pressure h_v inches is as follows:

$$Q = 4000 \times 0.9 \times A \sqrt{h_v}$$

$$= 3600 \, A \sqrt{h_v}$$

The figure, 0.9, known as the pipe factor, represents the ratio of average to center line velocities usually found. It varies considerably in practice, depending on the nature of upstream disturbances. It follows, then, that its use introduces some uncertainty.

Where discharge of air follows immediately after the fan or shortly after passing an elbow, the distortion of velocity pressures across the pipe diameter is too great for a single reading to be of even approximate value. Where this is true, a traverse of the pipe should be made, as described under "Pitot tube" below. This method in conjunction with an inclined gage can be made to give accurate results.

The Alnor velometer with angle jet \$2220 can also be used for measuring air velocities issuing from pipes into free space. (Figure 18 A.)

Pitot Tube

The Pitot tube with manometer is a basic instrument for measurement of velocity pressures and will give accurate results if properly used. How[illegible] air flow measurements with it in industrial exhaust systems are not usually obtained by a single operation. It will seldom need to be employed in industrial hygiene work, except where no other method is available or where a closer estimation of the air flow in an exhaust system is wanted. It should be used where data of fundamental engineering value are being obtained on plant scale equipment.

The Pitot tube, for best results, should be used in conjunction with an inclined gage and by making a pipe traverse, although in some circumstances passable results may be obtained with only the center line reading on a vertical gage. The possible combinations of the instrument and number of readings are indicated below in increasing order of their accuracy:

(1) With a vertical U-tube, single center line reading only.

(2) With a vertical U-tube, making a traverse.

(3) With an inclined gage, single center line reading only.

(4) With an inclined gage, making a traverse.

In general, a vertical U-tube may be used only for the velocity pressure that is 1 inch or more of water. An error of 0.1 inch in reading the gage at this range result in an error in rate of air flow of about 10 percent, which may be a permissible error. If the velocity pressure be 1.0 inch in reading, an error of 0.1 inch in reading would amount to about 5 percent error in rate of air flow.

Velometer Duct Jet. Jet attachments are available for use with the velometer for making velocity pressure readings in a ventilation duct. In addition to the usual 36 and 18 inch duct jet (32425) a nine inch duct jet (33290) is available and is more convenient, as it can be transported inside the smaller carrying case and requires only a small hole (3/8 x 7/16") in the pipe for its insertion.

A change in frictional resistance to the flow of air through the jet and tubes may affect the accuracy of the reading; hence, care should be exercised to avoid lodgment of scale or the like in the air passages. Periodic check calibration should be made at intervals by the manufacturer.

Pipe Traverse. A pipe traverse is a method of taking several readings across the diameter of a pipe in order to obtain the true average velocity, the locations along the diameter being systematically selected to justify averaging the velocities so obtained. A traverse should be made where the measurement must be made closely following an elbow, branch connection or main, or similar disturbance, or where superior accuracy is desired. A six-point traverse along one diameter is satisfactory for most work in this field with another six-point traverse sometimes taken along a diameter at right angles to the first (the combination is a twelve-point traverse).

A six-point traverse across one pipe diameter is made by taking a reading at each of six points located at the distances from one wall shown in Table III expressed in percentage of the diameter, and averaging the velocities computed.

When circumstances justify only a single center line reading with the Pitot tube, a factor of 0.9 should be applied to the velocity thereby measured, since center line velocities are greater than average velocities in approximately that ratio.

TABLE III.

PROPER LOCATIONS OF PITOT TUBE IN SIX-POINT TRAVERSE FOR OBTAINING AVERAGE AIR VELOCITY

Reading Number	Distance of Tip of Tube from Pipe Wall (Percent of Pipe Diameter)
1	5
2	15
3	30
4	70
5	85
6	95

No center line reading is included in this average.

Examples

Example 1. Air flow is to be measured by means of a Pitot tube in a twelve-inch pipe by traversing the diameter for six readings. The proper location of each of the readings is obtained from the data given in Table III. Those locations are given in column II (below). Velocity pressure readings observed with an inclined gage are in column III, computed velocities in column IV, and average velocity and air flow in cubic feet per minute under the tabulation.

I Reading Number	II Distance of Reading From Pipe Wall (Inches)	III Observed Velocity Pressure (h_v) (Inches water)	IV Computed Velocity $V = 4000 \times \sqrt{h_v}$ (feet per minute)
1	0.6	0.74	3440
2	1.8	0.79	3560
3	3.6	0.85	3690
4	8.4	0.80	3580
5	10.4	0.81	3600
6	11.4	0.72	3390

Average velocity = 3540 f. p. m.

Air flow, $Q = A V = 0.785 \times 3540 = 2780$ c. f. m.

