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CONTENTS

Physics and Protection against Industrial Dust

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INTRODUCTION

INDUSTRIAL dust presents two main hazards to the workers in factory and mine: (1) risks to health, (2) risks to life and limb through fire and explosion from certain types of dust. Space will only permit reference to but a few aspects of the subject and therefore only factory dust problems will be dealt with, and, in particular, the physical aspects of those problems. The corresponding problems in mines, whilst covering a somewhat narrower field, are essentially similar though modified by the special environmental conditions of working underground in confined spaces.

Many factory operations give rise to dust, the chief being those of crushing, breaking, disintegrating, grinding, abrading, drilling, sawing, turning, mixing, sieving, rumbling, sand- or shot-blasting, linishing, spraying, polishing, carding, weaving, spinning, and almost any operation involving material which is itself a dust or contains a percentage of dust.

The risks to health from industrial dusts arise from the damage they can cause to the respiratory system, and from the action of certain dusts as general systemic poisons or skin irritants.

Thus the inhalation of silica or asbestos dusts, which is cumulative in effect, can cause the incurable lung diseases of silicosis (1) and asbestosis (2) respectively, in which the lung tissue is gradually destroyed, with the result that blood aeration diminishes; the inhalation of animal or vegetable dusts such as cotton, jute, flax, hemp, wood, hair, silk, and of some mineral dusts such as limestone, glass, cement, marble, and emery may affect the respiratory passages and give rise to bronchitis, asthma, or catarrh. Again, the breathing of certain metallic oxide fumes such as zinc oxide, magnesium oxide, manganese dioxide, and copper oxide, can give rise to metal fume fevers, while the inhalation or swallowing of certain toxic dusts such as lead, arsenic, cadmium, or manganese, and their compounds, leads to poisoning. The dust produced when handling certain kinds of infected raw wool, hair, and hides, may carry spores, which, by skin contact or inhalation, may cause the disease known as anthrax, while finally almost any dust appears to be capable of causing the inflammations and affections of the skin, known as dermatitis, to workers who happen to be allergic, or sensitive, to them.

Of these dangers to health the most serious are undoubtedly those due to silica and asbestos dusts and to the poisonous dusts such as lead.

Physical principles are involved at many stages in the estimation and control of dusty conditions in the working atmosphere, and it is these rather than the health risks with which this article is concerned.

ESTIMATION OF THE DUST HEALTH HAZARD

Protective measures against health risks arising from the inhalation of industrial dust must take many forms, which must be based on a sound knowledge of the way in which dust can enter and affect the lungs and respiratory system, and through them the rest of the body. This is largely a medical problem, but one to the elucidation of which physics has contributed substantially. Thus it is of primary importance for the physiologist to have available a knowledge of the concentration (in numbers of particles per unit volume), the size distribution, mass per unit volume, and mineralogical nature and chemical composition of the air-borne dusts which are breathed by industrial workers with known duration of exposure to the dusts, so that correlations can be made with the workers' clinical history of silicosis and other pulmonary diseases, and with the medical data to be obtained from X-ray examination of workers' lungs in vivo, and from examination of lung sections of workers known to have died from such lung diseases. In the examination of lung sections themselves it is important to ascertain by physical methods the nature and size of the dust particles to be found there. In experimental work on dust inhalation by animals of toxic or fibrosis-producing dusts it is equally important to have an accurate knowledge of the amount, size and type of dust being inhaled to correlate with the medical observations on the effect of the dusts.

It is now established (3) that the majority of the particles found in the lungs are less than 5 microns in diameter (1 micron $= 1\,\mu = 10^{-4}$ cm.), very few exceeding $10\,\mu$. Within the range of sizes below $10\,\mu$ it has still to be established conclusively which size or range of sizes of dusts such as silica and asbestos is the most dangerous, and how much of such dangerous dusts can be regularly breathed by workers without appreciable shortening of life. Large numbers of comparable dust samples from various industries and processes need to be accumulated and analysed to enable conclusions to be drawn on these and related matters.

