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INDUSTRIAL AIR ANALYSIS*

by

BENJAMIN FEINER

Engineering Unit

GENERAL CONSIDERATIONS

Enormous expansion of governmental and private industrial hygiene activities in recent years has been the impetus for a concomitant increase in the scope of industrial air analysis. The reason for this will be apparent when we consider the role played by industrial air analysis.

The industrial hygienist must correlate atmospheric contaminant concentrations with clinical findings and occupational analyses in order to promulgate safe concentrations, dangerous concentrations for long term exposure (chronic intoxication), and dangerous concentrations for short term exposure (acute intoxication). The industrial hygiene engineer finds industrial air analysis an invaluable tool in choosing the type and amount of ventilation for any particular process. In addition, air tests are the ultimate and absolute criteria of the efficiency of and protection provided by a ventilating system.

Industrial air analysis is becoming increasingly important in the fields of compensation medicine, forensic medicine, and industrial safety and sanitation code enforcement. Public health agencies, more and more concerned with the problem of atmospheric pollution, are finding outdoor air analysis necessary in connection with setting up safe limits for continuous, 24 hours a day, exposure to air contaminants. (Safe limits within the plant are based on exposure for eight hours per day.)

The evaluation of an industrial atmosphere depends on many variables and imponderables, and only a trained industrial hygienist is in a position to balance the various factors involved in determining the degree of exposure of a worker to air contaminants. In a plant where the contaminant-producing operations are relatively uniform and continuous (paint dipping and drying, conveyorized degreasing, etc.), it may be possible for a skilled industrial hygienist to train a technician to make routine air tests under supervision.

There are many important functions of routine air analysis in a plant. Any significant rise in atmospheric contamination can be detected and eliminated before serious illness results. Contaminant levels high enough to produce chronic intoxication can be detected and prevented before observable clinical symptoms are discovered. These are often not apparent until irreparable damage has been done. In many cases, one or two processes may contaminate an entire plant atmosphere. These offenders can be identified by air analysis and controlled individually much more economically than by safeguarding the entire plant atmosphere.

The need for industrial air analysis became apparent long before the era of modern chemistry. We are all familiar with the coal miner's former practice of carrying a live canary into the mine with him. Any obvious sign of distress on the part of the canary, such as falling off its perch, was an indication of a rising concentration of toxic gases. The canary's death was a signal to leave the shaft immediately. Among the earliest objective air analyses were the relatively crude methane and carbon monoxide analyses made in mines.

USE OF THE SENSES

The use of the senses in industrial air analysis can be made an important, and often time saving, factor. The industrial hygienist, while making air analyses, consciously makes a mental note of the smell of the gas or vapor, its effect on his eyes, nose, and throat; in dusty atmospheres he will note the visual appearance of the dust. The hygienist retains a "memory" of these observations and correlates them with the results of the precise chemical and physical analyses. There is after a time accumulated a series of mental correlations between the subjective observations of the senses and the qualitative and quantitative results of the air tests. A trained observer will recognize the odor of most of the common substances used in industry, and can even distinguish vapors of similar odor, such as benzene, toluene, or xylene, where all are present in the atmosphere.

It is possible to educate the senses so that crude attempts at quantitative determinations can be made.

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TABLE 1
SCALE OF ODOR INTENSITIES

Degree	*Intensity*	*Description*
0	No odor	No detectable odor
1	Very faint	Minimum, but positively perceptible odor
2	Faint	Weak odor, readily perceptible
3	Easily noticeable	Moderate intensity
4	Strong	Cogent, forcible odor
5	Very strong	Intense effect, may irritate

TABLE 2
IRRITANT SCALE (NASAL IRRITATION AND EYE IRRITATION)

Degree	*Intensity*	*Description*
0	No irritation	Not detectable
1	Faint	Just perceptible, not painful
2	Moderate	Moderate irritation, midway between 1 and 3
3	Strong	Discomforting, painful, but may be endured
4	Intolerable	Exceedingly painful, cannot be endured voluntarily

(The scales in Tables 1 and 2 have proved convenient for this purpose.) One can often determine, in this manner, whether an atmospheric vapor concentration is well below or well above the maximum allowable concentration. In the former case, precise air analyses are not usually necessary. In the latter, air analyses are necessary only if corroborative or legal evidence is required. Where there is any doubt whatsoever, air analyses must be made.

