Air-Borne Matter, Part I

Characteristics and Industrial Implications

By Henry L. Muntgomery Larcombe

THE centralisation of industrial activity in and around the great cities of the world has resulted in the pollution of the surrounding air by a great variety of air-borne matter. This matter may range from heavy process dust to smoke particles beyond human visibility. It may be a direct product or an indirect product, but it is essentially a nuisance. The direct importance of collecting dust that has commercial value is obvious. In addition, there should be taken into consideration the indirect financial importance of eliminating or collecting all kinds of dust, fog, fume or smoke, to reduce building and equipment maintenance, to increase human comfort and well-being, eliminate dangers of occupational disease and generally increase the efficiency of the industrial machine.

The average impurity content of the atmosphere in country districts is less than 1 mg. of solid matter per cu. m. This increases in a city to an average of 3 mg. per cu. m. and as much as 5 mg. in an industrial centre. This has been confirmed by dust counts with apparatus designed especially for this work. The number of particles counted in 1 cu. ft. of air varies, but the dust count is basically dependent on the manner in which the dust counter collects the particles on glass slides and upon the degree of magnification. Dust determination made with the Aitken dust counter in Glasgow found 3,736,000 particles per cu. in. In the United States experiments made with the Hill dust counter in a number of large cities have resulted in an average of 9,700 particles per cu. ft.; an average of 500,000 particles per cu. ft. was counted during an investigation of the open atmosphere of New York City by means of the Owens jet apparatus.

Between the hours of 8 a.m. and 6 p.m. in winter months the average impurity content is in the region of 0·56 lb. per 10,000,000 cu. ft. of free atmosphere. In London it has risen to a peak content of 1·1 lb. per 10,000,000 cu. ft. of free atmosphere.

Air-borne matter is not confined to the free atmosphere. The dust hazards in factories and mines are of an extremely dangerous nature, and comprise the most important section so far as health is concerned. Any figures we may give for the free atmosphere are dwarfed by the dust content of air in mines and factories where concentrations of anything up to 400 mg. per cu. m. are experienced.

The field of study of dust technology is such a vast one and touches so many schools of science, that all its branches cannot be covered in any single work. It is the purpose of this discussion to review the fundamental characteristics of air-borne matter which must be set down before any detailed research can be made on any particular branch.

Origins of Air-Borne Matter

Dust dispersoids or aerosols in the air are generally assumed to be originated in the following manner :—

(1) *Combustion and Explosion.* Reduction of solid and liquid fuels to ashes, fumes and smoke.

(2) *Crushing.* Disintegration of concrete and asphalt, process dust, milling, pulverised coal, etc.

(3) *Mechanical Dispersion of Liquids.* Spray evaporation, particles of salt in the atmosphere of seaboard districts.

(4) *Condensation of Gases and Vapours.* Formation of rain from water vapours. Condensation of metallic vapours.

(5) *Chemical Reaction.* Production of chemical smokes in industrial plants.

(6) *Various Natural Origins.* Pollens, animal excreta, fungi, soil, sand, bacteria and particles of dead insects.

Measurement of Particle Size

Particles of very small dimensions have a relatively large surface area as compared with their weight. Therefore, when suspended in a gaseous medium they are carried freely by virtue of the viscosity of this medium. The consequent system is not in equilibrium, and is subject to constant and numerous changes. The degree of instability is dependent on the properties and size of the particles, the medium of suspension and the influence of external forces such as gravity, centrifugal force, convection currents or magnetic force.

Measurement of Particles.—These dispersoids may be of a solid or liquid nature. If they are liquid they may take on a spherical form. Solid particles, however, are not usually round, their outline depending upon the structure of the material of origin, and upon the process by which they were generated. They are generally reproductions of the original materials; silicaceous particles assume the form of irregular broken stones; wood dust has the appearance of minute splinters.

The unit of measurement of particle size is now almost universally accepted to be the micron (1/1,000 mm.). For this branch of science it is obvious that the microscope is the chief instrument of size classification. The detection of many ranges of dust necessitates the use of polarised light.

For a standard of comparison the diameter of the human hair varies from 60 to 150 microns, the average being in the region of 90 microns, and an object of 10 microns diameter is generally considered to be the absolute limit of unaided human vision. Considering the above remarks, it is not surprising that such a small unit of measurement is required for this particular work.

Arithmetical Mean.—To indicate the size of such particles, the diameter is usually given. Only perfectly round particles have an accurate diameter, and as has already been pointed out, solid particles have usually an irregular form. Therefore, for these particles another method of measurement is introduced; that is, the arithmetical mean, which is a single figure, and will be the equivalent of the diameter in a spherical particle. This figure is the mean of length, width and height. In the case of particles of which the length is considerably greater than the other dimensions, which include fibres and other elongated shapes, a correction factor must be applied when the laws of settling have to be considered.

Surface Mean Diameter.—When studying dust in the form of a very fine and fairly even powder, it is usually more accurate and convenient to work with the surface mean diameter of the powder. This can be calculated after the arithmetical mean diameter has been determined.

The resulting figure represents the diameter of uniform spherical particles which, for a *similar weight of dust*, samples have very closely the same equivalent surface area as the original particles. The formula used in finding the surface mean diameter is as follows :—

$$\text{Surface mean diameter} = \frac{\Sigma d^3}{\Sigma d^2}$$

This figure is always a larger value than the arithmetical mean and is a measure of the specific surface of the dust.

The specific surface is the factor which determines the ability of the particles to remain suspended. It also has an important influence on its chemical activity and in the case of dusts of carbonaceous and various other substances has a direct bearing on its explosive possibilities.

Characteristic Dimensions

Volume Mean Diameter.—Maintaining the foregoing procedure, this figure is arrived at in a similar manner to the surface mean diameter. The formula in this case is :—

$$\text{Volume mean diameter} = \frac{\Sigma d^4}{\Sigma d^3}$$

The volume mean diameter gives us a single value specifying spherical particles with an equivalent volume to that of the original dust particles for an equal weight of dust sample.

Particle Specific Surface.—Consider a mass of identical particles having a characteristic dimension (side, diameter, etc.), L. Calling the total weight of all the particles ΔW and density S_1, the total surface $\Delta A'$ is the number of particles $\frac{\Delta W}{S_1 kL^3}$ multipled by the surface area of each KL^2.

$$\Delta A' = \frac{K\Delta W}{kS_1L}$$

the constants K and k depending on the shape of the particles.

For any given material $\frac{K}{k}$ often remains approximately constant over a wide range of size ; hence $\frac{K}{k}$ need not be known to compare the specific surface of different grades of division. Let ΔW be the weight of material passed by a sieve of mesh width L_1, and retained on a smaller sieve having a mesh width L_2. If the ratio $\frac{L_1}{L_2}$ does not exceed 2, little discrepancy can be introduced by using the arithmetic mean giving :—

$$\Delta A' = \frac{K\Delta W}{kS_1\frac{(L_1+L_2)}{2}} = \frac{K\Delta W}{kS_1L_{AV.}}$$

Where $\Delta A'$ is the surface of the fraction of the weight ΔW. One should use a series of screens so that ΔW for each screen is only a small fraction of the original sample. The total surface is readily estimated by graphical integration, *i.e.*, by plotting $\frac{1}{L_{AV.}}$ as ordinates against W as abscissæ, the area under the curve, multiplied by $\frac{K}{kS_1}$ is the total surface.

If the particles have the shape of a cube or sphere the shape factor $\frac{K}{k}$ is 6. This is frequently used for all shapes, but $\frac{K}{k}$ is 7 to 8 for powered coal. For flat particles, *e.g.*, mica basing, L on the average diameter of the large face $\frac{K}{k}$ is 55.

If, however, a large fraction passes the finest sieve, the summation will not be accurate, since the specific surface varies rapidly with diameter at small diameters. In a great many cases in dust control work it is required to make size analysis of a sample, giving, for instance, the percentage of a lesser range than the 10-20 micron range. As the British standard sieve of 300 mesh and the American screen of 325 mesh have openings of 53 microns and 44 microns respectively, it is not possible to study the problem by this means as often less than 10 per cent. of dust samples will be retained by them, and the rest of the sample, which is of the most vital range of size, will not be entrained and so cannot be differentiated. This is most important, as size is the factor which perhaps influences health and well-being more than any other. The size causing lung damage is from 0·5 to 8 microns. To enable the required separation to be made, the process of elutriation is employed, using either air or water at the medium. By feeding the sample into a rising current of water or water at constant velocity, certain particles fall to form a residue, whilst smaller ones are carried over according to Stokes' law. By running the apparatus at a series of velocities, the sample may be divided into a number of fractions far beyond the range of mechanical sieving. Study of these fractions gives most important information as to the behaviour of a dust in filtration, precipitation and health.

With air-borne matter in the free atmosphere, the dust sample is somewhat difficult to obtain and is, therefore, small. The measurement of this is usually done by direct optical means by microscopic projection.

In the case of smoke and fume particles where the size becomes extremely small, and at which stage the optical microscope becomes inadequate, we have to resort to the ultra-microscope which renders particles down to 0·001 microns visible. Even with this instrument no definite outline of the object can be seen, the larger particles showing up brighter than the smaller ones. Perhaps the electron microscope which has been developed in this country and in Germany will open up new fields of study in this direction. With this instrument it is possible to obtain useful magnifications of the order of 30,000 diameters as compared with 2,000 diameters which is the limit for the optical microscope.