For the measurement and control of actually existing dust conditions it is equally important to have accurate data on which to base estimates of the protection required, the type and arrangement of the devices most

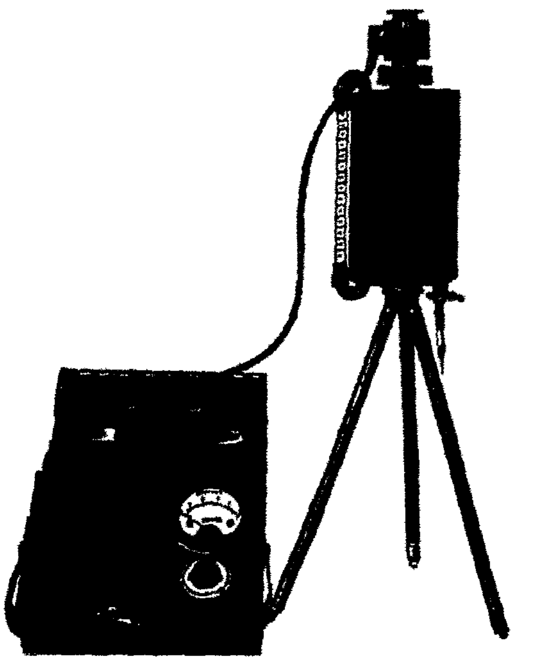

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Fig. 1. Thermal precipitator

likely to be effective, and to assess their efficiency and value when provided.

A large number of scientific instruments is available for these purposes, all based on well-established physical principles. For the measurement of air-borne dust concentrations and size distributions, the chief instruments available for field use are:

(*a*) *The Thermal Precipitator* (4) (Fig. 1). This instrument, which is rapidly becoming the standard instrument in this country, employs the principle of the dust free space surrounding a heated body (5). The dust laden air sample is drawn between two thin microscope cover-glasses, part of whose surfaces lies in the dust free space of a heated wire, and the dust is completely deposited on the cover-glasses.

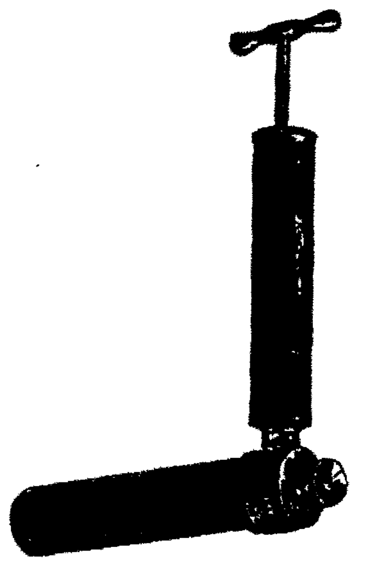

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Fig. 2. Owens jet dust counter.

(*b*) *The Owens Jet Dust Counter* (6) (Fig. 2) and similar type instruments in which a hand-operated suction pump fitted with a non-return valve draws a measured volume of the dusty air via a damping tube through a slit. The rapid expansion and consequent drop in temperature of the air passing through the slit results in the condensation of moisture on each dust particle and so assists the particles to adhere to a chemically clean cover glass, which, placed just behind the slit, acts as the impinging surface.

(*c*) *The Greenburg-Smith Impinger* (7, 8) (Fig. 3), based on the high-velocity impingement of the dust aspirated through a jet against a glass disk immersed in a known volume of water, which captures the dust. A sample of this water is then transferred to a shallow sedimentation cell for evaluation of the dust content.

(*d*) *Konimeters* of various kinds (9, 10), one of which is illustrated in Fig. 4, in which the dust is abstracted from the air sample by impingement at high velocity through a jet on to a slide coated with a sticky substance.

(*e*) *Electric Precipitators* (11, 12) *or Electrostatic Dust Samplers* (Fig. 5), in which a measured volume of dust-laden air is passed through a cylindrical glass collecting tube fitted with a central wire electrode maintained at a potential difference of up to 15,000 V with respect to a gauze electrode wrapped round the tube. The electric field produced results in an electrostatic attraction of the particles of dust and in their being charged by the corona electric discharge, the effect of which is to drive them in a direction normal to the motion of the air along the tube. The dust particles are precipitated on the inside surface of the glass tube or upon a thin celluloid lining placed inside the tube, from which they