Similarly, visual observations of a dusty atmosphere are often sufficient to determine whether the dust concentrations are well below or well above the maximum allowable concentration. The time saving effected by "educated senses" in routine plant surveys will be readily apparent.

Certain limitations of organoleptic observations, as those depending upon the senses are known, must be recognized. They are purely subjective and may vary from time to time for a number of causes. They must be made at the first or second inhalation since the sense of smell is readily fatigued. Similarly they must not be used as a warning of rising concentrations since fatigue sets in so rapidly. Where more than one substance is present, the effect may be additive. The sense of smell may be impaired for various reasons. In the case of visual observation of dustiness, illumination, type of material, and particle size, will influence the observations.

Sampling and Analysis

An air sampler consists essentially of a collector (to collect and retain the contaminant), an air meter (to measure air flow), and an air moving device (to draw air through the system). The device may be as simple as an evacuated flask for collecting a volume of air, where the flask is both the collector and air meter, and the vacuum in the flask is the air mover. On the other scale, there is the combustion apparatus with a furnace for converting the contaminant to a measurable state; a collector in the form of a glass bead filled tube containing reagents, first to convert the combusted contaminant to a soluble form and second to react with and retain it; an orifice flowmeter with manometer; and an electrically driven air pump. The volume of air sampled will vary from 50 milliliters obtained in a fraction of a second by an instantaneous sampler to that secured by a high volume sampler which can sample at the rate of 30 cubic feet of air per minute continuously for many hours. The sampler should be portable, rugged and simple as possible.

Each sampling method was originally devised to meet a particular need. While many of these methods have been modified to sample a variety of substances, care must be taken to select the right sampler for each job. Usually, there is one method which is best for a particular purpose. In general, it may be stated that it is possible to sample and analyze industrial air for most substances used in industry today. Whenever necessary to determine the atmospheric concentration of a new substance for which a method has not been previously formulated, it is always possible to devise a new technique or modify an old one.

Selection of Instruments

Since the number of sampling devices available to the industrial hygienist are many, the ultimate selection of one for a particular problem will depend not only on the substance being sought, but on other considerations:

1. Efficiency of collection. The sampler must be 100% efficient or its percent efficiency must be accurately known.

2. Volume of air collected. The sampler must operate at such a rate and be operable for such a period of time that a quantity of contaminant capable

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of being analyzed accurately is collected. This may be an instantaneous small volume or a long duration high volume sampler. In all cases an optimum rate and duration must be established. Several factors will determine the selection of a particular device.

If we assume an existing atmospheric concentration of approximately half the maximum allowable, the sampler must in most cases be able to collect within a reasonable time a quantity of contaminant capable of being analyzed with the desired accuracy. The rate of sampling must not be so great as to negate reasonable retaining efficiency, and at the same time must be slow enough to obtain as much of an averaging effect as possible, except where peak concentrations are sought. The duration of sampling must not be so long as to introduce an error due to aeration or carry-over of contaminants, but must be long enough to obtain a fair sample of workroom atmosphere or worker exposure over a representative cycle of operations. It is usually desirable for the sampler to have provisions for taking a large number of samples in a given period of time.

3. Type of process being examined. All other things being equal, where a contaminant is disseminated to the atmosphere at a uniform rate, a low volume sampler may be used. Where a fluctuating wide range of concentrations may be expected, a continuous sampler must be used to provide an integrating effect. The conditions to be encountered can usually be predicted if the processes under investigation are known ahead of time.

4. The sampler must not introduce a hazard to the workroom. Samplers with sparking or static producing electrical equipment, or unprotected heated elements or wires, must not be brought into a potentially flammable or explosive atmosphere.

Representative Samples

The most important part of air analysis is the proper determination of sample location, time, duration, and number so that a result truly representative of the actual conditions under investigation is obtained. Depending on the industry, process, season of the year, etc., this requirement may be met by one small instantaneous sample or may require a large number of long term samples.

Following are the factors which will govern the setting up of a sampling rationale for any particular problem. (The type of sampler to be used has at this point been narrowed down to one or two by the considerations discussed in the preceding section.)

