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HEATING VENTILATING AIR CONDITIONING GUIDE 1951

An Instrument of Service Prepared for the Profession containing

A TECHNICAL DATA SECTION of reference material on the design and specification of heating, ventilating and air conditioning systems based on—the Transactions—the Investigations of the Research Laboratory and Cooperating Institutions—and the Practice of the Members and Friends of the Society; A MANUFACTURERS' CATALOG DATA SECTION containing essential and reliable Information concerning Modern Equipment; COMPLETE INDEXES to Technical and Catalog Data Sections.

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Fever Therapy Locally Induced by Conditioned Air, by M. B. Ferderber, F. C. Houghten and Carl Gutberlet (A.S.H.V.E. TRANSACTIONS, Vol. 46, 1940, p. 307).

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CHAPTER 5

AIR CONTAMINANTS

Classification of Air Contaminants; Sizes of Airborne Particles; Air Pollution by Smoke, Ash and Cinders; Smoke-Abatement and Air Pollution Control; Odor Nuisance; Maximum Allowable Concentrations of Industrial Air Contaminants; Flammable Gases and Vapors; Combustible Dusts; Atmospheric Pollen; Airborne Bacteria

THE normal constituents of the earth's atmosphere are oxygen, nitrogen, carbon dioxide, water vapor, argon, small or negligible amounts of other inert gases, hydrogen, variable traces of ozone, and small quantities of *microscopic* and submicroscopic solid matter, sometimes called *permanent atmospheric impurities*. From the viewpoint of the air conditioning engineer, all other airborne substances may be termed *contaminants*. This term is applied preferably, however, to undesirable or chance impurities, since the occasion may arise for adding to the air controlled amounts of solid or gaseous diluents for the prevention of explosions; germicidal vapors or mists (aerosols) for bacteria control; masking substances for odor control; or a substitute for one of the normal gases, as, for example, when helium is used to replace nitrogen in atmospheres for compressed air workers or divers.

Control of the chemical quality of air is one of the functions of complete air conditioning, and some knowledge of the composition, concentration and properties of air contaminants under various circumstances is therefore essential.

Air contaminants arise from the normal processes of wear, erosion, windstorm, sea-spray evaporation, thermal disintegration, earthquake, volcanic eruption, combustion, manufacturing, transportation, agriculture, and the biochemical or biological processes of life. They are classified at various times as organic and inorganic, visible or invisible, microscopic or macroscopic, particulate or gaseous, toxic or harmless, beneficial or destructive. The following classification is based chiefly upon the origin or method of formation of air contaminants.

CLASSIFICATION OF AIR CONTAMINANTS

Dusts, Fumes, and Smokes are solid particulate air contaminants.

Dusts are solid particles projected into the air by natural forces, such as wind, volcanic eruption or earthquake, and by mechanical processes, such as crushing, grinding, milling, drilling, demolition, shovelling, conveying, screening, bagging and sweeping. Some of these forces produce dust from larger masses, while others simply *disperse* materials that are already pulverized. Generally, particles are not called dust unless they are smaller than about 100 microns. Dusts may be of *mineral* type, such as rock, ore, metal, sand; *vegetable*, such as grain, flour, wood, cotton, pollen; or *animal*, such as wool, hair, silk, feathers, leather.

Fumes are solid particles commonly formed by the condensation of vapors from normally solid materials such as molten metals. Metallic fumes generally occur as the oxides in air because of the highly reactive nature of finely divided matter. Fumes may also be formed by sublimation, distillation, calcination, or chemical reaction, whenever such processes create airborne particles predominately below the 1 micron size. Fumes permitted to age tend to flocculate into clumps or aggregates of larger size, thereby facilitating removal from air.

Smokes are the extremely small solid particles produced by incomplete combustion of organic substances such as tobacco, wood, coal, oil, tar and other carbonaceous materials. The term *smoke* is commonly applied to the mixture of solid, liquid and gaseous products of combustion, although the technical literature prefers to distinguish between such components as soot or carbon particles, fly-ash, cinders, tarry matter, unburned gases, and gaseous combustion products. The finest particulate constituents are much less than 1 micron in size, often in the range of 0.1 to 0.3 micron.

Mists and Fogs are liquid particulate air contaminants.

Mists are very small airborne droplets of materials that are ordinarily liquid at normal temperatures and pressures. They may be formed by atomizing, spraying, splashing, mixing, violent chemical reaction, electrolytic evolution of gas from a liquid, or escape of a dissolved gas upon release of pressure. Very small droplets expelled or atomized into the air by sneezing constitute mists containing microorganisms that become air contaminants.

Fogs are limited by some classifications to airborne droplets formed by condensation from the vapor state. This arbitrary distinction between mist and fog is of minor importance, as both terms are used to indicate the particulate state of airborne liquids (occasionally termed *aerosols*). *Fog nozzles are so named because of their* ability to produce extra fine droplets as compared to the mist from ordinary spray devices. The highly volatile nature of some liquids quickly reduces their airborne droplets from the mist to the fog range, and eventually to the vapor phase until the air becomes saturated with that liquid. Many droplets in fogs or clouds are microscopic and submicroscopic in size, and may be conceived as the transition state between the larger mists and the vapors.

Vapors and Gases are non-particulate air contaminants.