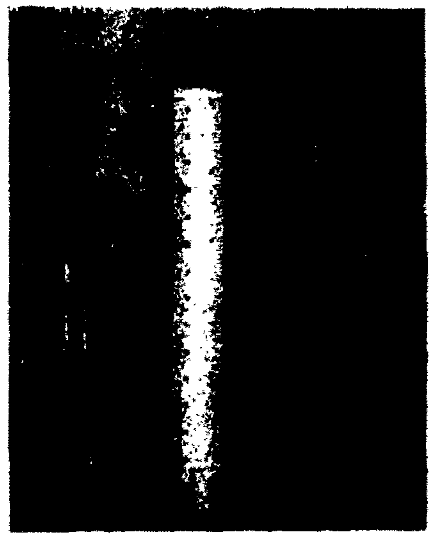

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Fig. 3. Modified Greenburg-Smith midget impingers. *Right:* with hose and inlet guard, ready for use. *Left:* sealed for carrying

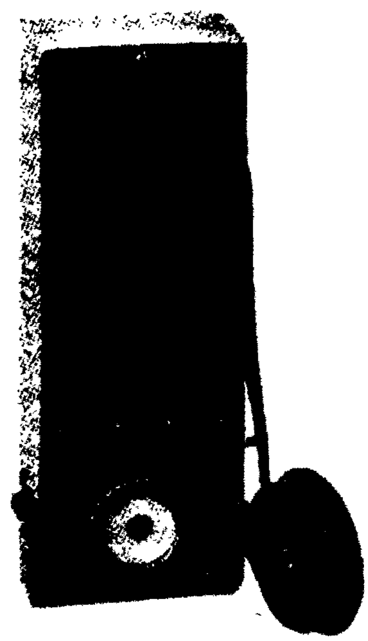

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Fig. 4. Konimeter

can be washed into water or other liquid for sedimentation and evaluation, as with the Impinger samples.

For counting and sizing the dust records obtained, some of these instruments incorporate their own microscope equipment, but this is usually only capable of giving a low overall magnification of about × 200 so that the smaller particles under $0{\cdot}8\,\mu$ are missed. Such in-

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struments are chiefly used for routine dust checks and for preliminary surveys of dust conditions. For research work or for accurate dust surveys the dust samples need to be examined by a microscope of high resolving power incorporating a 2 mm. oil-immersion apochromatic objective and giving an overall magnification of about ×1500. High power microscopy is essential because industrial dust clouds contain considerable numbers of very small particles down to 0·2 μ or even less, and with low resolving power these are not seen. The tendency now is to substitute microprojection of the dust samples for direct counting with the microscope, to obviate or reduce the eyestrain inseparable from the direct method and to save time and work. An example of such equipment as used in the dust estimation work of the U.S.A. Bureau of Mines in Washington is shown in Fig. 6.

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Fig. 5. Electrostatic dust sampler

For fundamental laboratory work on dust cloud concentrations and sizes the special ultramicroscope (13) and sedimentation cell (14) instruments are available, and the development of the electron microscope will undoubtedly extend knowledge of the nature of dust particles in the regions of size beyond the capability of ordinary high power microscopy to resolve. Thus Preston (15) has shown, using a ×23,000 electron microscope, that zinc oxide fumes contain particles in the form of needles of remarkably uniform length (about 0·4 μ) and less than 0·04 μ thick; while Prockat and Windel (16) with a similar apparatus have demonstrated that the fibrous structure of Cape asbestos is maintained down to particles of only 0·02 μ in thickness.

For dust samples not air-borne but in powder form, methods of sedimentation or elutriation analysis as described by Heywood (17) are available.

It is not proposed to discuss here the relative efficiencies of the various instruments, as an excellent critical survey (18) is already available which shows that they differ widely in their sampling efficiencies and that some instruments, which depend on impingement of the dust for collection, shatter a proportion of the particles sampled and so lead to erroneous figures for concentrations and size distributions.

It may be emphasized that there is a real need for international agreement on the choice and specification of dust-counting instruments and standards of counting suited to fundamental research work and industrial dust surveys in the various industries, in order that the results obtained by workers in this field may be comparable.