1. Location of Sampling.

(a) General workroom atmosphere. Where one or two operations or a large number of operations are contaminating an entire workroom, and where all the workers spend their time at a variety of tasks and locations rather than at one particular process, sampling the general workroom atmosphere will be representative of the conditions to which the workers are exposed. This is accomplished by walking around the entire workroom while carrying the sampler. Illustration: A large chemical plant where several workers will periodically operate control valves and check gauges at various locations in the plant.

(b) Breathing zone of workers. This location is sampled where the workers are each assigned to a particular operation and work within circumscribed limits; where each process disseminates different types or quantities of contaminant and the exposure at each process is desired; where the operations are discontinuous or where a particular worker spends his time at a variety of processes and the exposure of this one worker is sought; and, in general, in all cases where an exact picture of the exposure of an individual worker is desired. The sampling tube may be attached to the worker's person near his nose, or the investigator may follow the worker during his normal operations holding the sampling tube as close to his nose as possible. In some cases, general workroom samples may be taken in conjunction with breathing zone samples to determine the extent of the spread of contamination from a particular process. Illustration: Breathing zone samples will be taken near a worker who spends his entire time loading and unloading a vapor phase degreaser and carrying the degreased parts to a different location.

(c) Process. Samples may be taken at several processes or machines to determine the extent to which each contributes to atmospheric contamination. Samples may also be taken inside machinery enclosures to determine the explosibility of the atmosphere.

(d) Ventilating systems. It is often desirable, for a variety of reasons, to sample the air inside ventilating system ductwork or in the effluent from the exhaust system. These reasons may include determining the amount of material escaping from a process, estimating the load to be placed on a dust or fume separator, sampling both in the duct and effluent air to determine the efficiency of separation of a separator, and measuring the contribution of contaminant-laden effluent air to general atmospheric pollution.

2. Time of sampling. Samples may be required in a plant before contamination begins, during dissemination of contamination, and after contamination has stopped. These samples will indicate control conditions, maximum concentrations and residual concentrations. Diurnal variations will be detected by sampling at different times during the day and night. Sampling at different seasons of the year will expose any climatic or cyclical business factors which will tend to influence atmospheric concentrations.

3. Duration of sampling. Where the work cycle is continuous, sampling should encompass at least one work cycle, more if necessary. When the work cycles are discontinuous or intermittent, sampling should be continuous through several work cycles, including the hiatuses between cycles. In many cases, the sampler must be operated continuously for a full work day.

4. Number of samples. Enough samples should be taken to indicate exposure of workers to a contaminant, or to provide such other information as may be sought. A small number will be adequate where the environment is homogeneous or the atmospheric concentration is constant. A large number is required where the environment contains a wide range of concentrations or where the concentrations fluctuate unpredictably during the day.

5. Unusual working conditions. Atmospheric concentrations of an industrial contaminant as determined by air sampling and analysis are interpreted

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and evaluated in the light of the maximum allowable concentrations for the particular substance. Since the limits are usually based on a worker breathing normally during an eight-hour work day under normal conditions, abnormal working conditions require careful interpretation of field results. Where the rate of work is unusually high because of piece work, incentive systems, etc., the rate of inspiration and of contaminant generation will be high so that more contaminant would be inhaled than under normal conditions. Similarly, where a good deal of overtime is worked, worker exposure is greater than the eight-hour day upon which maximum allowable concentrations are based.

Common Errors in Sampling

The novice or beginner will tend to sample for only as long as required by the sensitivity of the analytical method and will ignore the necessity of obtaining a sample representative of actual exposure. Thus, intermittent cycles of operation, several successive cycles of operation, or varying contaminant dispersal may require a sampling period much longer than the minimum time governed by the analytical method. An error often made when seeking to evaluate a worker's exposure is to sample at a machine only, regardless of the fact that the worker's normal duties may take him away from the machine into a less contaminated atmosphere for long periods of time. Further, the tendency exists to locate the sampling tube at the contaminated part of the operation where the worker seldom exposes himself. Conversely it may be inconvenient to follow a worker during a cycle of operations to get a breathing zone sample so that actual sampling may be three or four feet away in a much less contaminated atmosphere.