Example 2. Air flow is to be measured in a twelve-inch pipe with a Pitot tube. An elbow more than ten diameters upstream from the test hole is believed far enough distant to permit reliance on a single center line reading. A qualitative "probe" with the tube while observing gage readings confirms that no extreme distortion of flow exists from one wall to the other. The single center line reading found = 0.92 inches.

Calculation:

$$Q = 4000 \times \text{Area} \times 0.9\sqrt{h_v}$$

$$= 3600 \times 0.785 \times \sqrt{0.92} = 2710 \text{ c. f. m.}$$

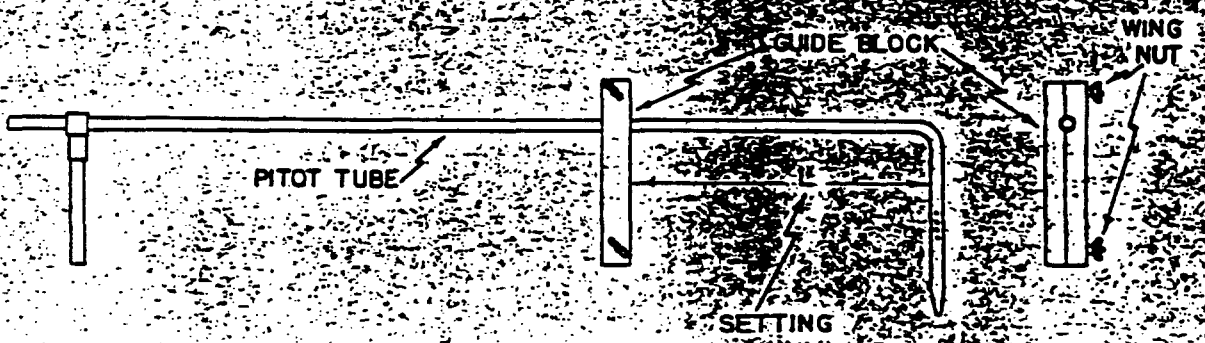


Figure 19.
Guide for Pitot tube when inserted in pipe with guide block held against pipe surface. L setting may be measured either by a scale like the one illustrated in Figure 20 or by an inch scale aided by Table III. (See also Reference 4.)

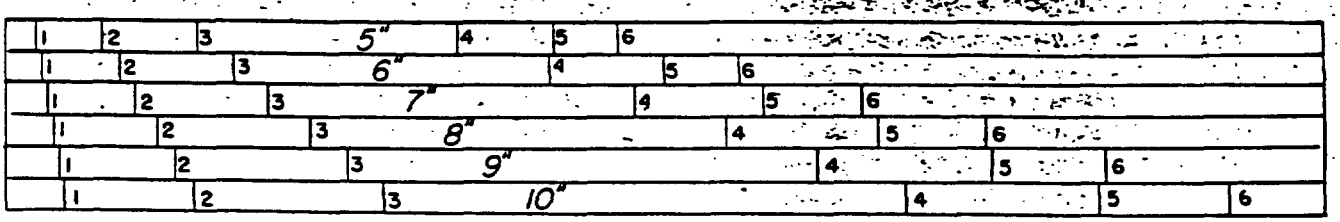


Figure 20.
Wood scale to facilitate proper positioning of the Pitot tube in pipe, for a 6-point traverse. Shown are scales for pipe sizes 5"-10" inclusive. Positions may be interpolated for pipes of intermediate diameters, e. g., 6½", use 6" and 7" scales.

come to some extent by inserting the jet #2420 and making the readings on the higher range scale (0-1000 f. p. m.).

In order to obtain a satisfactory reading of face velocities in booths for spray painting and at other large areas, successive readings may be made in adjacent areas of the booth face and the results averaged. *For example,* in a booth 4 feet by 4 feet, several readings would be taken in as many squares and the results averaged. The instrument should be held at arm's length and at one side of the body to avoid undue distortion of the velocity of air currents.

The angle jet #2220 applicable to *air supply duct openings* (Figure 18 A) can be included with a range of 0-6000 f. p. m. In the past, this jet has been widely used by engineers to measure face velocities at small exhaust hoods or slots, but should not be used for such measurements, as it does not adequately compensate for the rapid change from static to velocity pressure.

The air flow from such data is calculated, as before, by multiplying the average velocity in feet per minute by the area, in square feet, of the opening.

$$Q = A V$$

Sometimes the total air flow into a room from which air is exhausted passes through one or two doorways. When this is so, the total ventilation rate may easily be determined by measuring velocities through the doorways and, as described above, multiplying this average velocity by the doorway area. *This method of determining* air flow is obviously most suitable to a room or space where air supply openings are well-defined areas and easily measured. It is often valuable as a check on total air flow based on measurements made on individual exhaust units.