The dust samples obtained from industrial atmospheres with the thermal precipitator and similar instruments, which are intended to be counted and sized under high resolution microscopes, are heat treated to remove atmospheric pollution particles which are necessarily sampled along with the mineral dust which

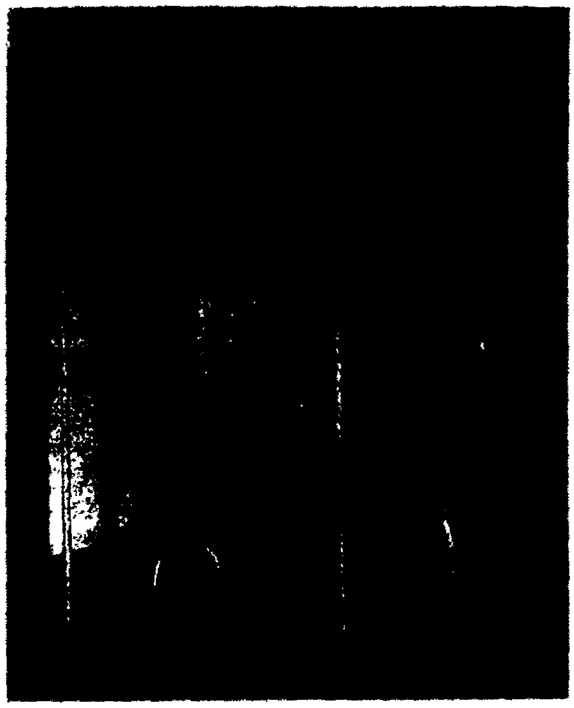

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Fig. 6. Microprojector for dust samples, utilizing high power microscopy. Black cloth screening of counting cubicle and projection cone removed, to show details of construction and method of remote control of microscope adjustments

it is desired to evaluate, since the size ranges of both overlap. With the lower power microscope equipment incineration of records is unnecessary as atmospheric pollution particles are almost wholly under 0·8 μ in size and so are not seen. The problem of removing all atmospheric pollution particles from a dust slide without removing mineral particles as well or cockling the thin cover glasses on which the dust is deposited is a very real difficulty worthy of further research work. The amount of atmospheric pollution can be gauged from a recent series of dust counts taken in a field in the centre of the Potteries at Stoke-on-Trent. The heaviest concentration measured was 27,000 particles per c.c. of pollution, of median size 0·25 μ (as counted down to the limits of visibility with a 2 mm. oil-immersion apochromatic objective and overall magnification ×2000) on a January afternoon; the lightest, on a day in the middle of Wakes week (the holiday week when all potteries were closed down), of 760 particles per c.c.

The dust records obtained with the instruments mentioned above are sized by direct comparison of each particle in a representative strip of the deposit with a series of calibrated circles in a special graticule fitted in the eyepiece of the microscope equipment. Some typical size distributions of air-borne industrial dusts are as follows:

Flint milling. Median particle diameter 0·8–1·3 μ. 20–30 % < 0·5 μ, 70–80 % < 2 μ, 94–99 % < 5 μ.

Potters' shop general atmosphere (Plate making and towing in progress). Median particle diameter 1·0 μ. 19 % < 0·2 μ, 50 % < 1 μ, 73 % < 2 μ, 92 % < 5 μ.

Sandstone dust produced from mason's mallet and chisel work. Median particle diameter 0·6–1·1 μ. 25–45 % < 0·5 μ, 70–90 % < 2 μ, 92–99 % < 5 μ.

Asbestos dust (in a spinning room). Median fibre length 2·6 μ. 15 % < 1 μ long, 75 % < 5 μ long, 92 % < 10 μ long. Median fibre diameter 0·2 μ. 51 % < 0·2 μ diameter, 92 % < 0·5 μ diameter. Median size of mineral particles present in asbestos dust clouds, 0·3 μ. 40 % < 0·2 μ, 73 % < 0·5 μ, 97 % < 2 μ.

The results of numerous determinations of size distribution of particles in industrial dust clouds have led to the conclusion (19) that particles under 0·2 μ in diameter are present to the extent of only a few per cent. That so much of the dust in typical factory atmospheres where mineral dusts are disseminated is under 5 μ is largely accounted for by the rate at which dusts settle. Thus particles of quartz of specific gravity 2·65 fall in free air at the rates given in the following table.