A sampling device may not be 100% efficient and the efficiency may vary with varying conditions. An unstable contaminant may be oxidized or converted to a more stable and often less toxic material between the period of sampling and the time the analysis is made. Thus lower oxides of nitrogen may be partially oxidized to the higher oxides.

Contaminants, other than the one being sought, but which are capable of giving a similar chemical reaction, may be present in the atmosphere. These interfering substances may be of low toxicity and will therefore introduce an error to the result. For instance, one method of determining carbon tetrachloride involves a chloride analysis. Should sodium chloride or ammonium chloride be present in the atmosphere, they will increase the chloride content of the sample and raise the apparent carbon tetrachloride concentration.

At best, the various methods of measuring the volume of air sampled are inaccurate as compared with the precision of the usual chemical analysis. Since concentrations are expressed as parts of contaminant per million parts of air, the air volume measurement is an integral part of the determination and introduces an unavoidable error.

Analytical Methods

Discussion of chemical and physical analytical and quantification methods does not come within the scope of this article and will only be discussed briefly.

(Continued in May, 1955 issue)

THE INTEREST AND ACTIVITIES OF THE STATE LABOR DEPARTMENT IN AIR POLLUTION CONTROL

(Continued from the March, 1955 issue)

Excluding New York City, there are six other counties in the State, each of which has a competent Sanitary Engineer in its County Health Department. In one of these counties, there are two municipalities employing full-time air pollution control inspectors. In four of these six counties there has been a more or less consistent policy of referring industrial air pollution problems to the Labor Department for cooperative solution.

A final finding is that in 20% of the communities with industrial air pollution, the pollution sources are both outside the jurisdiction of the community affected and located in counties without means to help their constituent local units. In these localities, the only legal remedy now available is an application to the courts for an injunction. It is suggested that as a preliminary step State legislation to cover this type of situation would be highly desirable. It may well be that the excellent pattern your Legislative Committee has set in coping with the problem of water pollution could be used as a guide in dealing with these not dissimilar types of air pollution problems.

Proposed Method for Obtaining Air Pollution Data

It seems apropos in conclusion to digress to a description of how the British Department of Scientific and Industrial Research has for more than the past 10 years collated and published monthly data on atmospheric pollution in Great Britain. Having some years ago standardized on four relatively simple and inexpensive devices for measuring pollution, the above noted Department has entered into agreements with several hundred municipalities, school boards, water districts, sewage districts, libraries, hospitals, and churches whereby each acquires and operates at its own expense one or more of these devices. Each reports its findings monthly in a standard manner to allow direct correlation of results from all reporting agencies. The co-ordinating agency publishes this data monthly and, from time to time, analyzes it. Each cooperating body receives a copy of the collated data and is thus able to compare its own pollution with that in the other areas of Great Britain. By virtue of having so many different cooperators, the validity of the data is not too adversely affected by the normal turnover in cooperating bodies as some drop out and new ones join.

This scheme offers a pattern that might well be adopted in New York to fill a need for factual information now lacking on the extent of our air pollution. Should your honorable committee pursue this matter further, the Department of Labor desires to continue its cooperation with you and to work with you to the extent its facilities and resources allow.

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INDUSTRIAL AIR ANALYSIS

(Continued from the April, 1955 issue)

There are usually several methods available to the analyst for any one substance and the one to use must be selected on the basis of experience. In industrial hygiene, as in all other scientific fields, the worker should work as inaccurately as he may, i.e., the most inaccurate measurement in a determination determines the required accuracy of all other measurements. With several exceptions, therefore, most workable analytical methods will be sufficiently accurate.

One exception to the above, is in the case of contaminants of exceedingly high toxicity (very low maximum allowable concentrations). A chemist who made an ordinary analysis with an error of one microgram (one millionth of a gram) in the final result would be justifiably proud of his technique. However, in the case of beryllium, where the maximum allowable concentration is of the order of one or two micrograms per cubic meter of air, an error of one microgram in the analysis might give an entirely misleading result.