Vapors are the gaseous phase of substances that are either liquid or solid in their commonly known state, examples being gasoline, kerosene, benzene, carbon tetrachloride, mercury, iodine, camphor. Vapors may be changed to the solid or liquid form by increasing the pressure, decreasing the temperature or applying both processes simultaneously. They are removed from the air by condensation with less difficulty than are the gases.

Gases are normally formless fluids which tend to occupy a space or enclosure completely and uniformly at ordinary temperatures and pressures. The following substances qualify as gases: oxygen, nitrogen, carbon dioxide, carbon monoxide, hydrogen, ammonia, sulfur dioxide. Gases, likewise, may be solidified or liquefied by the proper control of temperature and pressure.

The preceding classification is not suitable for the airborne living organisms, which range in size from the submicroscopic viruses to the largest pollen grains, not considering the smallest insect life. Bacteria range from about 0.2 to 5 microns in size, fungus spores from 1 to 10 microns, and pollen from 5 to 150 microns.

SIZES OF AIRBORNE PARTICLES

Fig. 1 is a graphic tabulation of the properties of airborne solids and liquids arranged according to size on the micron scale. There are 25,400 microns in 1 inch.

Particles larger than 10 microns are unlikely to remain suspended in air currents of moderate strength, but settle out by gravity at speeds dependent upon the shape, size and specific gravity of the particle, wind velocity, orientation of the collecting surface, and topography. These larger particles are of major interest to the engineer in the solution of nuisance problems, but it is usually the smaller particles, or those below 10 microns, that remain in the air long enough to be of hygienic as well as economic significance.

Industrial dust particles are predominantly of the order of 1 micron in size. Tremendous numbers are also present in the submicroscopic range below 0.5 micron, but those below 0.1 micron are not believed at present to be of practical importance, possibly due to their exceedingly small mass in comparison with the balance of airborne matter. In fact, particles this small may become the *permanent* atmospheric impurities that have little, if any, opportunity of settling because of the continual motion imparted to them by air currents and the molecular activity of gases (Brownian Movement).

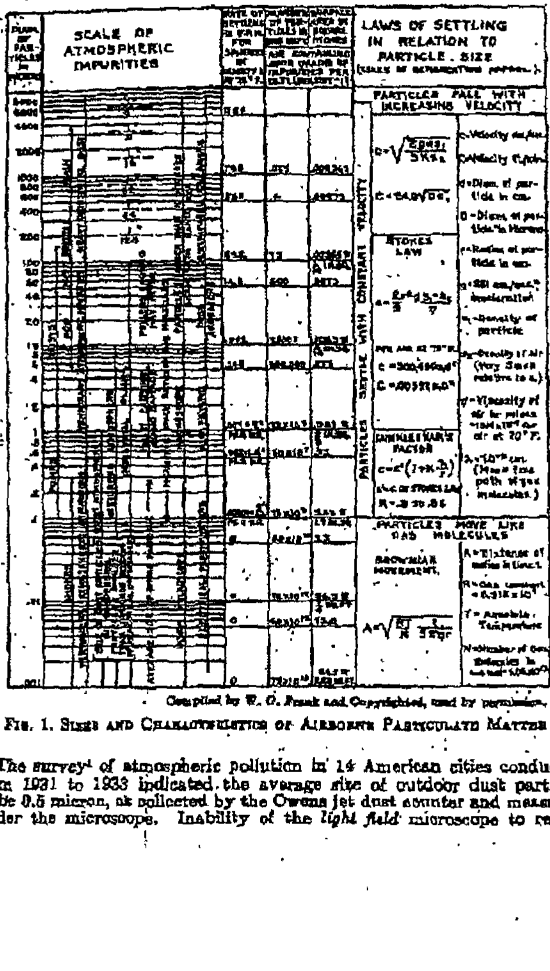

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FIG. 1. SIZES AND CHARACTERISTICS OF AIRBORNE PARTICULATE MATTER

The survey[1] of atmospheric pollution in 14 American cities conducted from 1931 to 1933 indicated the average size of outdoor dust particles to be 0.5 micron, as collected by the Owens jet dust counter and measured under the microscope. Inability of the *light field* microscope to reveal particles in the 0.1 micron vicinity may have influenced the determination of average particle size.

The lower limit of particle size visible to the naked eye cannot be stated definitely. It depends not only upon the individual eye, but also upon the shape and color of the particle, intensity and quality of the light, and nature of the background or opportunity for contrast. Under ideal conditions a particle of 10-micron size might be recognized, while under less favorable conditions it may be impossible to distinguish a particle smaller than 50 microns. The lower limit of visibility probably ranges from 10 to 50 microns.

Dusts, powders and granular materials are frequently classified by reference to the size of screens used for separation. Particles above 40 microns are said to be the *screen sizes* and those below, the *sub-screen* or microscopic sizes. Approximate or theoretical sizes of particles corresponding to the mesh scale of the U. S. Standard Sieve Series are given in Table 1.