Example. A department houses a dust exhaust system, and the only openings into the room are three doors each 8 feet x 4 feet. The air flow estimated on the basis of individual hood suction measurements is 14,400 c. f. m. It is desired to check this value, which is done by determining the average velocity through each of the three doorways. This velocity is found to be 140 f. p. m. Air flow, $Q = A V = (3 \times 8 \times 4) \times 140 =$ 13,400 c. f. m., which agrees well with 14,400 c. f. m.

Conclusion: Total air flow is about 14,000 c. f. m.

Checking

The alert engineer will discover many opportunities for checking air flows like that described in the above example. It should, in fact, be a cardinal rule that air flow measurements should, whenever there is doubt as to the accuracy by one method and when it is possible, be checked by another method of measurement. Another useful combination of methods: Air flow by hood suction measurements versus air flow by velocity pressure (total pressure) measurement at discharge from the system.

This pamphlet has confined its discussion of air-flow measurements to a limited number of techniques that are simple, and hence best serve the purposes of industrial hygiene. The engineering literature on the subject of air-flow measurement in general is vast. The references given below are those more closely related to the present subject.

References

1. Alden, J.: Design of Industrial Exhaust Systems. The Industrial Press, 148 Lafayette St., New York, 1939.

2. American Foundrymen's Association: Tentative Code of Recommended Practices for Testing and Measuring Air Flow in Exhaust Systems. 222 West Adams St., Chicago, Ill., 1936.

3. Heating, Ventilating, Air Conditioning Guide. Published annually by American Society of Heating and Ventilating Engineers, 51 Madison Ave., New York, N. Y.

4. Hemeon, W. C. L.: Industrial Health Defense—How Plant Engineers Can Make Field Measurements of Industrial Ventilation. Heating, Piping and Air Conditioning, January, 1941. (Reprints available from the author—Massachusetts Division of Occupational Hygiene, 23 Joy St., Boston, Mass.)

5. National Association of Fan Manufacturers: Standard Test Code for Centrifugal and Axial Fans; third edition, April, 1941. 5-208 General Motors Building, Detroit, Mich.

Sources of Equipment

Alnor Velometer: Illinois Testing Laboratories, 420 North La Salle St., Chicago, Illinois.

Inclined Gage for Pitot Tube: Ellison Draft Gage Company, 314 West Kinzie St., Chicago, Illinois.

U-Tube Manometer: Ellison Draft Gage Company (address above).
Trimount Instrument Company, 37 West Van Buren St., Chicago, Ill.
Any supplier of chemical laboratory apparatus.

Pitot Tubes: Ellison Draft Gage Company (address above).
E. Vernon Hill, 6826 West Highland Ave., Chicago, Illinois.

TABLE IV.

PIPE AREAS

Pipe Diameter Inches	Pipe Area Sq. Ft.	Pipe Diameter Inches	Pipe Area Sq. Ft.
2	.0218	17	1.576
2⅛	.0341	17⅛	1.670
3	.0491	18	1.767
3⅛	.0668	18⅛	1.867
4	.0873	19	1.969
4⅛	.1104	19⅛	2.074
5	.1364	20	2.182
5⅛	.1650	21	2.405
6	.1964	22	2.640
6⅛	.2304	23	2.885
		24	3.142
7	.2673	25	3.409
7⅛	.3068	26	3.687
8	.3491	27	3.976
8⅛	.3942	28	4.276
9	.4418	29	4.587
9⅛	.4923	30	4.909
10	.5454	31	5.241
10⅛	.6010	32	5.585
11	.6600	33	5.940
11⅛	.7215	34	6.305
		35	6.681
		36	7.069
12	.7854	37	7.467
12⅛	.8520	38	7.876
13	.9218	39	8.296
13⅛	.9937	40	8.727
14	1.0690	42	9.621
14⅛	1.146	44	10.56
15	1.227	46	11.54
15⅛	1.310		
16	1.396	48	12.57
16⅛	1.485	50	13.64

TABLE V.