Other important factors to be considered in selecting an analytical method are specificity, sensitivity, and time. Where interfering substances may be encountered in the atmosphere, the analytic method must be specific for the contaminant sought. For instance, it is not uncommon for benzene vapor to be present in the atmosphere at the same time as its homologue, toluene. The commoner analytical methods for benzene will determine toluene as well. Since benzene is so much more toxic than toluene, a specific method for benzene must be used.

The method finally selected must not be so insensitive that unreasonably large volumes of air must be sampled to secure an amount of contaminant that can be analyzed with suitable accuracy. The time required by the analysis should, if possible, be reasonably short. This is particularly important where a plant survey may require 40 or 50 air samples.

Sampling Methods

General

All air samplers must be equipped with a suitable air flow measuring device and an air mover. Air flow measuring devices may consist of the bottle itself, as in the vacuum bottle where the volume of the bottle is the volume of the air sampled, capillary or orifice meter, pressure gauge, the resistance of the sampling medium to air flow, rotameter, dry gas meter, etc. Common air movers include the low pressure in the vacuum bottle, water flow, water aspiration, rubber aspirating bulb, hand-operated piston or valve pump, gas or electric motor-driven pump, air ejector, etc.

Air sampling devises may be grouped into several classifications. One of these might be instantaneous (spot or grab) samplers versus long time continuous samplers. The principles governing the selection of either of the above types of samplers have been fully discussed in the sections dealing with the criteria for selecting a sampling device and for securing a representative air sample. There may seem to be a bewildering variety of sampling devices but the problems to be encountered in industrial air analysis are diverse and most of the instruments to be described fulfill one or more specific needs.

Air samplers may be further classified into those for gases, vapors, and mists, and for those for dusts and fumes. These will be listed and described briefly. More complete information may be obtained by consulting the numerous reference works in the field. Table 3 gives a list of the more common substances with an accepted method for their sampling.

Gases, Vapors, and Mists

Methods for the sampling of gases, vapors, and mists may be subgrouped into those which collect a volume of air, those which remove the contaminant from the air, colorimetric methods, and instrumental methods.

1. Devises which collect a volume of air. In these, a bottle or tube is filled with a sample of the air to be tested at the existing atmospheric pressure. Since the volume of air thus sampled will be necessarily small, the contaminant must be present in appreciably large quantities, as carbon dioxide in air, or the analytic technique must be very sensitive as in the case of benzene vapor.

One such device is the vacuum bottle with either a long capillary neck or stopcocks at each end. The bottle is evacuated by suction in the laboratory and

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TABLE 3

TYPICAL SAMPLING METHODS FOR SOME COMMON INDUSTRIAL AIR CONTAMINANTS

Contaminant	*Sampling Method*
benzene vapor (minute quantities)	sampling bottle
benzene vapor (large amounts)	benzene detector
carbon disulfide vapor	wet absorber with 5% potassium hydroxide, or sampling bottle
carbon monoxide	carbon monoxide tester
chlorine	wet absorber with o-tolidine
chromic acid mist	impinger with 5% sodium hydroxide
formaldehyde gas	impinger with sodium bisulfite solution
granite dust	impinger with water or propyl alcohol
hydrogen chloride gas	wet absorber with N/200 sodium hydroxide
mixed lacquer vapor	benzene detector (specially calibrated)
lead fume	electrostatic precipitator or filter paper
mercury vapor	ultra violet light absorption apparatus
nitrogen oxides	sampling bottle
sulfur dioxide	wet absorber with 5% sodium hydroxide, or tester
trichlorethylene vapor	combustion apparatus with sodium carbonate solution
wood dust	paper or aloxite thimble
zinc dust	impinger with water

sealed by either flaming the capillary or closing the stopcocks. It is then transported to the field and opened by breaking the sealed capillary tip, or momentarily opening and closing the stopcocks. The capillary is sealed with a wax cap. The bottles are returned to the laboratory for analysis.

Other methods of using double inlet bottles are by filling them with water or other suitable liquid and allowing the liquid to flow out of the bottle, or by drawing the air into the bottle by means of a two-way rubber aspirating bulb or hand pump until the original air in the container has been completely replaced by the contaminated air. A variation of this method is the citrate of magnesia bottle or ordinary laboratory bottle. The bottle is filled with water, emptied in the workroom so that the air replaces the liquid, and covered.