Sizes of Some Industrial and Other Particles

	Microns
Cement dust	40
Talc dust	10
Sprayed zinc dust	15
Silica dust	5
Coal dust	5
Flour mill	15
Alkali fume	1 to 5
Ammonium chloride fume	0·01 to 1
Zinc oxide fume	0·05
Condensed zinc dust	2
Tobacco smoke (tar mist)	0·25

Laws of Behaviour of Air-Borne Matter

When studying air-borne matter it is usual to group it into three general categories, but the limits of demarcation are not definite, one category merging gradually into the next. This classifying into groups, though not strictly scientific, is very convenient by virtue of its being descriptive of their mode of behaviour and also because it refers to their origin and to the process by which they were generated. These groups are : dusts, fumes and smokes.

Dusts

Dusts are particles which are heavy enough to fall in still air with a velocity due to gravity varying from constant to increasing, depending on their size and form. The general laws of Newton referring to gravity fall are usually not applicable for objects less than ¼ in. (7,000 microns) in diameter, and are of little, if any, importance in considering dust. The influence of the viscosity and subsequent friction of the gaseous medium of suspension, which is usually air, is a factor which is of utmost importance in the determination of the rates of fall.

There is comparatively little data concerning the exact rates of fall for particles below this size (¼ in. diameter) down to the 200-100 microns diameter range, where Stokes' law comes into operation. Study of this size range is still in progress, and in 1929, as the result of careful experiment, Prockat developed this formula :—

$$c = \frac{\sqrt{2gdS_1}}{3KS_2}$$

$$C = 24 \cdot 9\sqrt{DS_1}.$$

Particles of this range of sizes are, however, not of much importance, as their rate of settling is very great, and with the exception of liquid particles (rain) are very rarely found in the atmosphere, though they do occasionally occur as heavy industrial dust as the result of certain processes.

Below the 200 microns line is the great majority of air-borne matter that is of a scientifically important nature, and this range extends down to particles of approximately 0·1 micron. Below this infinitesimal size particles are of little practical importance, not having any appreciable effect on health or industry.

Stokes' Law

About 1902, G. G. Stokes formulated the well-known Stokes' law. This law states that particles of such size (200 microns down to 0·1 micron) will fall at a constant velocity, the viscous resistance of the air balancing the downward pull of gravity. This velocity will be in direct proportion to the square of the diameter of the particle. For different materials, the heavier particles will fall faster, but if at equal velocity will be of lesser dimensions than the lighter particles. This law is only exact for spherical particles, but subsequent experiments have shown that particles which do not vary too greatly from a spherical shape follow the law very closely. They include fly ash, silica and other materials of a crystalline make-up akin to them. For materials whose dust is of a scaly or fibrous nature, suitable correction factors must be brought into consideration, because these shapes assume a position in falling in which they encounter the maximum air resistance. Stokes' law can thus be expressed as :—

$$c = \frac{2}{\rho} r^2 g \frac{S_1 - S_2}{n}.$$

For air at 70° F.,

$$c = 300{,}460\ S_1 d^2$$

$$C = 0 \cdot 00592\ S_1 D^2.$$

In applying Stokes' law it is apparent that the upper limit of particles size is dependent upon the density of the medium of suspension, as well as that of the falling body. The upper limit for fly ash has been determined as 100 microns, and for water droplets as 200 microns. It can be said that the rate of fall of particles depends upon the following factors: the size, shape and density of the particle; the density and viscosity of the medium of suspension; the gravitation attraction of the particles; and the nature of the fluid flow of the medium in the vicinity of the particles.

The attraction of gravity can be assumed as constant, although the separation force on the particle can be increased by centrifugal force as is applied in cyclonic separation in the ordinary cyclone. The nature of the fluid flow is brought into consideration in applying centrifugal force as a means of separation. This is either viscous or turbulent, as is indicated by the Reynolds number for the existing conditions.

The rate of fall of small particles settling in a fluid when the flow around the particles is of a viscous or streamline nature is proportional to the square of the size. As the size of particle is increased, the motion of the flow becomes turbulent, which causes an increase in the resistance offered by the fluid and the consequent rate of fall is less than that calculated from Stokes' law. If the motion becomes 100 per cent. turbulent, the rate of fall is proportional to the square root of the size of particle. The rate of fall of particles under only partially turbulent conditions can be calculated by using Stokes' law as a rough approximation and then applying factors of correction to allow for the degree of turbulence.

It must be remembered that Stokes' law assumes that the fluid which is the medium of suspension must be continuous and of uniform viscosity.

Fumes

The line of demarcation between the matter known as dust and that known as fumes or clouds is not a definite one. In the 10-1 micron range we find fumes as well as dust. This range is, perhaps, the most important when considered from a point of view of human health. From the 8 micron size to the 0·5 micron size is the particle which, if its concentration is sufficiently high, is very dangerous to the lungs.

Fumes are very unstable; the individual particles conglomerate to the order of 1 to 10 microns, and consequently settle out steadily in still air. This rate of settling, however, is so slow that fumes may be hindered or even prevented from settling at all by convection currents. This inability to settle out renders particles in the region of 1 micron and less to come under the influence of Brownian movement; this means that it is subject to the movement of the gas molecules, and in the case of fumes in the free atmosphere where there are constant convection currents, they practically never settle.

The mean free path of gas molecules is in the region of 0·1 micron, and where there are no convection currents particles approaching this size will find less resistance to the movement through the air than is shown by Stokes' law; they will, therefore, settle faster and their rate of fall is calculated by introducing Cunningham's factor :—

$$c = c' \left(1 + K \frac{\lambda}{r}\right)$$

where $c' = c$ of Stokes' law.

It must be remembered, however, that convection currents are the ruling influence in the gravitational settling of fumes.

The particle size of 1 micron is generally accepted as a critical limit for gravity precipitation of matter suspended in the open atmosphere and that only on aggregation to this size will smaller particles settle.

Smokes

This range of air-borne matter is the most difficult to study and classify. The particles are so minute, being from 0·3 micron to sizes beyond the limits of the ordinary microscope, that gravity has little effect on them. They are bombarded by gas molecules and driven about at a much greater velocity than by gravity in a continuous Brownian movement. The larger diameter particles from 0·3 to 0·1 micron do settle when suspended in an absolutely still gaseous medium, but this rate of fall is so small that it is generally assumed that smoke is subject to Brownian movement all the time. By using Stokes' law with a suitable Cunningham's factor, a particle of 0·1 micron with a density of 1 only settles at 0·00007 ft. per minute in air at 70° F. W. E. Gibbs has said that smoke particles of 0·025 micron will only settle 10 ft. in 30 days. The behaviour of smoke in air is gradually to diffuse. The rate of movement in diffusion may be determined by the formula of Brownian movement, given below, but this is not of great practical value :—

$$A = \sqrt{\frac{RT}{N} \cdot \frac{t}{3\pi\eta r}}$$

When A = distance of motion in time t, R = gas constant = $8 \cdot 316 \times 10^7$, T = absolute temperature, and N = number of gas molecules in 1 mol. = $6 \cdot 06 \times 10^{23}$.

Smoke and fumes, though in some ways the most destructive of air-borne impurities, do a great service to mankind. Without particles of these sizes there would be no nucleus for rain drops. In fact, without them to form these nuclei it would never rain, and the earth would be continually enveloped in a cloud of vapour.

Electrical Characteristics of Air-Borne Matter

When dust is blown about by a current of air, it becomes electrically charged. The magnitude and sign of the charge is dependent on the nature of the dust and the electrical state of the atmosphere. While this charging is taking place, the air or extremely fine permanently suspended particles in the air become charged with the opposite sign. A great deal of data on this phase of dust research has been obtained and classified by Rudge. By raising a cloud of dust by means of a blast of air in a brass tube, so that it impinged on a fine wire gauze basket, he was able to collect the static electrical charge on the basket. Then he determined whether the dust was charged, and if so whether positive or negative.

In all, he studied the behaviour of almost 200 different specimens of dust, and summarised his experiments with the following conclusions :—

(1) Nearly all kinds of finely-divided material when blown into a cloud of dust by a current of air, gives rise to electrical charges upon the dust and upon the air.

(2) The nature of the resident charge upon the dust depends on the chemical characteristics of the material.

(3) In general the charge obtained upon the dust is opposite to that associated with the "ion" of the same when in solution, *i.e.*, strongly basic bodies (*e.g.*, limestones) give negative charged dusts and strongly acid bodies (*e.g.*, silica) give positively charged dusts.

(4) In the case of salts the charge apparently depends on the relative strengths of the acidic and basic ions.

(5) Similarly constituted bodies give similar charges.