Diam. of particle μ	Rate of fall cm./sec.	Time to fall 1 ft.
10	0·784	39 sec.
5	0·196	2 min. 36 sec.
1	0·008	56 min.

Actually these theoretical times to fall 1 ft. will be increased appreciably by convection currents and air eddies, but dust over 10 μ very rapidly falls below a worker's breathing level under ordinary conditions. Dust particles of 1 μ and less in diameter are probably kept indefinitely in suspension in the atmosphere through the agencies of convection currents and Brownian movement.

For the measurement of the mass of dust per unit volume in air-borne dust clouds there are available, amongst others, the following methods:

(*a*) *The Sugar Tube* (20) *or Potassium Nitrate Tube* (21) in which a bed of sugar or potassium nitrate acts as a filter for a known volume of air-borne dust. The sugar etc. is subsequently removed from the collected dust by solution in water and filtration through a filter paper which is ashed and the residue weighed.

(*b*) *The Tyndallometer* (22) which measures the intensity of the light scattered by the dust in a measured volume of air, the intensity being a measure of the mass of dust present.

(*c*) *The Volatile Filter* (23), e.g. a bed of naphthalene or anthracene through which a measured volume of dusty air is drawn. The filtering material is subsequently sublimed away at 70°–75° C and the dust residue weighed on a microbalance.

(*d*) *The Salycylic Acid Filter* (24) in which a bed of this material traps the dust from a measured volume of dusty air. The dust is recovered for weighing by extracting the salycylic acid with alcohol and ether, and reclaiming the dust by centrifuging.

Such determinations of mass concentration are not of great significance in practice as a few large size particles present in the sample outweigh completely the very much larger number of particles under, say, 10 μ. This results in a misleading idea of the amount of potentially injurious dust being obtained.

For micro-chemical analysis of air-borne dust the salycylic acid filter will abstract enough dust, some 50 mg., in a reasonable time (3 hr.) from a dust cloud of moderate concentration. Sufficient dust for micro-chemical analysis can also be obtained from the sugar tube apparatus or the naphthalene filter.

For complete chemical analysis, and for solubility determinations, much larger quantities of dust, of the order of 1–5 g., need to be extracted from the dust cloud, and can be conveniently obtained by the use of the Labyrinth instrument designed by Briscoe and his co-workers (25). The instrument consists of a tube, containing a series of baffles, through which the dusty air is pulled, the dust particles being deposited on the baffle plates by impingement.

The mineralogical nature of air-borne dust particles as small as 3 μ in diameter can in favourable cases be determined by direct examination with the petrological microscope. To obtain similar data for particles under 3 μ and thus cover the range of particle sizes of particular interest in connexion with industrial health risks from air-borne dust clouds, recourse must be had to the X-ray and electron diffraction methods, which are now attracting the close attention of physicists. Clark and Reynolds (26) have, for example, developed the ordinary powder X-ray diffraction method to enable accurate estimations to be made of the percentage of free silica in the form of quartz in a few milligrams of mine dust, while von Hevesy (27) has used secondary X-rays for the direct qualitative and quantitative micro-analysis of finely powdered mineral and rock samples.

Again, X-ray diffraction is being increasingly utilized by medical workers in pneumoconiosis research (28) on mineral dusts, down to colloidal sizes, such as are used for animal inhalation or injection experiments or are present in chemically extracted mineral residues of lung tissue or in pulverized and dried lung tissue.

Protection against industrial dust

By a suitable combination of the physical and physical-chemical methods outlined above, a fair assessment of the amount and nature of the dust clouds being breathed by workers in any particular case can be made. Methods of protection to suit can then be devised. This is the ideal approach to the problem which can only be adopted at present in a limited number of cases on account of the time involved in such surveys. In practice a selective survey of dusty conditions associated with typical processes in an industry (29) offers valuable guidance for more general application of protective measures to generally similar conditions in a whole industry.