Microscopic examination of screened dust indicates that the average diameter of a sample of irregular particles may be substantially larger

TABLE 1. RELATION OF SCREEN MESH TO PARTICLE SIZE

U. S. Standard Sieve Mesh...	400	325	200	140	100	60	35	18
Nominal Sieve Opening in Microns....................	37	44	74	105	149	250	500	1000

than the openings of the screen through which it has passed, if the particle shapes deviate considerably from the spherical form.[3] The smallest dimension of many such particles will correspond with the maximum permissible distance between the wires of commercial screens made to *ASTM* Standard Specifications. Screening does not give sharp separation into size groups, and accordingly, such a classification is statistical rather than absolute.

AIR POLLUTION BY SMOKE, ASH AND CINDERS

Total airborne solids settling in urban areas are usually reported as *soot fall* in tons per (square mile) (month). Such data published for the cities in this country range from 20 to 200 tons per (square mile) (month). To the air conditioning engineer this information may indicate the effectiveness of smoke abatement or fuel combustion control methods in his locality, but it does not provide a suitable index of the suspended dust that air cleaners in a ventilating system are expected to capture.[1, 4, 6] Gravimetric or weight data of the type given in Table 2 are preferable. In some cases airborne particle counts may be necessary, as for pollen, bacteria, spores, and insoluble dusts causing illness or lung disease.

Dust concentrations by weight cannot be converted readily to concentrations by particle count because of the variability of particle size, shape and specific gravity, and the inherent characteristics of dust counting and weighing procedures. One milligram of dust per cubic meter of air may represent dust counts from 1 million to 100 million particles per cubic foot of air (lightfield microscope technic) according to the size distribution of the airborne dust sample. Information of this type for a specified application is best obtained by simultaneous sampling for both counting and weighing and noting carefully at the time all factors that might affect the reproducibility of the count-weight ratio.

Smoke Abatement and Air Pollution Control

Successful abatement of atmospheric pollution caused by smoke requires the combined efforts of the combustion engineer, industrial executive, public health officer, city planning commission and the community at large. Electrification of industry and railroads, increase in the use of domestic oil and gas furnaces, and segregation of industrial districts are gradually providing effective aid in the solution of this problem. In the large cities where nuisance from smoke, fly-ash and cinders is more serious, limited areas obtain some relief by the use of district heating. (See Chapters 13, 14 and 16 for further discussion on fuel burning technic.)

TABLE 2. DUST CONCENTRATION RANGES

Location	Grains per 1000 Cu Ft*	Milligrams per Cubic Meter
Rural and suburban districts	0.02–0.2	0.05– 0.5
Metropolitan district	0.04–0.4	0.1 – 1.0
Industrial districts	0.1 –2.0	0.2 – 5.0
Ordinary factories or workrooms	0.2 –4.0	0.5 –10
Excessively dusty factories or mines	4–400	10–1000
Minimum explosive concentrations†	4000–200,000	10,000–500,000

* 1 grain per 1000 cu ft = 2.3 milligrams per cubic meter.
† 1 oz per cubic foot = 1 gram per liter = 1000 grams per cubic meter.

Many present ordinances limit the number of minutes in any one hour that smoke of a specified density (determined by comparison with a Ringelmann Chart which is described in Chapter 49) may be discharged.

There is now considerable interest and activity in the control of air pollution factors in addition to smoke. Difficulty in the establishment of acceptable criteria for certain corrosive and irritant gases, such as fluorides and the oxides of sulphur and nitrogen discharged with the gases of combustion, and the frequently complicated technical and economic problems encountered in control, have delayed the drafting and enforcement of legislative measures. Recent reports of an increased incidence of diseases, such as pneumonia and lung cancer, in areas high in certain air contaminants, require further critical investigation before acceptance. The values finally adopted will undoubtedly be lower than the M.A.C. (Maximum Allowable Concentration) limits for use in industry, because the exposure is continuous compared with the 8-hour day, 5 or 6-day week upon which M.A.C. values are based, and because the exposed population contains individuals with greater variation in age and health status.

In foggy weather, or with an *inversion* of atmospheric conditions, accumulation of gaseous contaminants may cause irritation of eyes, nose, and respiratory passages, and possibly cause even more serious physiological effects. The Meuse Valley fog disaster (Belgium 1930) and the Donora smog (Pennsylvania 1948) are classic examples in the history of gaseous air pollution. In both instances it is believed that irritant gases, principally from industrial plants, accumulating during periods of exceptionally prolonged meteorological *inversion* and fog, contributed to the illness of many persons, and to the death of some who were especially susceptible.

Absorption of Solar Radiation

Absorption of solar ultraviolet light by smoke and soot is recognized as a health problem in many industrial cities. Measurements of solar radiation in Baltimore[6] by actinic methods demonstrated that ultraviolet light intensity in the country was 50 percent greater than in the city. In New York City[7] a loss as great as 50 percent in visible light was found by photoelectric measurements.

ODOR NUISANCE

A problem companionate with smoke abatement is the control of odor nuisance in the neighborhood of industrial plants discharging noxious or offensive air contaminants. Community planning and zoning will avoid much of the difficulty in the future, but meanwhile many industrial cities must resort to corrective measures by requiring installation of air cleaning devices, alteration of manufacturing processes, or termination of the offensive operation in residential or commercial districts.