Charges Generated on Moving Dust Particles

		Aluminium	—
		Aluminium oxide ..	—
Carbon	+	Dextrine	—
Copper chloride ..	+	Dextrose	—
Potassium nitrate ..	+	Iron	—
Sand	+	Iron oxide	—
Sodium chloride ..	+	Magnesium	—
Fine soil	+	Magnesium oxide ..	—
Sulphur	+	Sodium carbonate ..	—
		Zinc	—
		Zinc carbonate ..	—
		Zinc oxide	—

Dust may become charged as the result of friction against a solid surface. By this means electricity is developed in grinding mills and pulverisers by the friction between the material being ground and the components of the machine itself. The fine dust which always escapes is electrically charged, and if the machine is not earthed it also becomes charged and in very dry atmosphere of low humidity, discharge is liable to occur. This may have serious consequences where the nature and concentration of the dust content in the air has explosive qualities.

In practice it has been found that charges of over 10,000 volts can be accumulated. Such charges are often found upon the filter bags that are used to separate sugar dust from air. These bags act as a kind of electrical machine separating positively-charged dust from the negatively-charged air. Similar charges are observed in threshing machinery. Unless steps are taken to humidify the air in the zones of working or by the designing of suitably earthed collecting apparatus, there is every likelihood of the dust being ignited by a spark discharge.

Cohen has shown that the nature of the resulting electrical charge of this type of friction is dependent on the relative dielectric constant of the dust being generated and the material used for the grinding components of the machine. The material which has the higher dielectric constant becomes positively charged.

These rules apply to liquid particles in the air besides solid matter. When a liquid is disintegrated or atomised the increase of specific surface (since the electrical capacity of any substance is proportional to its surface area) is generally associated with the electrification of the droplets.

The ordinary thunderstorm can be explained by this principle. When large raindrops exceeding 4,000 microns are flattened and disintegrated by the resistance of the air they become positively charged. Meanwhile the air around them has become negatively charged.

During the violent vertical circulation that occurs in a thundercloud, the positively charged droplets travelling downwards become separated from the negatively charged air that is carried upwards, so that the potential difference which accumulates between the upper and lower zones becomes enormous and the tension becomes great enough for a discharge to occur. This discharge is what we all know as lightning. Similarly, when drilling for oil, the surrounding atmosphere becomes laden with minute oil globules, and when a discharge occurs we have the phenomena which has become known as "The Holy Fire of Baku."

(*To be continued*)

STANDARD FOR PETROLEUM JELLY

IN the series of A.R.P. Specifications which the British Standards Institution is preparing at the request of the Home Office, a specification has been included for petroleum jelly. This compound is intended for sealing doors, windows and other cracks in order to make them gas tight. The specification lays down limits for the various properties of the jelly so as to ensure that it will be capable of being applied easily. A further specification in the same series which affects the oil interests is BS/ARP.22 mixture for anti-gas cloth. This mixture is applied to textiles for the purpose of rendering them impermeable to gas and is made up of lanoline, together with a heavy oil. The detailed properties of the oil suitable for this purpose are set out in full in this specification.

COAL ANALYSIS

FUEL Research Survey Paper No. 48, covering the Nottinghamshire and Derbyshire coalfields, has recently been published by H.M. Stationery Office, price 3s. This report forms part of the general survey of the national coal resources and records the results of the analysis of 277 grades of coal from 17 collieries. The survey proceeds roughly on two lines: analysis of coal awaiting exploitation and a survey of the coal delivered by the various collieries. The present report deals with work of the latter type. The Nottinghamshire and Derbyshire area produces coal suitable for metallurgical coke, high-grade gas and house coals, locomotive and bunker fuels and free burning coals for steam raising and general industrial purposes.

Air-Borne Matter, Part II

Characteristics and Industrial Implications

By Henry L. Muntgomery Larcombe

INDUSTRIAL process air-borne matter covers the whole size range from heavy particles of ¼-in. diameter to industrial smoke of sub-micron dimensions. Because of the extreme diversity of kinds, sizes, shapes and densities of dust, variable percentages of concentration and different volumes and temperatures of the gaseous medium, almost every problem in this branch requires individual study.

It may be that the dust is the direct commercial product of a process and should be retained for economic reasons, or it may be that its dispersion in the free atmosphere would prove to be a community nuisance, and with these and other points in mind it is for the engineer to design the equipment on a practical and economic basis.

These collecting or separation methods can be classified in the following manner:—

Method	Equipment	Particle Size Collected
Inertial ..	Cyclonic or centrifugal apparatus	Down to 60 microns, dry method Down to 5 microns, wet method
Filtration..	Filter bags	Down to 0·3 microns
Sprays ..	Scrubbing towers ..	Down to 0·2 microns
Electrical.	Precipitation	Down to the smallest detectable dimensions

Gravitation

The gravitational method is exemplified by the ordinary settling chamber and is only applicable to mechanical and solid dispersoids because its effectiveness depends on the rate of fall of the particles and, as has been pointed out, this rate is dependent upon the size and weight of the particles. The rate of fall becomes so slow for the condensed dispersoid that it makes this method impracticable.

The actual rates of fall are from 50 to 60 per cent. of the theoretical as calculated by Stokes' law. It is evident, therefore, that particles of 75 microns will have an actual rate of fall of 0·8 ft. a second, and this is too slow to use this method.

Settling chambers should be designed to give sufficient settling time for the smallest particle it is desired to remove and this demands that chambers should be made wide and low rather than high and narrow. Wire curtains are often fitted to minimise eddies and these also tend to remove the finer dust through contact.

The actual settling rate of the finest particle to be collected should preferably be determined experimentally. When this is not practicable, but where this particle size is known the theoretical rate can be calculated from the following approximate numerical expression for Stokes' law:—

$$C = \frac{D^2 S_1}{10^4} \times 60$$

Thus, if the smallest particle to be settled out is 50 microns with a sp. gr. 4, the theoretical rate is 1 ft. per second. Assuming 50 per cent. of this figure for the actual rate, the result is a figure of 0·5 ft. per second.

Inertial Method

Although with certain apparatus some condensed dispersoids may be collected by the inertial method, it, like the gravity method, is chiefly applicable to mechanical dispersoids, but on account of the much larger separational forces available, smaller particles may be collected. As gravity is the separating force in the settling chamber, so centrifugal force causes the separation of dispersoids from the gas in the centrifugal apparatus. This force, being directly proportional to the gas velocity and inversely proportional to the radius of curvature of the gas path, can, therefore, be made very large by designing the equipment to have a large gas velocity and a small radius gas path. Although Stokes' law is not strictly applicable to moving gases, it can be assumed that in this case also the resistance to the motion is proportional to the effect of the net force and the resisting or frictional force on the same factors.

On this assumption the separating velocity in cyclonic or inertial apparatus corresponds to the settling rate of the gravitational method and may be expressed as—

$$\text{Separating velocity} = \frac{S_1 D^2 Z Y^2}{HQ}$$

Since ZY equals the tangential gas velocity V, the above relations can also be expressed:—

$$= \frac{S_1 D^2 V^2}{Q Z H}$$

In the inertial or cyclonic apparatus the important factor is not so much the separating velocity but the " separating distance " that the particle will move under the action of the centrifugal force in the time the gas remains in the apparatus. There is little data on the distribution of gas velocities in such gas streams, but for the purpose of approximate calculation it can be assumed that the tangential velocity is constant, that the average time the gas remains in the apparatus is that required for the gas moving with the maximum radius for the maximum angular distance U. Furthermore, while in the inertial apparatus the gas path may be simple and almost parallel, its path in the ordinary cyclone is very complicated and involves a double vortex. It is highly probable, however, that the majority of the separating action takes place in the outer vortex, so we may consider the gas path in all apparatus as simple and approximately circular.

Considering the above remarks in conjunction with Stokes' law for moving gases:—

$$\text{Separating distance} = \frac{S_1 D^2 U V}{QH}$$

For a specified gas and a uniform size of dispersoid this simplifies to:—

$$\text{Separating distance} = QUV$$

Process Dust

The table on the next page gives cyclonic values for air of standard viscosity, spherical particles of sp. gr. 3. It has been assumed that for the above conditions Stokes' law *gives values of twice the actual values.*

Filtration

The filtration method of dust separation is generally considered a sieving action and this method is well exemplified by the bag filter system used in processes of every kind.

The bag, or its equivalent, is a screen or sieve of certain size through which the particles like gas molecules and certain dispersoids smaller than the meshes pass through but which retains and collects larger particles. In this method collection by contact and adhesion plays a large part. In addition, the medium of filtration itself becomes greatly dependent upon the particles rather than on the filter.

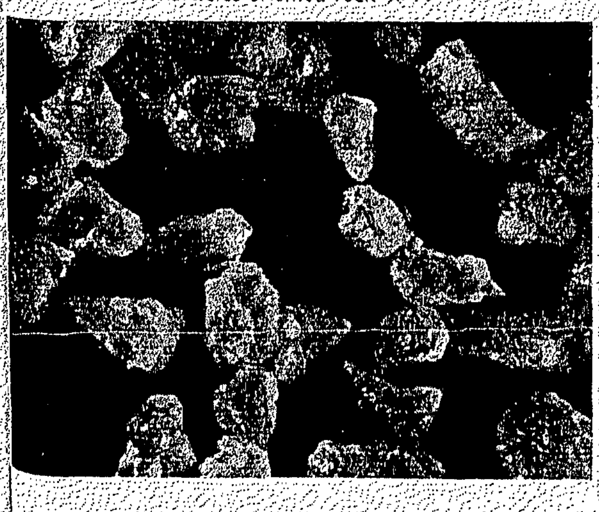
The ability of dust particles to adhere to cloth and other baffles is very difficult to formulate and it seems that in the design of equipment of this nature, experience and empirical formulæ, determined by testing and research, remain the only guides to the problems of dust elimination by this method.