In the normal individual the human nose, throat, and lungs in themselves provide a defensive mechanism for arresting fine dust and preventing its reaching the ultimate air sacs in the lungs. The nose traps large particles in the nostrils and finer particles in the maze of passages above the nostrils in which dust is deposited

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from eddy current action, particle aggregation, and from impingement on the sticky secretion of mucus which lines all the air passages from the nose downwards. The windpipe and air tubes of the lungs are also lined with minute whip-like processes known as cilia, whose function is constantly to sweep upwards to the windpipe for expectoration the mucus and the dust particles it has trapped, the process being aided by the rhythmic contraction of the smaller muscular air tubes. Fine particles which succeed in reaching the air sacs of the lung are attacked and ingested by phagocytic cells, some of which manage to carry the dust back into the air tubes where they can be expelled. The importance of nose breathing in dusty atmospheres, in order that all the natural defences of the respiratory system may be brought into full play, will be appreciated, though individuals differ widely in the power of these defences.

The main methods of protection against industrial dust take a wide variety of forms.

Application of localized exhaust ventilation

This is the commonest and most usually effective way of protecting workers against local dust concentrations. The basic idea is to capture the dust or fume as near as possible to its point of origin by means of concentrated air currents flowing into suitable exhaust hoods, which need to be designed on sound physical principles to suit each individual case. The collected material is sucked away through ducting by a fan and passes to filtration plant.

It is found that most industrial dusts can be captured by exhaust hoods designed to produce a linear air speed of from 100 ft.–500 ft./min. at the point of origin of the dust.

The design of efficient exhaust hoods, of which Fig. 7 is a good example, is an important matter and is dealt with adequately in another publication (30) as is also the design of the associated ducting system, fan and dust collecting apparatus, all matters calling for the careful consideration of appropriate physical principles.

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Fig. 7. A well-designed localized exhaust ventilation system protecting conveyor workers assembling lead accumulator plates from the risk of lead poisoning. Fumes from lead burning, and lead dust created in the assembly process are sucked away by the exhaust draught. A glass screen forming part of the hood is interposed between the work and the workers' noses

Application of general mechanical ventilation

The purpose of general ventilation is to dilute with fresh air the dust laden air liable to be breathed, so that the resulting dust concentration is below the toxic or otherwise harmful limit. Such ventilation can take two forms, the extraction system with wall fans removing the contaminated workroom air, which is replaced by warmed fresh air, entering through suitably disposed openings in other parts of the room, or the plenum system in which clean, warmed and possibly humidified air is blown into the workroom under slight positive pressure through a ducting system, the air finding its way out via doors, windows or other openings. These methods of dealing with dust in workrooms, or a combination of them both, are of strictly limited application and are only successfully applied where the dust concentrations are generally disseminated in the workrooms. Even then, the use of general mechanical ventilation is often a confession of failure to provide what is more effective, namely, adequate localized exhaust ventilation.

Ducting resistance is an important item contributing to running costs, and proper application of the laws governing the flow of dust laden air in pipes will enable resistance to be reduced to a minimum by securing a symmetrical layout of adequate sectioned piping, fed by branch ducts at small angles in the direction of air flow and provided with gradual bends, tapered connections to fans, cleaning panels suitably sited, smooth joints and the like.

The type of fan used for dust exhaust systems is the paddle type, receiving the dusty air approximately radially and discharging it tangentially against resistances which may reach as high as 14 in. w.g. In many cases the fans are placed downstream from the air cleaning plant, which is thereby kept under suction, an advantage where filters are, against the best practice, sometimes located in workrooms. The fan itself also thereby handles practically clean air.

The main types of dust collecting apparatus are all based on physical principles and are summarized below in the approximate order of their ability to filter out the finest dust.

(*a*) *The Gravitational Settling Chamber*, in which the dusty air is introduced from ducting into a comparatively large chamber, with a correspondingly large fall in velocity. The dust particles settle out in the chamber under gravity if their time of passage through it is long enough. On account of the large size of the chamber necessary for efficiency, practicable size chambers will not separate out appreciable quantities of dust under 50 μ.

(*b*) *The Centrifugal Settling Chamber, or Cyclone*, which utilises centrifugal force to throw the dust out of suspension in the air stream, and is useful for dusts above 10 μ in size.