Control of outdoor odor nuisance is especially troublesome because of the extremely minute quantities of contaminant that are capable of offending through a wide area. New industrial chemicals with strange or unfamiliar odors tend to receive more attention from the neighborhood than the customary odors generated by well known processes and raw materials. Methods of odor control currently in use include charcoal adsorption, scrubbing towers and air washers, chlorination, condensation, masking, passage of the odorous air through combustion chambers, dispersion through a tall stack, and best of all, substitution of less offensive materials whenever possible.[8, 9, 10, 11]

Control of air quality within buildings ventilated for human occupancy is discussed in Chapter 6. Tobacco smoke odors, cooking odors and body odors are air contaminants of the nuisance type which now command a decisive position in the standards of air quality for indoor comfort. However, the engineer will find, at times, that odors originating *outside* buildings in industrial or business districts may determine the kind and capacity of equipment he must provide for a high quality air supply installation.

INDUSTRIAL AIR CONTAMINANTS

Many industrial processes are sources of contaminants. Their control is an important function of the ventilating or air conditioning engineer, because the atmosphere within buildings is the medium whereby such finely divided matter is dispersed and transported from the source to remote locations where it may cause property damage, nuisance, fire, explosion, disease and even death.

Tables 3, 4 and 5 give the *maximum allowable concentration* values for many industrial air contaminants as adopted by the Sectional Committee Z37 on Allowable Concentrations of Toxic Dusts and Gases of the *American Standards Association*, and as reported by the Committee on Threshold

Limits and accepted by the *American Conference of Governmental Industrial Hygienists* at its 1946 meeting.

It must be emphasized that these limits in the great majority of instances are only *suggested maximum working levels* since they are estimates, based in many cases upon incomplete environmental and medical studies. Where there is agreement between the *ASA* Standard Z37 and *A.C.G.I.H.* values, reliability of the *ASA* Standard is increased. The values are not fixed, but are subject to revision, upward or downward, with the development of new information. There is by no means complete agreement regarding these values among responsible industrial hygienists.

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

1. The duration of exposure is 8 hr a day for 5 or 6 days a week.

2. The measurements are indicative of the concentration in the breathing zone of the exposed person.

3. The M.A.C. is usually accepted as the average exposure value when the upper limits do not greatly exceed the M.A.C. value. For example, it cannot be assumed that if 100 ppm is considered *safe* for 8-hour exposure, that 800 ppm for one hour will be permissible.

4. Two substances with similar M.A.C. values may be quite different as to physiological effects at other concentrations. In one *instance the selection of a limit* may be predicated *upon* a discomfort factor, with a wide margin of safety before systemic effects would be encountered, while in another case the value represents an appreciable fraction of the concentration which may be associated with severe and irreversible injury.

5. These values are upper limits; it is desirable to operate well below the levels if the engineering and economic factors permit. The prudent engineer will incorporate a reasonable margin of safety in his estimates of ventilation capacity.

In Table 3, Column 1 lists the *ASA* Sectional Committee Z37 M.A.C. values; Column 2, those of the *A.C.G.I.H.* Committee on Threshold Limits. Column 3 gives the value in grams per cubic meter or ounces per 1000 cu ft for the corresponding *A.C.G.I.H.* limits; Column 4 shows the fluid ounces of chemical, if it is a liquid at 20 C (68 F), which, if equally dispersed in 1000 cu ft, would give the *corresponding* M.A.C.

In Table 4, Columns 1 and 2 are respectively the M.A.C. values from the *ASA* and *A.C.G.I.H.* *Committees*.

In Table 5, the M.A.C. values for a number of industrial dusts as given were obtained from data of the *A.C.G.I.H.* Committee on Threshold Limits.

Information on the properties and effects, with respect to health, of specific industrial air contaminants is available in publications listed at the end of this chapter.

FLAMMABLE GASES AND VAPORS

Adequate ventilation is a primary requirement for minimizing the hazard of fire or explosion due *to* gases and vapors. The need for good ventilation is not removed by the use of other precautions, such as the elimination of known ignition sources, segregation of hazardous operations, adoption of safe building construction, and installation of automatic alarms. Some safety engineers regard over-ventilation of an operation employing flammable liquids as a legitimate operating charge for the privilege or necessity of using a dangerous process. However, it is not possible to