Inertial Separation

Dia. of particle	Separating distance	Tangential gas velocity, ft.p.s.	
		$U = \pi$ radians	$U = 4\pi$ radians
50	0·5	6·8	1·7
20	0·5	42	10·6
10	0·5	170	43
1	0·5	17,000	4,300
100	1·0	3·4	0·8
50	1·0	13·5	3·2
20	1·0	85	20
10	1·0	340	80
1	1·0	34,000	8,000
100	2·0	6·8	1·6
50	2·0	27	6
20	2·0	170	40
10	2·0	680	160
1	2·0	68,000	16,000
100	3·0	10	2·3
50	3·0	41	9·6
20	3·0	255	60
10	3·0	1,020	240
1	3·0	102,000	24,000
100	6·0	20	48
50	6·0	81	19
20	6·0	510	120
10	6·0	2,040	480
1	6·0	204,000	48,000

A filter with zig-zag passages has also been designed. These passages are covered with a very viscous non-drying oil and the change of direction of the gaseous medium of suspension results in the dust particles impinging and being retained by the oil. Again we have the problem of formulating mathematically the theory of this action and

Particles of silica rock × 79



realise that testing and experience are the main factors of successful design.

Spray or Scrubbing Method

In this method the principle of operation is that the dust particles are caught by water droplets from sprays which hold the particle by means of their surface tension, and so, having a greater mass than the particle itself, settle, depositing the dust into special hoppers or similar receivers. The main factor in the selection of this type of equipment is the nature of the dust to be collected. Any material which would be damaged or rendered unfit commercially cannot be collected by this means. This method of elimination and collecting is usually used for flue gases and the like.

The effectiveness of the spray method does not depend entirely upon the contact between dust and water droplets. A great proportion of the collecting is due to impingement and contact on the wetted surface. By using labyrinth passages and so altering the direction of flow of the gaseous medium, the particles impinge on the wet surfaces of the passages by their own inertia. Passing gases through straight flues or towers fitted with sprays is very inefficient, because the dispersoids are usually surrounded by a gas film which tends to prevent their entrainment.

The spray chamber is particularly well suited to act as a second stage collector in combination with a cyclone or similar dry method of inertial separation.

Electrostatic Precipitation

This method, although investigated as long ago as 1819, is the most modern of all practical systems of collecting air-borne matter. The power of an electrified stick of sealing wax to attract dust is well known, and C. S. Rafinesque, Hohlfield, Guitard and Gaugain experimented with this and other apparatus, proving that precipitation was a scientific possibility. These pioneers were held up by inadequate high-tension apparatus and insulators, and the development of electrical technique was the factor which

Particles of gypsum × 79

halted the application of this principle until the researches of Cottrell, Lodge and Moller led to electrostatic precipitation becoming a commercial proposition.

In the operation of this means of collection, a unidirectional electrical potential difference is maintained and current set up between two electrodes insulated from each other and between which the gas is allowed to pass. In ordinary circumstances one of these, which is usually called the discharge electrode, is of small cross-section area and curvature like a point or edge, so making possible the high electrical field at its surface which is necessary for the ionisation of the gas. The other, which is called the collecting electrode, has a lesser or no curvature and serves for the precipitation of most of the separated dispersoids.

Mechanism of Precipitation

Due to the high electrical field, the ions formed through ionisation by collision near the discharge electrode, and of the same electrical sign as this, are carried over through the gaseous medium to the collecting electrode with a velocity which is probably more than 100 ft. per second. When the gas between the electrodes carries dispersoids, the ions attach themselves to the particles which thus themselves become ions and are, therefore, also forced towards the collecting electrode. The velocity of these ionised dispersoids is naturally much smaller than that of the gas ions. It is, however, considerably higher than is ordinarily surmised.

Since the gas ions are molecular, they are smaller than the smallest fume or mist particles. The number of these gas ions ordinarily present in the gas of the precipitator is also probably many thousand times larger than the greatest possible number of dispersoid particles in that gas.

By studying these remarks, it can be seen that the effectiveness of this process is not limited by the size, weight, or number of the particles. With the progress which has been made in materials of construction, it is possible to build electrodes to withstand both high temperatures and chemically active gas and so make the process practically universally applicable to the separation and collection of air-borne matter.

In addition to serving to move the ionised particles to the collecting electrode, the electrical field and current also exert a pressure on the collected material which serves to prevent its being re-dispersed in the gas.

The efficiency of a precipitator is a function of the time that the gas remains in the active field and can be made to approach 100 per cent. very closely. Since, however, the size of equipment increases with the efficiency, an economic limit is necessarily set which usually lies between 90 and 99·9 per cent.

The precipitation rate depends to a large extent on the size of the particles and their characteristics, *e.g.*, their surface conductivity, since sufficient surface conductivity is necessary to permit the discharge of the dispersoid ion when reaching the collecting electrode.

This surface conductivity is perhaps the most important factor; where this is inadequate the addition of water or other conducting material which can be absorbed on the dispersoid surface increases the surface conductivity and greatly increases the rate of precipitation.

The particles having arrived at the collecting electrodes adhere to them and are dislodged in most designs by rapping. Certain classes of dust are removed from their gaseous medium of suspension in such a hot dry atmosphere that either their own weight is sufficient to remove them or comparatively very light rapping; in most precipitators, mechanically-operated rapping gear is required for both discharge and collecting electrodes. Liquid particles which are precipitated require no removal apparatus, but trickle down the walls of the tubular collecting electrode. On being removed by the rapping operation the particles must not be re-dispersed. In ultra-high-efficiency equipment, the precipitator is divided into sections which are shut down during the periods of rapping and are scavenged by an air blast thoroughly to remove dispersoids which may still adhere before putting the section back into service.

With careful design, however, this is not necessary in the majority of instances. When the gas flow along the tubes is streamline, the gas velocity is highest in the centre and falls off at the walls. With this low velocity at the wall, it is possible for particles to gravitate without being entrained in the gas stream. Another reason is that, during the period between rapping, particles adhering to the collecting electrodes agglomerate into larger particles which gravitate more rapidly on account of increased weight.

Numerous factors effect the design of equipment of this sort, the principal ones being the volume, temperature and analysis of gas, and the composition, size and concentration of the dispersoids.

Almost every process presents a different problem, great variations being obtained by relatively small differences in conditions.

Sound Wave Precipitation

In addition to the methods of collecting air-borne matter described, the United States Bureau of Mines is developing another method of precipitating fly ash, smelter fumes, etc.

In 1866, Kundt discovered that sound waves passed through a tube containing fine powder will cause that powder to concentrate at points free from vibratory motion. It has also been shown that high frequency sound waves affected the diffusion of solid or liquid particles in a gas. With these facts as foundation to build on, the Bureau developed its process, initially for the purpose of treating smelter fumes. It consists of simply passing the smoke or fumes through a tube in which stationary sound waves are maintained. The tube must be carefully proportioned, however, and must be of such a length that the waves reflected from the upper end are in phase with the original sound waves produced at the lower end. Furthermore, to get the best results, the wave-length must be approximately equal to the diameter of the tube. For a tube of practical diameter the frequency ranges from 3,000 to 20,000 cycles per second.

To set up sound waves of the proper frequency a shrill air whistle is used. The sound waves produced by this are reflected at the top of a closed glass tube, so as to be in phase with the original wave, setting up standing waves separated by planes of no motion, called nodes, spaced approximately half a wave-length apart. In its complicated movement between nodes, the suspended matter collides and thus coagulates, the heavier flocculated masses finally collecting, at the points of no motion.

Dust Explosions

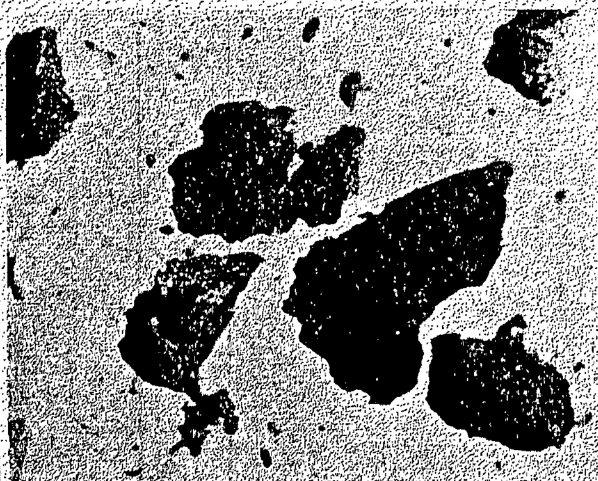
This hazard is found most frequently in coal mines where fine coal dust is mixed with inflammable gases. It is not, however, limited to coal dust or to mines. There are dusts that are to a lesser or greater degree explosive, and in fact all carbonaceous materials and other substances which will burn must be included among the dangerous dusts. To this category belong sugar, rice, cork starch, cocoa, wood-dust, malt grain, wheat-flour, tea, spice and numerous other common industrial powdered materials.