(*c*) *Inertial Separators*, in which dust is caught by being given a sudden change of direction by impingement on baffles in a chamber. They can be designed to catch dust efficiently down to 10 μ.

(*d*) *The Viscous Filter type*, in which the dusty air is sucked at high speed through a maze of oiled springs or steel wool and the like, the dust being caught through sticking to the oily surfaces. These filters will trap dust efficiently, down to about 3 μ, only if carefully maintained.

(*e*) *The Wet Scrubber Type Filter*, such as the wet coke bed filter, water and steam spray towers, and various patent filters utilizing fine water mists with or without wetting agents added to reduce the surface tension. Good filtration of particles down to 2 μ in diameter, and lower in the case of easily wetted particles, can be achieved.

(*f*) *The Bag Filter*, an excellent all round type of filter which will filter dust down to 0·5 μ with good efficiency.

(*g*) *The Electrostatic Precipitator*, which will filter out dust and fumes of the very finest sizes with high efficiency.

Other methods

Space does not allow of more than a brief reference to other methods. Considerable use, for instance, is made of the wetting of materials to prevent dust creation, but Watson (31) has pointed out that in certain cases this practice may be more dangerous than dry working. The substitution of enclosed mechanical methods for dusty hand work generally, as in the conveying, elevating, machine packing and weighing of dangerous dusty materials, is already a widely adopted form of protection, though there is considerable scope for its extension.

In some cases safe material may be substituted for dangerous dusty material, for example in the classic cases of the substitution of steel shot for sand in the operation of sandblasting iron castings, and of alumina for powdered flint in the process of china bedding in the pottery industry.

All dusty processes should, of course, be separated from other processes so as to limit the number of workers exposed to any particular dust risk. By what is called 'good housekeeping' a great deal can be done to protect workers from dust; for example by widely spacing dust producing machines, by storing dusty materials not in immediate use outside workrooms, and by keeping plant and workrooms as clean as possible, preferably with the aid of vacuum methods of cleaning. The periodical medical examination of workers now required statutorily in a number of dusty industries is of great value, whilst much may also be achieved by the education of workers in the risks they run, and in their personal responsibility for preventing and suppressing dust clouds.

A respirator of good design and with high filtering efficiency for low breathing resistance is useful as a secondary line of defence against dusty conditions, but is no substitute for other preventative measures such as have been outlined. Such a respirator, the Government approved Mark IV Dust Respirator (32), is now available.

Fire and explosion risks from industrial dusts

The extent to which protection is needed against the risk of fire and explosion from many industrial dusts under certain conditions is not generally realized, yet such dust fires and explosions frequently involve serious loss of life and injury to workers, and extensive damage to factory premises and plant. The accompanying photograph (Fig. 8) speaks for itself.

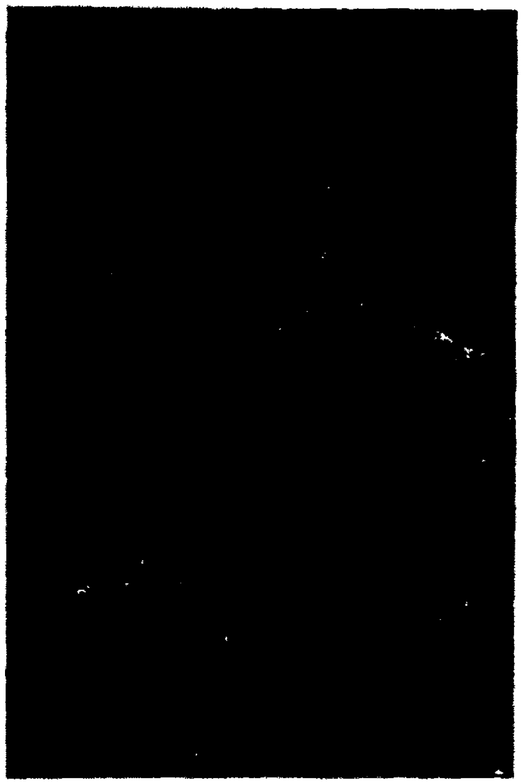

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Fig. 8. Wreck of a factory following on the ignition of a starch dust cloud. Eighteen workers were killed and many injured

Examples of dust liable to burn or explode under appropriate conditions are pulverized coal, sugar, dextrine, cocoa, various cereal dusts, cork, shoddy and rags, sulphur, wood flour, various resins and dyes and plastics, malt, tea, magnesium, and aluminium, to name but a few.

