will be variation, depending on the vision of the observer, the color of the dust, and the contrast available. Dark field microscopic techniques will reveal particles smaller than these, to a limit of approximately 0.4 micron. The smaller submicroscopic dusts can be sized and compared by the use of the electron microscope. Other sizing techniques may take into account velocity of samplings in calibrated devices and actual settlement measurements in laboratory equipment. The electron microscope and various sampling instruments, including the cascade inpacter, have been used with some success for the sizing of liquid particulates, including fogs and mists. Concentrations of these materials are usually reported on a weight basis.

Permanent Atmospheric Impurities

The size of the air contaminant, its physical properties, and its toxic effect on man are of prime importance in the design of ventilation systems and the application of air cleaning equipment. In actual practice, the need for air handling and air cleaning is established by the toxic, flammable, or nuisance qualities of the contaminant. Considerable evidence and data are available from experience and research to indicate the toxic actions and the permissible exposure level of many common materials. However, it must be emphasized that, for the most part, these exposure levels are based upon the industrial exposure for a few hours daily, and they must not be applied or extrapolated to include the air pollution situation where a broad spectrum of people are exposed continually. Accordingly, air contaminants may be grouped as industrial air contaminants and air pollutants.

INDUSTRIAL AIR CONTAMINANTS

Many industrial processes release air contaminants as dusts, fumes, smokes, mists, and as fogs, vapors, and gases. Unless control is applied, these materials will be dispersed through the industrial atmosphere and will be transported by air from the source to remote locations in the plant, exposing many workers to their toxic effects. The ventilation engineer must have an understanding of the process controls and ventilation controls which can be applied for their removal at the source; see Chapter 34 of the 1964 Guide And Data Book.

It is recognized, however, that absolute control cannot be maintained and that the individual is able to assimilate small quantities of various toxic materials without permanent injury. This is the basic concept which is applied to the entire science of industrial hygiene, and it is the basis for the standards of exposure level which have been developed.

Permissible levels of exposure vary considerably for different contaminants. Tables showing maximum allowable concentration values have been prepared by several sources, notably the American Standards Association. Industrial toxicologists today, however, advocate use of threshold limit values, which are time-weighted average concentrations for a normal workday, rather than maximum allowable concentrations. In the United States, these values are annually reviewed, revised, and published by the Committee on Threshold Limits of the American Conference of Governmental Industrial Hygienists. The latest available values (1963) are reproduced in Table 2. These limits are suggested guides, not hard-and-fast, rigid values. While they are based on working experience, laboratory research, and medical data, they are subject to constant revision. The engineer should refer to the latest standards available when evaluating a workroom exposure.

In applying these threshold limits, the following factors must be considered:

1. The duration of exposure is 8 hr per day for 5 or 6 days a week.
2. The measurements taken must be indicative of the concentration in the breathing zone of the exposed person. *Average* concentrations can be misleading in many instances.
3. The *average exposure* should not exceed the threshold limit value for an 8 hr day and, for shorter exposures, should not greatly exceed the threshold limit value. For example, it cannot be assumed that, if 100 parts per million is safe for an 8 hr exposure, 800 parts per million is permissible for one hour.
4. The threshold limit values presented are *upper limits*, and it is always desirable to operate well below these levels.
5. Two substances with similar threshold limit values may be entirely different in effect on the workman, and may have different actions at higher concentrations. In some instances, the threshold limit value has been placed at a level which minimizes irritation and provides a wide margin of safety. In other cases, the maximum value is close to the concentration at which severe or irreversible damage may be encountered.

It is obvious that there are wide limits of individual susceptibility. There also may be considerable variation in work habits between individuals, and, in some instances, exposure to contaminants may vary considerably in the day to day manufacturing operations.

The effects on health of selected toxic materials are summerized in the Hygienic Guide Series of the American Industrial Hygiene Association[1] in a manner that may prove more practically useful. Guides for about 150 industrial compounds have been published, showing recommended maximum atmospheric concentration (8 hr), severity of hazards, short exposure tolerance, atmospheric concentrations immediately hazardous to life, significant properties, industrial hygiene practice (recognition, evaluation, and control), and specific procedures. Each guide condenses into two pages a vast amount of published and unpublished research on the material under consideration.

FLAMMABLE GASES AND VAPORS[2,3,4]

The use of flammable materials is widespread in our society. Flammable gases and vapors may be found in such locations as sewage treatment plants, sewage and utility tunnels, dry cleaning plants, and automobile garages, as well as in industrial finishing process plants. Adequate ventilation is a primary requirement for minimizing or preventing fires and explosions of these materials. The need for good ventilation is not removed by the use of other precautions such as the *elimination of the ignition sources, safe building construction*, and *the use of automatic alarm* and *extinguisher systems*.

The ability of a flammable liquid or gas to form explosive mixtures is determined by its vapor pressure and volatility, or *rate of evaporation*. A convenient method of expressing these properties is to refer to the *flash point* of the material involved. The flash point may be defined as the temperature to which a combustible liquid must be heated to produce a flash when a small flame is passed across the surface of the liquid. Depending upon the test methods, this may be either the *open cup* or *closed cup* flash point, usually expressed in Fahrenheit degrees. The higher the flash point the more safely can the liquid be handled. Liquids with flash points under 70 F should be regarded as highly flammable.

In practical usage, the air-vapor or air-gas mixture must be in the explosive range before it will be ignited by a source of ignition. The explosive range is defined as being between the upper and lower explosive limits which are expressed as percent by volume in air. Concentrations of material above or

below the lower explosive range will not explode. Table 3 lists many of the common explosive materials, giving their upper and lower explosive limit in percent by volume, the closed cup flash point in Fahrenheit degrees, and the NBFU classifications by number. Where *mixtures* of flammable gases or vapors are present, the reader is referred to other publications for more detailed information on evaluating the hazard.