2. Devices which remove the contaminant from the air. These include dry adsorbers and wet absorbers. The dry adsorbers employ the ability of certain granular substances to adsorb most gases and vapors on the surface. In most cases, the total weight of adsorbed gases or vapors is determined, but the adsorbed substance may be driven off, collected, and analyzed chemically. Ascarite, silica gel, or activated charcoal are the usual adsorbents. In practice, air is drawn through a series of U-tubes containing the adsorbent. The tubes are weighed before and after sampling and the difference in weight determined. There are several shortcomings to this method. Because of handling, static charges, moisture, and other factors, constant and accurate weights are difficult to obtain. The adsorption is not selective. Atmospheric moisture and carbon dioxide may also be adsorbed. Attempting to establish an equilibrium between the adsorber and the water and carbon dioxide in the atmosphere before each required weighing, introduces an indeterminate error. The use of soda lime to remove these may result in some aliphatic organic vapors being removed as well.

Wet absorbers consist essentially of a sampling bottle with suitable liquid collecting medium, an air inlet tube extending into the medium, a method of diffusing the air or increasing its time of contact in the sampling medium, and an air outlet connected to the air mover.

The simplest of these is the impinger which will be described later. The Dreschel, Milligan, Friedrichs, and spiral sampling bottles are designed to increase the distance of travel of the air in the collecting medium and thus afford a greater period of time for the gas or vapor in the air to be in contact with and dissolved or reacted by the collecting medium.

In gas diffusing or scrubbing samplers, the bottle or tube contains a quantity of glass beads, or the end of the inlet tube is attached to a fritted glass or aloxite stone diffuser. These break up the incoming air into very fine bubbles and greatly increase the liquid-air interfacial area, providing for more intimate contact between the contaminant and the sampling medium.

The combustion apparatus, a refinement of the simple wet absorber, is essentially a sampling tube with glass beads, to the inlet end of which has been attached a platinum wire-wound quartz tube combustion furnace. The furnace burns all the vapor or gas in the incoming air, yielding a product of combustion which is easily collectible and readily analyzed. The concentration of the original substance is derived by a simple calculation.

The liquid media used in wet absorbers may be a simple solvent such as water or naphtha; a reagent which will react with the contaminant and convert it to a highly soluble compound; or a reagent which will react with the contaminant producing a color, making possible colorimetric analysis in the field.

Wet absorbers are simple, easily constructed in the laboratory, and lend themselves to a variety of uses. Almost any common gas or vapor may be sampled by

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this means, provided the type of bottle and collecting medium are carefully selected. The efficiency of collection depends on the solubility of the contaminant and the reagent. This efficiency may readily be determined in the laboratory. It is customary where the efficiency is low, to use several absorbing bottles in series and combine all the liquid portions for analysis.

3. Colorimetric methods. Where suitable colorimetric analytic methods are available, the adsorption or absorption method of air sampling may be used as a direct reading method as well. The medium used must be capable of reacting instantly with the contaminant to produce a definite permanent color. There are dry and wet types.

The dry adsorber consists of a tube with aspirator bulb and built-in color comparison chart. The tube is filled with granules of an inactive, insoluble compound coated with a suitable indicator reagent. Air is aspirated into the tube by means of a number of squeezes of the aspirator bulb. This number determines the volume of air sampled. The concentration is determined from the intensity of the color on the granules and the volume of air sampled. In atmospheres of very low concentration, an average or integral determination may be made by sampling until a detectable color is obtained.

There are now commercially available several colorimetric air samplers designed for specific substances. These include carbon monoxide, hydrogen sulfide, aromatic hydrocarbons, hydrocyanic acid gas, and sulfur dioxide. The instrument consists of an ampoule holder with attached rubber aspirator bulb and a case of sealed ampoules containing the reagent chemicals. In the field, the tips of the sealed ampoules are broken off, and the tube inserted into the holder. The contaminated air is passed through the tube by squeezing the bulb a counted number of times until the characteristic color appears in the reagent granules. This is compared with a calibrated color chart which is built into the tube holder and the concentration read off directly.