The fineness of the dust or degree of dispersion is of considerable importance in studying the explosive hazards of air-borne matter. The finer the particles of a dust concentration are, the larger is the area of the dust particles and the more readily a chemical reaction with the oxygen of the air takes place.

The most characteristic property of any explosion, however it may be caused, is the ultra-rapid, almost instantaneous generation of a sudden increase in pressure. This may be due to the production of an increased volume of gas which may shatter the confining walls of the containing structure, or it may be due to the impact of a wave of compression that travels through the gas with a velocity equal to or greater than the velocity of sound.

There is little increase in pressure if the combustion occurs so slowly that the heat of reaction is dissipated as rapidly as it is produced. It is obvious, therefore, that the more rapidly the combustion takes place, the higher will be the maximum pressure of the reaction. Considering these remarks, we may regard the maximum pressure produced by the explosion as a measure of the inflammability of a given dust under experimental conditions. Only in favourable circumstances will explosion result in the formation of a detonation wave.

The expansion pressure that is produced is due either to the rapid formation of gaseous reaction products, or to the expansion of the air by the heat of reaction. It was



Particles of emery × 79.

originally supposed that dust concentrations only explode when combustible gases were present in the gaseous medium of suspension and that they propagated the explosion through the volatile matter resulting from the burning particles. It has now been proved that at the correct concentration a spontaneous reaction takes place between the finely divided dust and the oxygen molecules of the air. This occurs so rapidly that the pressure therefrom is capable of igniting the remaining unburnt dust particles.

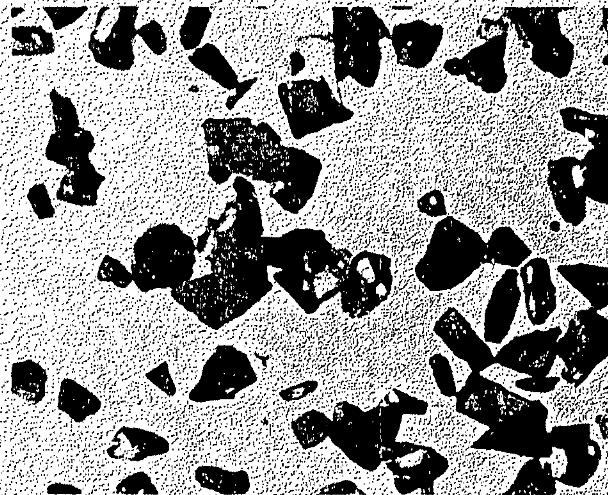
The pressure that is produced by an explosion of starch dust is mainly due to the rapid formation of relatively large volumes of gases. Sulphur, on account of its low ignition temperature, explodes more readily than starch, but, since it produces only half the volume of gas that an equal weight of starch produces, it explodes with correspondingly less violence.

With certain dusts, *e.g.*, aluminium, that do not produce gas, but on the contrary, use up oxygen from the air, the explosion pressure is due entirely to the thermal expansion of the air. The heat of reaction of aluminium dust is of such a high order that the explosion pressure is in the same range as that of starch.

In the majority of cases of factory explosions the damage is due to the expansion pressure that is produced, and a measurement of expansion pressures produced by different materials under standard conditions provides a satisfactory empirical basis for comparing the explosion hazard of each dust. It also is a method for the comparison of the inflammability of different concentrations of the same dust.

It has been found that the pressure developed by the explosion of a given dust is fundamentally modified by the following factors: the concentration of the dust; the chemical composition of the dust; the physical composition of the dust; the composition of the atmosphere; and the temperature, extent and duration of the ignition.

The particles of a dust cloud, although many thousand times larger in size than the molecules of a gas, are still exceedingly small, with the result that the finely-divided



Particles of carborundum × 79.

material is in intimate contact with the gaseous medium in which it is suspended. It seems logical to expect, therefore, that dust dispersoids will burn with maximum velocity when the concentration of the actual combustible is chemically equivalent to the concentration of oxygen in the gas, for, when this is the case, the number of molecules of combustible material that are in direct contact with molecules of oxygen is at a maximum.

This is found to be quite true when put to experimental test. The explosion pressure is at a maximum at this concentration and diminishes rapidly as the concentration departs from this value in either direction.

(To be continued)

MANUFACTURERS' PUBLICATIONS

CHEMICAL Plant.—The Gallenkamp catalogue No. 109 (1939 edition) deals with semi-scale chemical plant, the items being grouped together as far as possible under the various unit operations of chemical engineering. It is a 52-page catalogue fully illustrated.—*A. Gallenkamp & Co. Ltd.*

Fans.—The Sturtevant publication No. 1036 is a 12-page brochure giving particulars, diagrams and photographs of propeller fans and small electric ventilating sets.—*Sturtevant Engineering Co. Ltd.*

Lighting.—"A New System of Harmony Lighting" is the title of a recent Benjamin Electric publication (No. 1639/739) which has been circulated to the trade. It provides numerous details and pictures of the Anolier system of indirect lighting and its applications.—*Benjamin Electric Limited.*

Research Instruments.—A folder has been issued (Kip. 3) giving details of all the catalogues available describing the Kipp and Zonen research instruments, together with brief descriptions of the apparatus. Any of the catalogues therein listed is available on request from *W. Edwards & Company.*

Resins.—Complete ranges of Crestanol-Modified phenol-formaldehyde resins, Crestanol-Maleic anhydride resins, and Crestin-Pure phenolic resins are described in the second edition of a booklet issued recently by the manufacturers. Particular attention is drawn to Crestanol S.B. 226, described as a very hard, pale, high viscosity modified phenolic resin which can be dissolved in the cold in solvents or cooked direct into stand oil at a low temperature. Its colour retention is stated to be altogether unusual for a modified phenolic resin. Crestanol S.B. 248 can, it is stated, be used to produce very quick drying lacquers of great durability.—*Scott Bader & Co. Ltd.*

Air-Borne Matter, Part III

Characteristics and Industrial Implications

By Harry L. Muntgomery Larcombe

IT has been proved that different air-borne materials vary widely in their readiness to burn for several reasons. It may be that the substance under consideration oxidises with comparatively great ease, in which case very rapid combustion is attained. Some dusts may burn readily on account of their open structure; this is because there is little interference to the air in its access to the unburnt portions of the particle.

Perhaps the greatest factor is the amount of volatile matter created on the application of heat. It is often the case that volatiles are given off at temperatures which are well below the ignition temperature of the material itself. These volatiles often become particles in themselves much finer than the parent particle. This state of affairs is admirably shown in the example of powdered coal which is known to have volatiles of a highly explosive nature.

The presence of inert air-borne material in the air, however, may be in such a proportion that it may be sufficient to absorb so much of the heat of combustion that the temperatures of the combustible material will not be raised to the ignition temperature. Under these conditions the propagation of the flame through the dust cloud will be impossible.

Therefore, the extent to which inert material can prevent ignition is dependent upon the proportion of such matter that is present and also upon the specific heats of it and the combustible matter. Again, this is exemplified in coal mining where the practice of stone dusting is one of major importance.

The inflammability of a given dust is highly dependent upon the size of the particles, their structure, the presence of adsorbed gas upon them and the extent to which they are electrically charged. The enormously increased electrical capacity of matter in a finely-divided state is a frequent contributory cause of explosions of combustible dust.

Degree of Dispersion

For a given concentration of any dust cloud, both the inflammability and the rate of combustion are increased by increasing the degree of dispersion. In addition to the increase in surface area which makes it more available, it can be easily understood that the smaller the particle the more readily it can be raised to ignition temperature. Also, being in greater numbers, the particles are closer together and better able to communicate heat one to another. In circumstances where some of the material is exceedingly small some of the particles will be in Brownian movement; these will greatly facilitate the propagation of ignition in the cloud. As has already been indicated the more finely-divided the dust is, the more clearly does its behaviour approach that of a gas. In no case, however, has dust been observed to burn with a velocity comparable to that of a gas mixture. This is due to the fact that even the most minute particle of dust will take a relatively long time to become ignited and burn out when compared with the molecules of a gas. We must not forget the complete combustion of certain organic substance results in the formation of relatively large volumes of gas so that dust explosions may develop a maximum pressure that may be greater than that generated by a gas mixture.

Little is known at present of the relationship that exists between the inflammability of a given material when in a finely-divided state and the structure of the particle, in particular the surface characteristics. On account of the fact that powdered material readily absorbs the gas in which it is suspended, it may be reasonably concluded that an open cellular surface will absorb gas more easily than a relatively close-grained structure.

When particles possess an open structure they will, in similar conditions, burn more readily and more completely than particles of a compact make-up.

Composition of the Atmosphere

The inflammability of dust concentrations diminishes rapidly when the oxygen percentage of the air is reduced and increases with the increase of oxygen content.

At a certain minimum percentage of oxygen which varies with all air-borne matter, dust is no longer inflammable. This principle has been used with grinding machinery for reduction of material to powdered form by leading flue gases into the zone of working.

The theory which Harger put forward to eliminate entirely the dust explosions in coal mines, was to reduce the oxygen content to 17 per cent., at which figure explosion was impossible. It is well known that the introduction of combustible gases into the medium of suspension of dispersoids increases their inflammability.