TABLE 3. MAXIMUM ALLOWABLE CONCENTRATION OF GASES AND VAPORS

Substance	ASA Standards M.A.C. ppm	Threshold Limit Values A.C.G.I.H.[a] 1948 ppm	Gm/cu m or Oz/1000 cu ft	Oz/1000 cu ft[b]
Acetaldehyde		200	0.36	[illegible]
Acetic acid		10	0.02459	0.02
Acetic anhydride		5	0.02086	0.02
Acetone		500	1.1868	1.71
Acrolein		0.5	0.1145	0.002
Acrylonitrile		20	0.04335	0.05
Ammonia		100		
Amyl acetate		200	1.064	1.10
iso-Amyl alcohol		100	0.36	0.41
Aniline		5	0.019	0.02
Arsine		0.05		
Benzene (benzol)	100	35	0.11232	0.12
Bromine		1	0.00655	0.02
1,3-Butadiene		1000	2.210	1.9
n-Butanol		50	0.1515	0.15
2-Butanone		250	0.738	0.86
n-Butyl acetate		200	0.945	1.04
Butyl "cellosolve"		200	0.964	1.06
Carbon dioxide		5000		
Carbon disulfide	20	20	0.0625	0.06
Carbon monoxide	100	100		
Carbon tetrachloride		50	0.313	0.35
"Cellosolve"		200	0.736	0.74
"Cellosolve" acetate		100	0.54	0.55
Chlorine		1		
1-Chloro-1-nitroethane		20	0.0905	0.09
Chloroform		100	0.488	0.51
1-Chloro-1-nitropropane		20	0.101	0.09
Cyclohexane		400	1.376	1.62
Cyclohexanol		100	0.400	0.41
Cyclohexanone		100	0.401	0.41
Cyclohexene		400	1.34	1.36
Cyclopropane (propane)		400	0.0775	0.91
o-Dichlorobenzene		50	0.3005	0.34
Dichlorodifluoromethane		1000	4.94	5.13
1,1-Dichloroethane		100	0.405	0.43
1,2-Dichloroethane (ethylene dichloride)		75	0.3030	0.32
1,2-Dichloroethylene		200	0.794	0.84
Dichloroethyl ether		15	0.0874	0.09
Dichloromethane		500	1.74	1.85
Dichloromonofluoromethane		1000	4.29	4.55
1,1-Dichloro-1-nitroethane		10	0.0593	0.6
1,2-Dichloropropane (propylene dichloride)		75	0.3465	0.39
Dichlorotetrafluoroethane		1000	7.00	4.96
Dimethylaniline		5	0.02475	0.03
Dimethylsulfate		1	0.00515	0.005
Dioxane		100	0.36	0.38
Ethyl acetate		400	1.44	1.52
Ethyl alcohol		1000	1.885	2.0
Ethyl benzene		200	0.868	0.92
Ethyl bromide		200	0.890	0.95
Ethyl chloride		1000	2.64	2.78
Ethylene chlorhydrin		5	0.01645	0.018
Ethylene oxide		100	0.18	0.20
Ethyl ether		400	1.212	1.27
Ethyl formate		100	0.303	0.318
Ethyl silicate		200	0.851	0.47
Formaldehyde	10	5	0.006125	0.006
Gasoline		500	2.046	2.20
Heptane		500	2.05	2.17
Hexane		500	1.75	1.85
Hydrogen chloride		5	0.00745	0.008
Hydrogen cyanide		10	0.01104	0.012
Hydrogen fluoride		3	0.00245	0.003

TABLE 3. MAXIMUM ALLOWABLE CONCENTRATION OF GASES AND VAPORS (Concluded)

Substance	ASA Standards M.A.C. ppm	Threshold Limit Values A.C.G.I.H.[a] 1948 ppm	Gm/cu m or Oz/1000 cu ft	Oz/1000 cu ft[b]
Hydrogen selenide		0.05		
Hydrogen sulfide	20	20	0.02872	0.0007
Iodine		1	0.141	0.15
Isophorone		25	0.1406	0.22
Mesityl oxide		50		
Methanol	200	200	0.2618	0.27
Methyl acetate		200	0.606	0.63
Methyl bromide		20	0.0779	0.04
Methyl butanone		100	0.352	0.41
Methyl "cellosolve"		25	0.7775	0.075
Methyl "cellosolve" acetate	100	25	0.1208	0.11
Methyl chloride		100	0.2088	0.22
Methyl cyclohexane		500	2.005	2.44
Methyl cyclohexanol		100	0.466	0.47
Methyl cyclohexanone		100	0.458	0.44
Methyl formate		100	0.7384	0.25
Methyl iso-butyl ketone		100	0.409	0.42
Monochlorobenzene		75	0.3108	0.3
Monofluorotrichloromethane		1000	5.61	5.90
Monomethylaniline		5	0.020	0.02
Naphtha (coal tar)		200	0.838	0.73
Naphtha (petroleum)		500	1.942	2.4
Nickel carbonyl		1	0.00697	0.006
Nitrobenzene		1	0.00502	0.004
Nitroethane		100	0.302	0.318
Nitrogen oxides (other than nitrous oxide)	25	25		
Nitroglycerine		0.5	0.00464	0.005
Nitromethane		100	0.2415	0.21
2-Nitropropane		50	0.182	0.17
Octane		500	2.35	2.47
Ozone		1		
Pentane		1000	2.94	4.3
Pentanone (methyl propanone)		200	0.704	0.83
Phosgene		1		
Phosphine		0.05		
Phosphorus trichloride		0.5	0.00281	0.0028
iso-Propanol		400	1.002	1.20
Propyl acetate		200	0.834	0.885
iso-Propyl ether		500	2.085	2.75
Stibine		0.1		
Stoddard solvent		500	2.845	2.4
Styrene monomer	400	200	0.85	0.89
Sulfur chloride		1	0.00552	0.006
Sulfur dioxide		10		
1,1,2,2-Tetrachloroethane		5	0.343	0.03
Tetrachloroethylene		200	0.671	0.436
Toluene	200	200	0.763	0.42
Toluidine		5	0.0219	0.02
Trichloroethylene	200	200	0.534	0.15
Turpentine		100	0.546	0.58
Vinyl chloride (chloroethane)		500	1.28	1.33
Xylene	200	200	0.868	0.92

[a] A.C.G.I.H. — American Conference of Governmental Industrial Hygienists.
[b] Fluid ounces (at 20 C) of chemical in 1000 cu ft.

apply a reasonable safety factor to the ventilation estimate without consideration of the concentrations of gases or vapors that approach the danger point. Safety engineers prefer to limit the concentration to ¼ or ⅕ of the lower explosive limit, and this fact should be given full weight in determining the capacity and design of ventilating equipment. Rarely should consideration be given to *operation above the upper explosive limit* in the open areas of buildings or rooms—even though unoccupied—because the danger of temporary drop of gas concentration to a point within the explosive range is too great.