VELOCITIES CORRESPONDING TO VARIOUS VELOCITY PRESSURES

Calculated from $V = 4000\sqrt{h_v}$

Where V = air velocity, feet per minute, h_v = velocity head, inches of water

h_v	V	h_v	V	h_v	V	h_v	V	h_v	V	h_v	V
.01"	400.5	.51	2860	1.01	4025	1.51	4921	2.01	5678	2.51	6340
.02	566.4	.52	2888	1.02	4045	1.52	4938	2.02	5692	2.52	6358
.03	693.7	.53	2916	1.03	4064	1.53	4954	2.03	5706	2.53	6370
.04	801.0	.54	2943	1.04	4084	1.54	4970	2.04	5720	2.54	6383
.05	895.5	.55	2970	1.05	4103	1.55	4986	2.05	5734	2.55	6396
.06	981	.56	2997	1.06	4123	1.56	5002	2.06	5748	2.56	6408
.07	1060	.57	3024	1.07	4142	1.57	5018	2.07	5762	2.57	6420
.08	1133	.58	3050	1.08	4162	1.58	5034	2.08	5776	2.58	6433
.09	1201	.59	3076	1.09	4181	1.59	5050	2.09	5790	2.59	6445
.10	1266	.60	3102	1.10	4200	1.60	5066	2.10	5804	2.60	6458
.11	1328	.61	3127	1.11	4219	1.61	5082	2.11	5817	2.61	6470
.12	1387	.62	3153	1.12	4238	1.62	5098	2.12	5831	2.62	6482
.13	1444	.63	3179	1.13	4257	1.63	5114	2.13	5845	2.63	6495
.14	1498	.64	3204	1.14	4276	1.64	5129	2.14	5859	2.64	6507
.15	1551	.65	3229	1.15	4295	1.65	5144	2.15	5872	2.65	6519
.16	1602	.66	3254	1.16	4314	1.66	5160	2.16	5886	2.66	6532
.17	1651	.67	3279	1.17	4332	1.67	5175	2.17	5899	2.67	6544
.18	1699	.68	3303	1.18	4350	1.68	5191	2.18	5913	2.68	6556
.19	1746	.69	3327	1.19	4368	1.69	5206	2.19	5927	2.69	6569
.20	1791	.70	3351	1.20	4386	1.70	5222	2.20	5940	2.70	6581
.21	1835	.71	3375	1.21	4405	1.71	5237	2.21	5954	2.71	6593
.22	1879	.72	3398	1.22	4423	1.72	5253	2.22	5967	2.72	6606
.23	1921	.73	3422	1.23	4442	1.73	5268	2.23	5981	2.73	6617
.24	1962	.74	3445	1.24	4460	1.74	5283	2.24	5994	2.74	6629
.25	2003	.75	3468	1.25	4478	1.75	5298	2.25	6008	2.75	6641
.26	2042	.76	3491	1.26	4495	1.76	5313	2.26	6021	2.76	6654
.27	2081	.77	3514	1.27	4513	1.77	5328	2.27	6034	2.77	6666
.28	2119	.78	3537	1.28	4531	1.78	5343	2.28	6047	2.78	6678
.29	2157	.79	3560	1.29	4549	1.79	5359	2.29	6060	2.79	6690
.30	2193	.80	3582	1.30	4566	1.80	5374	2.30	6074	2.80	6702
.31	2230	.81	3604	1.31	4583	1.81	5388	2.31	6087	2.81	6714
.32	2260	.82	3625	1.32	4601	1.82	5403	2.32	6100	2.82	6725
.33	2301	.83	3657	1.33	4619	1.83	5418	2.33	6113	2.83	6737
.34	2335	.84	3669	1.34	4636	1.84	5433	2.34	6126	2.84	6749
.35	2369	.85	3690	1.35	4653	1.85	5447	2.35	6139	2.85	6761
.36	2403	.86	3709	1.36	4671	1.86	5462	2.36	6152	2.86	6773
.37	2436	.87	3729	1.37	4688	1.87	5477	2.37	6165	2.87	6785
.38	2469	.88	3758	1.38	4705	1.88	5491	2.38	6179	2.88	6797
.39	2501	.89	3779	1.39	4722	1.89	5506	2.39	6191	2.89	6809
.40	2533	.90	3800	1.40	4739	1.90	5521	2.40	6204	2.90	6820
.41	2563	.91	3821	1.41	4756	1.91	5535	2.41	6217	2.91	6833
.42	2595	.92	3842	1.42	4773	1.92	5550	2.42	6230	2.92	6845
.43	2626	.93	3863	1.43	4790	1.93	5564	2.43	6243	2.93	6857
.44	2656	.94	3884	1.44	4806	1.94	5579	2.44	6256	2.94	6867
.45	2687	.95	3904	1.45	4823	1.95	5593	2.45	6269	2.95	6879
.46	2716	.96	3924	1.46	4840	1.96	5608	2.46	6281	2.96	6890
.47	2746	.97	3945	1.47	4856	1.97	5623	2.47	6294	2.97	6902
.48	2775	.98	3965	1.48	4873	1.98	5637	2.48	6307	2.98	6913
.49	2804	.99	3985	1.49	4889	1.99	5651	2.49	6319	2.99	6925
.50	2832	1.00	4005	1.50	4905	2.00	5664	2.50	6332	3.00	6937