From the point of view of possibility of explosion the ignition of the dust is perhaps the most important factor. Methods of ignition can roughly be grouped in three classes:—

(1) *Spontaneous Combustion*.—In the case of dust, this is usually due to static electricity that has accumulated.

(2) *Thermal Ignition*.—This may cause explosions because of the ease of oxidation of many materials; however, the fact that the heat of oxidation is often dissipated very quickly after it is generated makes this method unusual in all materials with the exception of coal.

Particles of asbestos ×79

(3) *Electrical Ignition.*—See remarks under Laws of Behaviour.

The risk of dust explosions has been greatly lessened during recent years, due to systematic scientific investigation and study.

Influence of Air-Borne Matter on Health

In the year 1700, Ramazzani published a thesis which he called "The Diseases of Tradesmen." This was perhaps the first thorough investigation on occupational disease, and the forerunner of the State and individual study by which we have been able to alleviate and minimise the dust hazard in industry.

Study of the effects of these impurities has led modern opinion to believe that the hazards in dust-laden air are dependent on the following factors:—

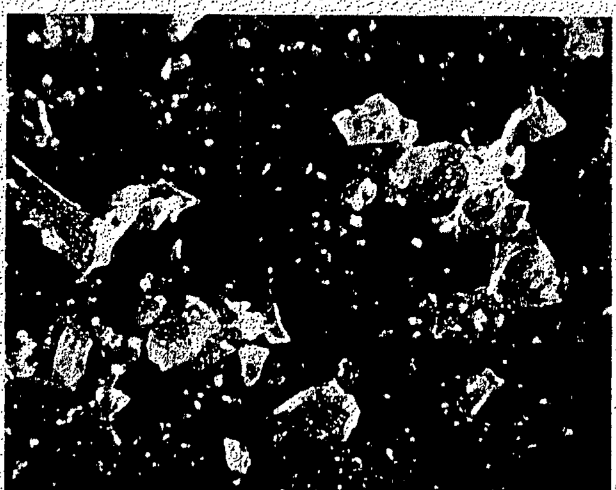
(1) The concentration of particles in the air at the zone of breathing.

(2) Composition of the particles, which in turn governs the shape and outline.

(3) The size of particles.

(4) The period of exposure of the workers.

All dust, however, is dangerous if inhaled consistently over a long period of time. Some materials may be highly injurious, while others of similar size and shape may be relatively harmless. Each problem must be given individual attention and studied from the point of view of particle size, chemical analysis, and concentration. Detection of dust in the air is sometimes a very difficult procedure. Heavy process dust with a high rate of settling is easily observed, but finer dust, which is the real danger, may remain in suspension indefinitely, not being visible in some conditions of light.



Glass powder × 79

A certain proportion of dust breathed is swallowed which, if not of a poisonous or infectious nature, is not highly or permanently dangerous, although it is possible to become violently sick if it has certain characteristics. The ratio of dust swallowed was determined by Lehmann to be 0.75 of the total quantity breathed. The swallowed impurities in certain classes of air-borne matter, such as lead, arsenic and mercury compounds, are the most dangerous, while the percentage passing to the respiratory system is of relatively small danger.

The first line of defence against air-borne impurities is the nose, in which large particles are trapped. Dust comes to the cavity of the nose, which is divided into a series of passages formed by a number of shelves of bone with thousands of glands for producing mucus. Finer particles which avoided being trapped by the nostrils are trapped in the viscous mucus and are caused to move either back to the nostrils or to the throat by the cilia, which are a multitude of hairs lashing continuously in constant direction.

Lehmann conducted a large number of experiments to determine the efficiency of the nose as a means of dust protection, and this was found to vary widely in different people. Very high efficiencies were recorded in which the finest of impurities of 0.5 to 2 microns were used. Very elaborate apparatus was used in these tests which took the form of jets of dust-laden air being blown into the nostrils and expelled by the mouth, and it was found that 63 per cent. of the healthy people who undertook to be tested retained 40 per cent. of the dust, the efficiency of all the subjects under test ranging from 70 to 10 per cent.

After the nasal cavities, the next of the natural defences are the trachea, bronchi and bronchioles. These also are lined with cilia constantly lashing in an upward direction any dust together with mucus, both being finally expectorated in the natural manner. This usually removes any dust which may have passed the defences of the nostrils and nasal cavities. Further defences consist of the air sacs of the lungs whose walls are lined with dust-absorbing cells known as phagocytes. These phagocytes have mobility when excited by foreign matter, such as dust, by which they are able to reach the tubes and so expel the foreign matter by the action of the cilia.

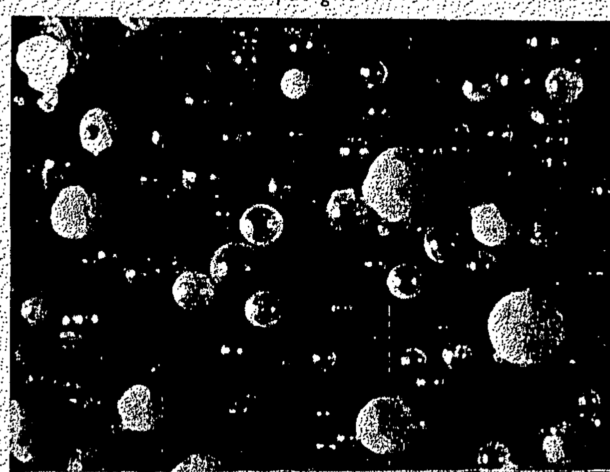
Each of the bronchioles terminates in a group of air sacs, there being about 6,000,000 of these sacs in the pair of human lungs, representing approximately 97 per cent. of the total air capacity. The thin membrane walls of the sacs are interwoven with blood vessels for oxygen transfer.

In comparing particle size with the size of lung passages, it is found that the smallest tubes are in the region of 500 microns diameter (the diameter of a dressmaker's pin), but the medical profession have shown that particles larger than 10 microns diameter (the diameter of a particle of pollen) are very seldom found in the alveoli of the air sacs.

The comparison shows the efficiency of the viscous baffles and the many changes of direction which are found in the respiratory system.

When considering them from the point of view of the effect

Boiler flue grit × 79



on health, dust can be divided into the three classes: animal, vegetable and mineral.

Animal Dust.—This is the class least found in industry and is perhaps the most harmless. The main danger with dust of this type is anthrax, which is not of a respiratory

nature, but is, however, classed as an industrial disease. The principal varieties of animal dust are essentially of relatively large dimensions and do not pass the first natural line of defence. The continual effort to clear away these particles is the cause of catarrh (*i.e.*, inflammation of the covering membrane of the upper cavities, nose, larynx and windpipe).

Vegetable Dust.—Under this comes wood dust, which is, along with others, capable of causing asthma. It is found that asthma is peculiar to vegetable dusts, and the reason for it is very difficult to ascertain. Various theories are put forward of which the following is the most likely. In contrast to mineral dust, these particles are soft and are not natural irritants. They aggregate into pulpy masses with mucus and moisture. It is highly probable that this pulpy mass blocks the smaller air tubes. This, in turn, reduces the surface area offered by the lungs for the transfer of oxygen to the blood, and the affected person is obliged to gasp in an attempt to get more air.

Mineral Dust.—Particles of this character are the most dangerous. They do actual physical damage to the lung structure. The widely-varied effect of particles of similar shape and size, but of different materials is proof that degree of sharpness is no dependable guide to the influence on health. The death rate among emery, carborundum and glass workers is not excessive.

Mineral dusts composed mainly of calcium carbonate are not highly dangerous, but those containing a proportion of free lime tend to be chemically irritant. Lime is believed to have been the cause of pneumonia epidemics amongst basic slag workers. These dusts which are chemically irritant, are really safer in industrial processes than those which are non-irritant, as they are sufficiently unpleasant to make workers take precautions to prevent inhaling them.

Silicosis

This is the worst of respiratory diseases caused by air-borne impurities. Certain siliceous rock in the course of blasting or drilling or grinding give rise to vast quantities of extremely fine dust, and it is this extraordinarily minute particle size coupled with the composition of the material which is the source of danger.

It has been shown by Gardner that the phagocytic cells behave in an absolutely different manner in the presence of certain siliceous materials from that shown toward other types of dust. This siliceous matter is soon absorbed by the phagocytes and appears to accelerate the migration of the cells; this is probably natural reaction to the extra effort required to remove the matter thoroughly. Then it seems the cells are killed, and aggregate into lumps around which a fibrous growth forms. In time, which is usually a period of years, this condition is general throughout the lungs and is known as silicosis. The lung tissues in this damaged and inflamed state is very easily attacked by the bacteria of tuberculosis, whose size is 0·5 microns wide by 2 to 6 microns long, and this is the final stage of destruction.

Dr. William R. Jones has done very valuable research work in the elimination of this terrible disease, and has led to methods of clearing the air from dangerous dust at the zone of breathing.

In reviewing means at present available in mines for checking silicosis three methods may be mentioned. The first, the use of water when drilling; secondly, well-directed and efficient ventilation; and thirdly, regulation times for blasting.