Ability of a flammable liquid to form explosive mixtures is determined largely by its vapor pressure, volatility, or rate of evaporation. *Flash point* is a convenient method of expressing this property in terms of the temperature scale. It 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. 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.

TABLE 4. LIMITS FOR TOXIC DUSTS, FUMES AND MISTS

Substance	A.S.A. Standards, M.A.C. mg/cu m	Threshold Limit Values, A.C.G.I.H. 1949 mg/cu m
Antimony		0.5
Arsenic		0.5
Barium		0.5
Cadmium	0.1 (W)	0.1
Chlorodiphenyl		1
Chromic acid & chromates (as CrO_3)	0.1	0.1
Cyanide as CN		5
Dinitrotoluene		1.5
Fluoride		2.5
Iron Oxide fume		15
Lead	0.15	0.15
Magnesium oxide fume		15
Manganese	6.	6
Mercury	0.1	0.1
Pentachloronaphthalene		0.5
Pentachlorophenol		0.5
Phosphorus (yellow)		0.1
Phosphorus pentachloride		1
Phosphorus pentasulfide		1
Selenium compounds as selenium		0.1
Sulfuric acid		1
Tellurium		0.1
Tetryl		1.5
Trichloronaphthalene		5
Trinitrotoluene		1.5
Zinc oxide fumes		15

Upper and lower limits of flammability of gases and vapors, and the flash points of the corresponding liquids are given in Table 6.

Methods for estimating the flammable limits of mixtures of gases or vapors must be applied with caution; the reader is referred to other publications for this information.[13, 14]

Design of equipment for the control of combustible anesthetics is outlined in Chapter 7. Construction of equipment for handling air containing flammable substances, or operating in atmospheres so contaminated, is discussed in Chapter 45.

It is customary to report the concentrations of flammable gases or vapors in percent by volume, or *volume percent*. Comparison with concentrations on the *part per million* scale used in chemical, medical or industrial hygiene literature is readily made by the conversion: 1 percent = 10,000 ppm (parts of contaminant per million parts of air, by volume, or in other words, cubic feet of contaminant per million cubic feet of air). It will be noted in Table 6 that nearly all of the substances listed have lower explosive limits above 1.0 percent, while the *maximum allowable concentrations* for gases and vapors in Table 3 are below 1000 ppm or 0.1 percent in most cases. Therefore, control of toxic or injurious vapors to levels below their maximum allowable concentrations for health usually requires much more effective ventilation than for the prevention of a fire hazard.

COMBUSTIBLE DUSTS

A dust explosion is essentially a sudden pressure rise caused by the very rapid burning of airborne dust. The *primary explosion* often originates from a small amount of dust in suspension exposed to a source of ignition, and the pressure and vibration it creates may be sufficient to dislodge large accumulations of dust on horizontal ledges or surfaces of the building and equipment, thereby creating a secondary explosion of great force.

TABLE 5. LIMITS FOR MINERAL DUSTS

Substance	Threshold Limit Values A.C.G.I.H. 1949 mppcf*
Alundum	50
Asbestos	5
Carborundum	50
Dust (nuisance, no free silica)	50
Mica (below 5% free silica)	20
Portland cement	50
Silica—high (above 50% free SiO_2)	5
Silica—medium (5 to 50% free SiO_2)	20
Silica—low (below 5% free SiO_2)	50
Slate (below 5% free SiO_2)	50
Soapstone (below 5% free SiO_2)	20
Talc	20
Total dust (below 5% free SiO_2)	50

* mppcf—million particles per cubic foot of air, standard light field count.

Thus the air conditioning engineer is involved for two reasons: (1) to obtain a movement of dust-laden air into exhaust hoods or openings, and through ventilating or pneumatic conveying ducts, in a manner that will prevent accumulation of highly flammable dust at points where it could ignite inside the equipment; and (2) to so design *process ventilation* as to prevent the escape of dust which might settle on horizontal surfaces and become a potential source of disaster at some distance from the dusty operation. (See Chapter 45).

Intensity of a dust explosion depends upon: chemical and thermal properties of the dust; particle size and shape; concentration in air; proportion of inert dust in the air; moisture content and composition of the air; size and temperature of the ignition source; and degree of dispersion of the dust cloud. Investigations on the explosibility of dusts require determination of the maximum pressure developed during explosion of a known air concentration, as well as determination of the rate of pressure rise. Investigators frequently experience difficulty in obtaining dust suspensions of uniform dispersion, and this should be kept in mind when comparing results from several sources.[14]

Minimum explosive concentrations of airborne dusts already tested range from 0.01 to 0.5 oz per cubic foot, or 10 to 500 grams per cubic meter

TABLE 6. APPROXIMATE LIMITS OF FLAMMABILITY OF SINGLE GASES AND VAPORS IN AIR AT ORDINARY TEMPERATURES AND PRESSURES[a]