Any gas or vapor which can be sampled in a wet absorber containing a suitable colorimetric analytic medium may be analyzed directly in the field. The permanent color standards are transported to the field in standard comparator tubes or in bottles similar to the sampling bottle. In the former case, the sample is transferred to a comparator tube and compared with the standards.

Halogenated hydrocarbons, when ignited in a flame which is in contact with copper metal, burn with a characteristic green flame. This property has been utilized to design a halide torch for the exploration of atmospheres which may contain harmful concentrations of very toxic halides such as methyl bromide. The torch is very sensitive and with experience may be semi-quantitative since the degree of color is proportional to the concentration. This principle has been used in an instrument in which the color is produced in an arc and read photoelectrically.

4. Instrumental methods. These employ a physical property of the contaminant as a means of determining and recording its concentration in air. The analysis is continuous but not integrating. Fluctuations in concentrations are determined although a rough average may be estimated. These instruments require frequent calibrations and adjustments. With the exception of the carbon monoxide meter, they are not specific. When used as originally designed, only one known contaminant may be determined and the atmosphere must be free of all other substances which may record on the instrument. However, in recent years, a technique has been perfected which permits the use of these instruments to determine several unknown contaminants which co-exist in the atmosphere. This will be described under "benzene detector".

(a) Carbon monoxide indicator. This instrument employs the ability of Hopcalite, a catalyst consisting of certain metallic oxides, to catalyze the oxidation of carbon monoxide to carbon dioxide. In practice, the air is drawn through a bed of Hopcalite in which sensitive thermocouples are located. The heat generated by this reaction, which is proportional to the concentration of carbon monoxide, is converted to electrical energy by the thermocouples and recorded on an electrical meter. The scale reads directly in concentration of carbon monoxide.

(b) Interferometer. This instrument measures changes in refractivity and is applicable to the determination of gases and vapors whose refractivity is appreciably different from that of air. In operation, the instrument compares the refractivity of the sample with that of standard dry air free of carbon dioxide and at the same pressure and temperature as the sample. A light source of constant wave length must be used.

(c) Ultraviolet absorption instruments. These utilize the opacity of vapors and gases to certain wave lengths of light in the ultraviolet range. The device consists essentially of a tube with a source of a fixed wave length of ultraviolet light at one end and a photoelectric cell at the other. Dust free air containing the contaminant is sampled and the diminution of light transmission is proportional to the concentration of the gas or vapor. Ultraviolet instruments have been designed for mercury vapor and some of the chlorinated hydrocarbon vapors. This principle will prove extremely useful for qualitative and quantitative analyses of gases and vapors, especially in the case of mixtures of unknown composition, provided that an instrument with a source of variable light wave lengths can be developed.

(d) Combustible gas indicator. Several instruments of this kind are available. The air flows over a heated platinum wire which is one arm of a Wheatstone bridge (balanced electrical circuit). Any combustible gas in the air is burned catalytically, raising the temperature of the wire, and increasing its resistance. This resistance change is measured by a galvanometer with a scale calibrated to give readings in terms of percentage of the lower explosive limit.

(e) Benzene detector. This is a very sensitive combustible gas indicator, modified for the detection of benzene and calibrated in parts per million of benzene vapor. This instrument has been adapted for the analysis of unknown mixtures of unknown flammable vapors. The air is sampled and readings in terms of numbers of scale divisions are recorded. At the same time a sample of the parent solvent which is evaporating into the atmosphere is obtained for chemical analysis in the laboratory. An accurately measured portion of the analyzed sample is intro-

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duced into a gas chamber of known volume, volatilized, and completely mixed with the atmosphere in the chamber. This synthetic contaminated atmosphere is then sampled with the benzene detector and the reading recorded. This is repeated several times with different volumes of samples. The concentrations of the various synthetic atmospheres are calculated and calibration curves can be drawn up, showing concentration versus instrument scale reading. This method assumes equal evaporation rates for individual components of a mixed solvent.

All of the above instruments come as self-contained portable devices containing an air mover and air flow measurement instrument. They require calibration except where calibration curves or charts are provided by the manufacturer. Some of them may be modified so that they are continuous and automatic recording.

Dust and Fumes

Dust and fume samplers fall into several principal categories—impingement methods, filtration methods, and other methods. The first are primarily used to collect samples for microscopic counting, and the second and third to collect samples to be weighed or chemically analyzed.