Wet drilling has brought about an enormous decrease in miners' silicosis and practically eliminated what is medically known as third stage silicosis. Scientific investigation has shown that wet drilling does materially allay the dust, but, where the dust has a high silica content, the concentration of dust and air is still highly hazardous. The main drawback with wet drilling is the disposal of the dust-laden water, because water droplets with entrained dust, often evaporate with the heat of the air, and leave the dust particles suspended. In spite of the fact that the rate of evaporation decreases when the relative humidity is increased, it has been proved that with a relative humidity as high as 90 per cent., droplets of 100 microns disappear before falling 6 ft.

A further disadvantage of the use of water while drilling and wetting walls of mine galleries is that, in hot deep mines a humidification of the air results which almost reaches 100 per cent. A condition such as this is extremely conducive to tubercular infection when combined with the high temperature of deep mines.

Importance of Ventilation.

Ventilation in conjunction with efficient air filters is perhaps the greatest factor in health in mines and this also applies to factories. With double and treble shift blasting, as is now the custom, an enormous amount of dust is created in mine working and, as this should be removed on account of explosive, as well as health hazards, it is a matter for engineers to decide whether it is better to extract air or to provide a forced draught; but by either method, ventilation is now regarded as the most efficient and important means in use to-day of ridding the air of fine dust and so preventing dangerous concentrations. It must be remembered that these considerations apply to all industrial processes.

Dust traps used in mining appear to be still on trial, but several specialists in this type of dust control work have obtained very encouraging results.

Absolute protection against air-borne impurities is often very difficult to provide, and an accurate scientific comprehension of the various factors which influence and cause any type of hazard for the workers in industry is vital. Industrial administration must strive to reach a point where these hazards are negligible.

Considerable advances have been made during the last decade in the fight against the dust danger in industrial plants, both above the ground and below. Dust-contaminated air still, however, occasions serious loss of working efficiency, damages our health, industrial equipment and materials in process.

(For permission to reproduce the photographs illustrating this article we are indebted to the Sturtevant Engineering Co. Ltd.)

Nomenclature

c	= Velocity in cm./sec.	
C	= Velocity in ft./min.	
d	= Dia. of particle in cm.	
D	= Dia. of particle in microns	
g	= 981 cm./sec./sec. acceleration	
n	= Viscosity of air in poises = $1{,}814 \times 10^{-7}$ for air at 70° F.	
	= 10^{-5} cm. (mean free path of gas molecules)	
r	= Radius of particle in cm.	
S_1	= Density of particle	
S_2	= Density of air	
A	= Distance of motion in time t	Brownian movement
N	= Number of gas molecules in 1 mol. $6{\cdot}06 \times 10^{23}$	Brownian movement
R	= Gas constant $8{\cdot}316 \times 10^{7}$	Brownian movement
T	= Absolute temperature	Brownian movement
A^1	= Surface area	Specific surface
K	= Constant	Specific surface
k	= Constant	Specific surface
W	= Weight	Specific surface
t	= Time	Centrifugal separation
H	= Gas viscosity	Centrifugal separation
Q	= Constant	Centrifugal separation
U	= Maximum angular distance	Centrifugal separation
V	= Tangential gas velocity	Centrifugal separation
Y	= Angular velocity of gas and entrained particles	Centrifugal separation
Z	= Radius of gas path	Centrifugal separation

Bibliography

W. E. Gibbs. "Clouds and Smokes." P. Blakistons Son & Co. 1924.

W. E. Gibbs. "The Dust Hazard in Industry." Ernest Benn Limited. 1925.

N. B. Cohen and A. G. Ruston. "Smoke." Edward Arnold & Co. 1925.

D. J. Price and H. H. Brown. "Dust Explosions." National Fire Protection Association, U.S.A.

Sir Thomas Oliver. "Diseases of Occupation." 1908.

Prof. E. L. Collins. Milroy Lectures. Public Health. 1915.

E. L. Macklin and E. L. Middleton. "Report on the Grinding of Materials and Cleaning of Castings with Special Reference to the Effects of Dust Inhalation upon the Workers." H.M. Stationery Office. 1923.

Perry. "Chemical Engineers' Handbook." McGraw-Hill Book Co. Inc.

Harold Heywood. "Measurement of the Fineness of Powdered Materials." *Engineering*, October 21, 1938.

Proceedings of Institution of Mechanical Engineers. Vol. cxxv. 1933.

Industrial Dust. Sturtevant Engineering Co. Ltd.

ENAMELLING ZINC ALLOY DIE-CASTINGS

(Continued from p. 436)

of the media used for the stoved aluminium finishes are given in Table 4.

Two other specific test results are worthy of note. Applied to zinc articles without chemical or mechanical pretreatment, clear lacquers of low consistency of the combination cellulose/glyptal variety, air dried, proved successful. On the 12 months' humidity test they showed no deterioration. This is interesting, because in the first place materials of this nature give exceedingly thin films which are very adherent and show good resistance to ageing. Secondly, these thin lacquer films are markedly more impermeable to moisture vapour than are the thicker coatings of the orthodox clear cellulose lacquers. This superior moisture proofing property, which again bears out the theories put forward, is demonstrated in the figure appearing on p. 436.

The curves given therein were derived in the following manner. Tests were made on the two types of lacquer in double thicknesses applied by spray to 0·0005 in. cellulose acetate film. The latter was selected as the base on account of its high moisture permeability properties. The test pieces after allowing a week for thorough air drying were then sealed by means of bitumen on to flanged cups containing absorbent (anhydrous copper sulphate or silica gel). They were weighed and exposed to 100 per cent. humidity, thus setting up a moisture gradient between the two sides of the film. Moisture passing through was determined by reweighing at intervals of time. Normal cellulose lacquers are good with respect to moisture proofing but it will be seen that the combination lacquer is superior, approximately halving the rate of penetration, this despite that, in actual thickness, its film is about one-fourth that of the orthodox material. Average laboratory data, including chemical and physical properties and the composition of the thinners for the combination lacquer are shown in Table 5.

Stoved Glyptal Varnish

The other result of note concerns the stoved synthetic glyptal varnish. While on untreated surfaces this failed completely by softening within four weeks of humidity test, on shot blasted furnaces it did not deteriorate in hardness or adhesion in a 12 months' test period, although it darkened in colour considerably.

Zinc alloy die-castings are being adopted widely in engineering industries. Accuracy of reproduction by the die-casting process, range of alloys to suit various needs, inexpensiveness, rapidity of fabrication: these factors ensure the advance of their popularity and utility. The automobile industry for door handles, lamp brackets, dash fittings, radiator ornaments, steering wheels, &c.; automatic slot machine parts; domestic fittings, handles, curtain accessories, refrigerator and vacuum cleaner components; washing machinery; clocks; electrical components; cine projector items; office equipment: this extended range illustrates their far-reaching possibilities. Consequently, the painting and enamelling problems associated with zinc alloys are likely to confront industrial chemists in many spheres; those to whom the technology of finishing is a full-time study, those with whom it is only one of many chemical processes in engineering, as well as those connected with paint manufacture itself. Consequently, the foregoing, briefly though it deals with the subject, should prove interesting and, it is hoped, informative.

Factory Lighting Installation

A part of the packetting hall in the new "drys" building of Boots Pure Drug Co. Ltd.; 195 Benjamin Saaflux R.L.M. reflectors are installed 200 watt lamps giving an excellent distribution of light over the conveyors

A Rotary Kiln Lime Plant

Installation at Abadan

Sea Shells as a Raw Material

THE burning of lime in rotary kilns is a well-established practice, but a recent installation by Edgar Allen & Co. Ltd., for the Anglo-Iranian Oil Co. Ltd., at their refinery at Abadan is of particular interest on account of the unusual raw material—sea shells—which the plant is designed to utilize. Abadan is situated on the river Shatt-al-Arab, which is the confluent of the Tigris and the Euphrates, about 40 miles north east of the Persian Gulf.

The plant was installed for the purpose of providing milk of lime for the oil refinery and also lime for building purposes.

Raw Material

The sea shells are deposited in large quantities on the shore of the Persian Gulf. They are brought to the works in barges. The size of the shells varies between about 2 in. and ⅛ in., and even smaller. On a sieving test it was found that approximately 40 per cent. passed through a sieve with ⅛ in. square holes.

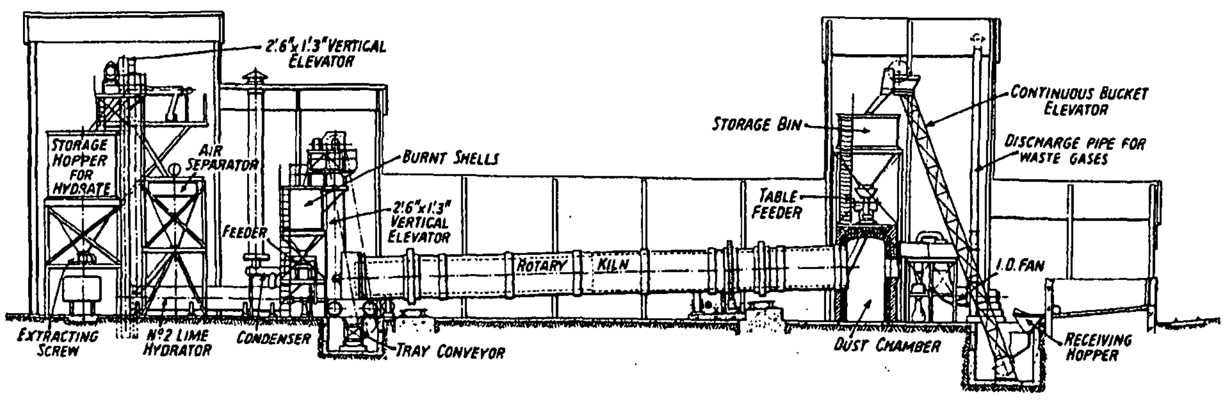
The chemical analysis proves that the shells are fairly pure calcium carbonate. The composition is :—

	Per cent.
Loss on ignition	43·03
Silica	1·10
Alumina .. .. / Ferric oxide	0·74
Lime	53·00
Magnesia	1·56
Difference	0·57
Total	100·000

The shells burnt in a rotary kiln are hydrated and the hydrate freed from nibs and impurities by passing it through an air separator. The arrangement of the lime burning plant, the hydrator and the air separator is illustrated in Fig. 1.