Gas or Vapor	Lower Limit Percent by Volume	Upper Limit Percent by Volume	Closed Cup Flash Point F Deg[b]
Acetaldehyde	4.0	57	−17
Acetone	2.5	12.8	0
Acetylene	2.5	80	....
Allyl alcohol	2.5	....	70
Ammonia	15.5	25.0	....
Amyl alcohol	1.2	....	100
Amyl chloride	1.6	....	....
Amylene	1.6	8.7	....
Benzene (benzol)	1.4	8.0	12
Benzyl chloride	1.1	....	140
Butane	1.9	8.4	....
Butyl acetate	1.7	15.0	[illegible]
Butyl alcohol	1.7	....	....
Butylene	2.0	9.7	....
Carbon disulfide	1.2	50	[illegible]
Carbon monoxide	12.5	74.2	....
Crotonaldehyde	2.1	15.5	55
Cyclohexane	1.3	8.4	1
Cyclopropane	2.4	10.4	....
Decane	0.67	2.6	115
Dichloroethylene (1, 2)	9.7	12.8	57
Dimethyl sulfide	2.2	....	....
Dioxane	2.0	22.2	54
Ethane	3.1	12.5	....
Ether (diethyl)	1.8	36.5	−49
Ethyl acetate	2.2	11.4	24
Ethyl alcohol	3.3	19.0	54
Ethyl bromide	6.7	11.3	....
Ethyl cellosolve	2.6	15.7	104
Ethyl chloride	4.0	14.8	−58
Ethylene	3.1	32.0	....
Ethylene dichloride	6.2	15.9	56
Ethyl formate	2.7	16.4	−4
Ethyl nitrite	3.0	50	−31
Ethylene oxide	3.0	80	....
Furfural (135 C)	2.1	....	140
Gasoline (variable)	1.4–1.5	7.4–7.6	−50
Heptane	1.0	6.0	25
Hexane	1.2	6.9	−15
Hydrogen cyanide	6.6	40.0	....
Hydrogen	4.0	74.2	....
Hydrogen sulfide	4.3	45.5	....
Illuminating gas (coal gas)	5.3	31.0	....
Isobutyl alcohol	1.7	....	82
Isopentane	1.4	....	....
Isopropyl acetate	1.8	7.8	43
Isopropyl alcohol	2.0	....	60
Methane	5.0	14.0	....
Methyl acetate	4.1	15.6	14
Methyl alcohol	6.7	36.5	52
Methyl bromide	13.5	14.5	....
Methyl butyl ketone	1.2	8.0	....
Methyl chloride	8.2	18.7	....
Methyl cyclohexane	1.1	....	25
Methyl ethyl ether	2.0	10.1	−35
Methyl ethyl ketone	1.8	9.5	30
Methyl formate	5.0	22.7	−2
Methyl propyl ketone	1.5	8.2	....
Natural gas (variable)	4.8	13.5	....
Naphtha (benzine)	1.1	6.0	30–110
Naphthalene	0.9	....	176
Nonane	0.83	2.9	88
Octane	0.95	3.2	56
Paraldehyde	1.3	....	....
Pentane	1.4	7.8	....

TABLE 6. APPROXIMATE LIMITS OF FLAMMABILITY OF SINGLE GASES AND VAPORS IN AIR AT ORDINARY TEMPERATURES AND PRESSURES[a] (Concluded)

GAS OR VAPOR	LOWER LIMIT PERCENT BY VOLUME	UPPER LIMIT PERCENT BY VOLUME	CLOSED CUP FLASH POINT F DEG[b]
Propane	2.1	10.1	....
Propyl acetate	2.0	8.0	58
Propyl alcohol	2.1	13.5	59
Propylene	2.0	11.1	....
Propylene dichloride	3.4	14.5	60
Propylene oxide	2.0	22.0	....
Pyridine	1.8	12.4	74
Toluene (toluol)	1.4	6.7	40
Turpentine	0.8	....	95
Vinyl ether	1.7	27.0	....
Vinyl chloride	4.0	21.7	....
Water gas (variable)	6	70	—
Xylene (xylol)	1.0	6.0	63

[a] Adapted from: Fire and Explosion Hazards of Combustible Gases and Vapors, by G. W. Jones; Chapter 14, Industrial Hygiene and Toxicology, edited by F. A. Patty (Interscience Publishers, 1948); Properties of Flammable Liquids, Gases and Solids (Associated) Factory Mutual Fire Ins. Cos., January 1945); and National Fire Codes for Flammable Liquids, Gases, Chemicals and Explosives—1948 (National Fire Protection Association).

[b] Closed cup refers to the equipment used in flash point determination.

of air. Maximum pressures generated have been reported as high as 500 psi, although they are more likely to be of the order of 50 psi. Investigations on the flammable characteristics of dusts are currently made at 0.1 and 0.5 oz per cubic foot.[18–21]

ATMOSPHERIC POLLEN

Properties of pollen grains discharged by weeds, grasses and trees and responsible for hay fever, are of special interest to designers of air cleaning equipment (see Allergic Disorders in Chapter 7, and Air Cleaning, Chapter 33). Whole grains and fragments transported by the air range chiefly between 10 and 50 microns in size, but some have been measured as small as 5 microns, and others over 100 microns in diameter. Ragweed pollen grains are fairly uniform in size within the range of 15 to 25 microns. Pollen grains can be removed from the air more readily than the particles of dust prevalent in outdoor air or produced by dusty processes, since the latter predominate in the range of 0.1 to 10 microns in size.