1. Impingement methods

(a) The Greenburg-Smith Impinger and the modified midget impinger are the most widely used instruments in the United States for obtaining dust samples for evaluation by counting. The effect of certain mineral dusts, such as rock, free silica (quartz, flint), talc, asbestos, clay, etc., on health when inhaled has been studied in conjunction with the number of dust particles in the atmosphere. In this country, all toxicological studies of the lung-damaging dusts and subsequent maximum allowable concentrations have been made on the basis of dust counts of samples obtained by the impinger method and counted by the low power light field microscope technique. Dusts between 0.7 and 10 microns in size are determined by this method.

The impinger is essentially a bottle with an inlet or impinger tube at the end of which is an accurately ground nozzle of a certain diameter located a specified distance from a glass plate or the bottom of the bottle. Air is sampled at a fixed rate (1 CFM for the Greenburg-Smith impinger and 0.1 CFM for the midget impinger). Dust laden air impinges on the glass plate and the dust particles, their travel momentarily arrested, are wet by the water or other medium and retained. The Greenburg-Smith impinger is operated by an electric pump or air ejector; the midget impinger has a hand-cranked pump and is completely portable.

The impinger can be used for weight or chemical analysis as well as dust counts. Mists and some gases and vapors may also be collected in the impinger.

(b) The konimeter consists essentially of a spring operated low volume piston pump and a circular glass plate. Air is pulled through a round orifice, impinging against the adhesive or grease coated glass plate. The coating retains the dust particles which are then counted microscopically.

(c) The Owen's Jet Counter is similar to the konimeter but it has an additional moistening chamber where the air to be sampled is humidified prior to impingement on an uncoated glass plate through a narrow slot. The rapid expansion of the air going through the slot causes a condensation of moisture on the dust particles which adhere to the glass as droplets and soon dry. The Bausch and Lomb counter is a modification of this device containing an integral microscope for on-the-spot counting.

The konimeter and Owen's jet counter counts are not comparable to the impinger counts since much smaller air volumes are sampled and much smaller particles are retained and counted. These devices are useful for day to day comparisons of conditions in the same plant, and before and after estimations of the efficiency of dust control methods.

2. Filtration methods. The filtration method most commonly used is a very simple and widely applicable device consisting of a piece of fine chemical filter paper mounted in a suitable ring and funnel device and attached to an electric pump and flowmeter. Air flows range from 0.5 CFM to 35 CFM. A large variety of metal and chemical fumes and fine dusts can be sampled on filter paper with a high degree of collection efficiency. The material is leached off the paper and analyzed chemically.

Filter paper or aloxite thimbles may also be used. These are mounted in a suitable holder and air-borne dusts can be sampled at high rate of air flow. These thimbles lend themselves to the sampling of large quantities of dusts, especially those in the large particle size range, since their shape acts as a container for transporting the sample back to the laboratory without loss of material. The sample is usually weighed.

3. Other methods. The electrostatic precipitator employs the principle of the Cottrell precipitator. Air is drawn through a tube within which is a concentric wire electrode, the tube or its lining acting as the other electrode. An electrostatic charge between the electrodes places a charge on all particles in the incoming air stream, opposite to that of the tube. The particles are thus attracted to and deposited on the inner surface of the tube which is returned to the laboratory for analysis or weighing of the adhered matter. The collection efficiency is high for all types of particulate matter. There is a commercial portable outfit available with built-in suction fan and flowmeter.

4. Settling methods. These are used to measure gross atmospheric contamination. Cans or jars are set out in desired locations for periods up to a month and the matter settling in these containers is analyzed in the usual manner. These methods are used primarily in general atmospheric pollution studies. The amount of matter collected depends on a number of factors, including meteorological conditions, location of container, etc.

Summary

This discussion has attempted to cover, in general terms, the principal methods of evaluating air borne industrial contaminants. Other hazards, which may be air borne, inherent in the air, or actuated through the air, and which have not been mentioned, include excessive radiant and radioactive energy; extremes of temperature, humidity, and pressure; inadequate illumination; excessive noise; and excessive air movement. Specialized instruments for the detection and measurement of these conditions are commercially available.

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