The raw shells are filled into a receiving hopper and are lifted by means of an elevator into an overhead storage bin placed over the kiln feeder. The bin is filled every morning in 2 to 3 hours and has sufficient capacity to supply the kiln with raw material for 24 hours.

Fig. 1—Elevation showing the arrangement of lime-burning plant, hydrator and air separator



Rotary Kiln

A rotating table feeder under the bin extracts the raw shells and feeds them at the required rate into the rotary kiln through an inclined pipe. The kiln is a steel tube lined with firebricks, and is slightly inclined. It rotates slowly on two sets of rollers and bedplates, being driven by a variable speed motor. The raw shells fed in gravitate slowly to the discharge end as a result of the inclination and rotation of the kiln, and the hot combustion gases from the firing equipment, which is fitted at the lower end, travel in the opposite direction, gradually heating the shells to the calcining temperature.

The inside of the kiln is fitted with a lining of refractory material and an insulating lining between the steel shell and refractory lining. For European conditions an insulation is recommended principally for the purpose of reducing the heat lost by radiation and thus for fuel economy, but for climates such as at Abadan, where the shade temperature in the summer reaches 125° F., it is also essential for the preservation of the plant.

The waste gases from the kiln pass through a brick dust chamber and through a cyclone dust collector, and are exhausted into the atmosphere by an induced draught fan. The fan is driven by a variable speed motor for the purpose of adjusting the speed in accordance with the volume of gas to be handled.

Oil Firing Equipment

Being located at an oil refinery, the kiln is, of course, fired with oil fuel. This fuel lends itself exceptionally well for burning lime because the firing is under close control, no impurity is introduced into the lime, and the calcining *temperature can be maintained between very narrow* limits. The oil is atomised in the burner by compressed air, which may be considered extravagant, but ensures very thorough atomisation besides being reliable, particularly when attended to by unskilled labour. The oil used has a viscosity of 140 secs. Redwood No. 1 at 100° F. and a specific gravity of 0·913, so that heating is not necessary.

The firing equipment comprises the burner, an oil pump with filters on the suction and delivery sides and an air compressor, control valves and gauges.

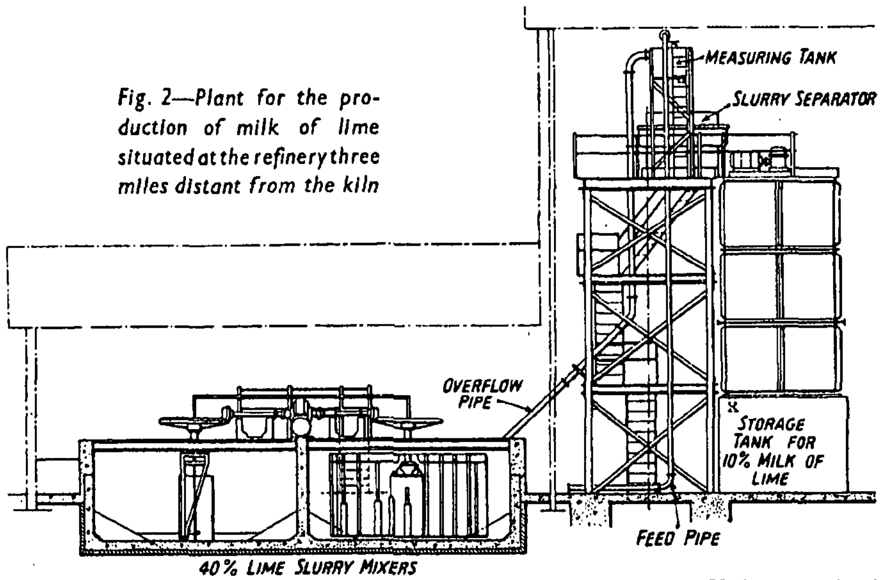


Fig. 2—Plant for the production of milk of lime situated at the refinery three miles distant from the kiln

Hydrating Plant

The quicklime, having been discharged from the kiln, is then conveyed on a steel tray conveyor and lifted by means of a bucket elevator into a hopper over the feeder for the hydrator. The duty of the hydrator is to convert the quicklime or calcium oxide into hydrated lime, a very light and fine powder. This conversion is effected by adding about 30 per cent. of water to the quicklime. The hydrating machine is designed to the Schulthess patents. The burnt shells are extracted from the hopper and fed into the hydrator by an automatic table feeder, and are moistened with a portion of the hydrating water in the preliminary hydrating compartment. Any hard lumps and impurities are retained in this compartment. The partly slaked lime passes into the second compartment, where more water is added. The steam created and the very fine dust suspended in it pass through a condenser into the atmosphere and are washed in it before being discharged. The washing water is the water used in the hydrator.

The grading analysis of the hydrate showed that it contained a few nibs and some impurities. These would be inconvenient in the milk of lime plant and objectionable if the lime were used for building purposes. It was, therefore, decided to instal an air separator for removing the nibs and impurities.

The pure hydrate is elevated into a storage bin from which it is withdrawn as required by an extracting conveyor.

Milk of Lime Plant

The milk of lime plant is erected in the oil refinery about three miles distant for the rotary kiln. It was not practicable to pump the milk of lime this distance from the kiln plant to the refinery, but it was decided to make a lime slurry containing about 40 per cent. of water at the kiln plant, and transport it to the refinery in tank wagons for further treatment.

The tank wagons, having arrived at the plant with 40 per cent. lime slurry, are emptied, and the slurry is run into two concrete mixers equipped with mechanical stirrers and pipes for agitating by compressed air. The mixers are of ample size so that if any irregularity in the percentage of water in the various tank wagons exists, the consistency of the slurry in the mixers is practically uniform.

In order to produce 10 per cent. milk of lime, more water is added to the 40 per cent. slurry. For this purpose it is pumped by a centrifugal pump into a measuring tank with V-notch and overflow for surplus slurry.

The V-notch is adjustable and allows a determined volume of slurry to flow out, and any surplus is returned to the mixers. Water is added in metered quantity to the slurry flowing over the V-notch from the measuring tank to make 10 per cent. milk of lime, and both liquids are run into a Clark's slurry separator which retains any impurities that may have found its way into the slurry and at the same time effects thorough mixing. The finished 10 per cent. milk of lime is run into a storage tank, where it is kept in suspension by mechanical stirring.

The plant is well equipped with instruments for the control of the temperature, where this is necessary. Unfortunately, there is no instrument on the market by means of which the calcining temperature can be indicated or recorded. The method adopted at Abadan is to measure the burnt lime as it falls out of the kiln by means of an optical pyrometer through a hole in the discharge hood. This temperature is in fairly close relationship to the calcining temperature, and the fuel supply is adjusted according to the reading. A great asset to the plant is the oil for firing. The ease of temperature control, and the speed with which adjustments can be made, make it possible to produce continuously well burnt lime of uniform quality, and it has been proved that a temperature maintained within narrow limits is necessary for maximum conversion of the lime to soluble hydrate. Such close temperature control is only possible in a rotary kiln and with oil firing this is comparatively easy. Another adjustable factor in the calcining process is the speed of rotation of the kiln, although alterations in this direction are not often necessary.

Control of Hydration

The hydrating process also is controlled by temperature of the hydrate discharged from the machine. It has been found that if the water supply be adjusted in accordance with the temperature of the hydrate discharged, the percentage of water is about correct. Normally the temperature is about 100° C.

One foreman is in charge of the plant and a staff engineer calls once every shift to take readings of the various instruments. Close watch is also kept on the kiln waste gases, the temperature is measured, and the chemical analysis checked for carbon dioxide and oxygen. The least volume of excess air, which would increase the fuel consumption, is allowed to enter the kiln.

DETECTION OF ANILINE VAPOUR

IN the series of leaflets describing methods of detecting toxic gases in industry, a new publication is No. 11, which describes a method whereby concentrations of aniline vapour ranging from 1 part in 5,000 to 1 part in 200,000 may rapidly be estimated by a refinement of the bleaching powder test. This test has been made quantitative by comparing the colours obtained at low concentrations with a series of standard colours prepared from a dye. This leaflet, and a pamphlet describing the complete series of gases and vapours to be covered, can be obtained from the Department of Scientific and Industrial Research.