Most grains are quite hygroscopic and therefore vary in weight with the humidity. Illustrations and data on individual pollen grains are available in the botanical literature.[23, 22, 24] Geographical distribution of plants known to produce hay fever is also recorded.[25, 26]

The quantity of pollen grains in the air is generally estimated by exposing an adhesive-coated glass plate outdoors for 24 hr, and then counting calibrated areas under the microscope. Methods are available for determining the number of grains in a measured volume of air,[21, 27, 28] but their greater accuracy has not caused them to replace the more simple *gravity slide method* used for most pollen counts. Counting technics vary somewhat, but the daily pollen counts reported in local newspapers during the hay fever season usually represent the number of grains found on 1.8 sq cm of a 24-hr *gravity slide*.

Hay fever sufferers may notice the first symptoms when the pollen count is 10 to 25, and in some localities the maximum figures for the seasonal peak may approach 1000 for a 24-hr period, depending upon the sampling and reporting methods of the laboratory. Translation of gravity counts by special formulas to a volumetric basis, or the number of grains per cubic yard or per cubic foot of air, is unreliable because of the complexity of the modifying factors. When such information is important, it is best obtained directly by a volumetric instrument. The number of pollen grains per cubic yard of air evidently varies from 2 to 20 times the number found on 1 sq cm of a 24-hr gravity slide, depending on grain diameter, shape, specific gravity, wind velocity, humidity and physical placement of the collecting plate.[33, 34, 35]

AIRBORNE BACTERIA

Study of the occurrence and significance of micro-organisms in the atmospheres of the indoor world is absorbing the energies of a substantial number of physicians, bacteriologists, aerobiologists, physicists, public health workers, engineers and hospital personnel. Some data are available on the types and quantities of bacteria found in a variety of spaces, but it is not possible at present to use this information as a conclusive index of the potential health hazard of a given environment. The reported number of airborne organisms may vary from 1 to 1000 per cubic foot of air, influenced somewhat by the method of testing.[36] Many are attached to the dust particles present in the air.

Where it seems advisable or desirable to control the bacterial content of rooms, public conveyances or buildings, highly effective methods are available (see Chapter 7), and their extended use may do much to assist the workers in this field in accumulating the necessary mass of evidence that will decide the practical value of air sterilization for the control of communicable disease. It is now well established that ultraviolet radiation is feasible for the protection or preservation of pharmaceuticals, cosmetics, and food products.

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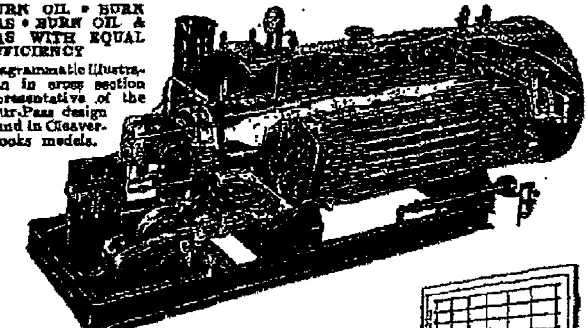

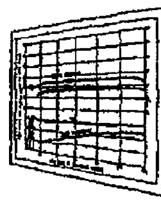

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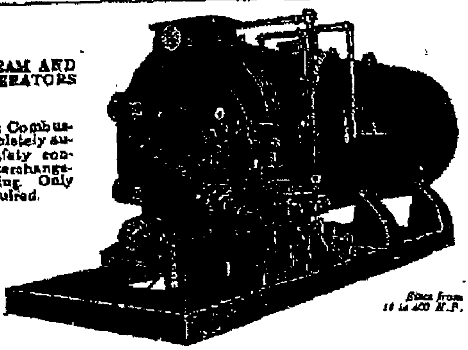

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C-500	15	502,200	520	2,080	620	3,350	56	44½	37½
C-700	20	670,000	690	2,760	825	4,465	77	44½	37½
C-1000	30	1,005,000	1,035	4,155	1,240	6,700	90½	45	41
C-1400	40	1,340,000	1,380	5,520	1,655	8,930	110½	45	41
C-2100	60	2,010,000	2,070	8,270	2,480	13,400	114	52½	45½
C-2800	80	2,680,000	2,760	11,165	3,308	17,865	138	55½	55
C-3500	100	3,350,000	3,450	13,815	4,135	22,330	162	63½	64
C-4400	125	4,187,500	4,312	17,245	5,170	27,915	173½	64½	68½
C-5000	150	5,025,000	5,175	20,700	6,205	33,500	187½	71½	76½
C-7000	200	6,700,000	6,900	27,615	8,270	44,665	224½	76½	81½
C-8700	250	8,375,000	8,625	34,500	10,343	55,785	251½	85½	81½
C-10000	300	10,050,000	10,350	41,690	12,408	66,900	251	102½	84
C-12000	350	11,725,000	12,075	48,340	14,475	78,115	252	102½	84
C-13800	400	13,400,000	13,800	55,200	16,540	89,330	252	102½	86