The designer of equipment for the control of combustible materials is referred to Chapter 10 with respect to combustible anesthetics, and to Chapter 35 of the 1964 Guide And Data Book. In designing ventilation systems for the control of flammable gases and vapors, the engineer must consider the following:

1. Most safety authorities and fire underwriters prefer to limit the concentrations to 20 to 25 percent of the lower explosive limit of the material. The resulting safety factor of 4 or 5 allows latitude for imperfections in air distribution and variations of temperature or miixture. It is also a further safeguard against unpredictable or unrecognized sources of ignition. In only rare instances should there be a resort to operation at concentrations above the upper explosive limit. It must be recognized that, in order to reach the upper explosive limit, the flammable gas or vapor must pass through the active explosive range, in which any source of ignition will cause an explosion. In addition, a drop in gas concentration due to unforeseen dilution or reduced evaporation rate will result in operation in the dangerous explosive range.

2. In occupied places where ventilation is applied for proper health control, the danger of an explosion will be minimized. In most instances, flammable gases and vapors are also toxic, and the maximum allowable concentrations are far below the lower explosive limit of the material. As an example, proper ventilation for acetone vapors will keep the concentration below 1000 parts per million. This is equivalent to 0.1 percent by volume. The lower explosive limit for acetone is 2.5 percent by volume. Thus, proper ventilation to reduce the health hazard will result in concentrations far below the lower explosive limit.

3. Proper location of exhaust and supply ventilation equipment depends upon the manner in which the contaminant is given off and upon other problems of the process, and only secondarily upon the relative density of flammable vapor. Again using acetone as an example:

density of air = 1.0 density of acetone vapors = 2.0

2.5% = 0.025 parts acetone	= 0.025 × 2 =	0.05
97.5% = 0.975 parts air	= 0.975 × 1 =	0.975
		1.025

The density of air-acetone mixture at lower explosive limits is then 1.025.

It can be seen that the specific gravity of the explosive mixture is substantially the same as that of air alone, and it is apparent that cross drafts, moving equipment, and temperature differentials may cause sufficient mixing to produce explosive concentrations and disperse these throughout the atmosphere, with no regard to *heavier than air* vapors. The engineer is cautioned to provide proper exhaust and supply air patterns to control the hazardous material, preferably at its source, or to take into account drafts, equipment movement, and convective forces, to provide good distribution of exhaust and supply air for general dilution and exhaust.

COMBUSTIBLE DUSTS[5,6]

Many mineral and organic dusts are capable of producing dust explosions. Often, a primary explosion results from a small amount of dust in suspension, which has been exposed to a source of ignition; the pressure and vibration created may then be sufficient to dislodge large accumulations of dust on horizontal surfaces, thereby creating a secondary explosion.

In general, dust clouds require high temperatures and a sufficient concentration of dust for ignition. The listing in Table 4 is representative of explosive concentrations, ignition temperatures, explosive temperatures, and pressure rise; however, it must be recognized that some discrepancies in obtaining test results are caused by the difficulty in obtaining dust suspension of uniform dispersion. This should be kept in mind when comparing results from several sources.[4]

Explosive dusts are potential hazards whenever the dust escapes, uncontrolled, to disperse in the atmosphere or settle on horizontal surfaces such as beams and ledges. Proper ventilation design will involve the principles discussed in Chapter 35 of the 1964 Guide And Data Book. Special care must be taken to insure that the ventilation systems and equipment chosen will prevent the pocketing of dust inside of the equipment itself. In many instances, magnetic traps are used to separate tramp iron from other metallic and organic dusts being conveyed in production equipment and ductwork. When local exhaust ventilation is used, it is often desirable to install separation equipment as close to the source of dust as possible to prevent the transport of the quantities of dust in the exhaust system.

AIR POLLUTION[7,8]

The total particulate load in the atmosphere includes all forms of air contaminants outlined in this chapter. The sources of these materials may be natural, as with the permanent atmospheric impurities, or man made, where the materials may arise from domestic, commercial, and industrial combustion process along with the air contaminants exhausted for health control. Contaminant sizes will cover the broad range illustrated in Fig. 1. The larger particles will settle out of the air rapidly, in the vicinity of the source. The smaller particles will remain suspended for long periods of time, settling many miles from the source, or becoming a permanent contamination in the air.

It has been common practice to evaluate atmospheric dust loads in terms of soot fall in tons per square mile per month. Such data published for the cities in this country range from 20 to 200 tons per square mile per month. To the ventilating and air-conditioning engineer, however, these values have little significance since they do not express any measure of the suspended material which must be cleaned from the ventilation air before it can be used.

Soot fall data are most useful in indicating the effectiveness of smoke abatement and proper combustion methods, and, to some extent, serve as comparative indices of such control programs.

In selecting air cleaning equipment for ventilation systems, the engineer requires data of the type illustrated by Table 5. Utilizing the air loading in terms of grains per thousand cubic feet, or milligrams per cubic meter, he may use technical literature provided by the air cleaner supplier or the supplier's representative in selecting equipment which will do the job adequately, with the minimum of power consumption and maintenance. It is apparent from the table that there is a considerable variation in the atmospheric loading between rural and suburban districts, and many industrial development areas. On the one hand, simple air filters may be all that is required for proper air cleaning, in other instances, it may be necessary to resort to heavy duty industrial gas cleaning equipment to supply air that is clean enough for human use, or for process requirements.

(*Continued on p. 154*)