Oxygen readily combines with many substances, including carbonaceous materials and most metals, the reactions being usually exothermic. If the reaction is fast enough, incandescence results, leading to fire. If the reactions are exceptionally fast, the volumes of the products of reaction may, due to the heat generated, increase very rapidly with the correspondingly rapid pressure rise which we refer to as explosion.

Oxidation of combustible material is a surface phenomenon and so is most rapid and capable of causing explosion with material in the finely divided state, i.e. with dusts, and particularly when these are in suspension in air as dust clouds. The increase of surface area with decrease in constituent particle size, for a given weight of dust, is striking. Thus Berger (33), on the basis of certain assumptions, shows that the surface of a cube of aluminium weighing 1 gram is approximately 3 sq. cm., whereas if the cube is comminuted until the thickness of the resulting lamellae is 20μ (coarse stamped powder) the surface increases to 429 sq. cm. If the process is continued until the thickness of the lamellae is reduced to 0·6μ (fine stamped powder), the surface of the 1 gram of metal becomes 14,290 sq. cm., while for the finest powder (prepared industrially in large quantities) with lamellar thickness 0·3μ, the surface of a gram becomes 28,570 sq. cm. The increase in intensity of explosion of dust clouds with decrease in constituent particle size is also of interest in this connexion. Gliwitzky (34) obtained the following figures from experimental explosions of three types of commercial aluminium pigment powder in a bomb of 53,000 c.c. capacity, for two powder concentrations.

Particle size μ	Duration of explosion (sec.) for 700 mg./l.	Explosion pressure (atm.) 700 mg./l.	Explosion pressure (atm.) 580 mg./l.
1·2	0·06	7·7	7·7
0·6	0·03	8·6	9·2
0·3	0·012	10·6	11·6

It will be seen how the velocity and pressure of the explosion increase with increase in the powder fineness until the maximum pressure of all was recorded, 11·6 atmospheres for a powder concentration of 580 mg./l. This pressure is higher than the maximum pressures recorded for the explosion of gas/air mixtures, including the hydrogen/oxygen mixture with which 9·7 atmospheres has been obtained. Pressures up to 18 atmospheres have been recorded (35) for coal dust and flour explosions at certain concentrations and finenesses. Much greater values still have been measured for starch dust. The dangerous potentialities of the finely divided carbonaceous and metallic dusts for fire and explosion are manifest, since factory buildings, unlike mines, are not capable of withstanding such high pressures and rates of pressure rise. For each combustible material there is an upper and a lower limit of concentration and beyond these limits the material will not burn. Within these limits there is also a minimum temperature or 'ignition temperature', below which the material will not ignite. Safety measures against dust cloud fires and explosions therefore aim fundamentally at keeping concentrations outside (and in practice usually below) the inflammable concentration limits, and avoiding sources of ignition; and if this should not be successfully achieved and a fire or explosion should result, one should aim at so designing the plant concerned and arranging the manner of working the process that there is a minimum of damage to workers and plant.

To describe how these aims can be achieved in connexion with grinding mills, disintegrators, grinding wheels, mixing machines, elevators, conveyors, cyclones and other dust collecting apparatus, storage hoppers, and other plant in which dust clouds may occur would need a separate article, and those interested are referred to other publications (33, 35, 36, 37, 38), which deal with the design, location and construction of grinding and associated plant and buildings, methods of grinding dust in inert gases, the design and provision of bursting disks (39) and other explosion reliefs on appropriate parts of dust plant, the provision of rotary valves and other flame arresting devices, fire precautions, the use of magnetic separators, and methods of avoiding sources of ignition, including electrical sources.

It is of interest, in connexion with sources of ignition, to mention that electrostatic charges are known to be formed when powder issues from nozzles, or is blown into a dust cloud, or rubs frictionally against machine surfaces (40). Belts running over pulleys also accumulate charges. Discharges of such accumulations may ignite dust clouds, and although very little is known about this danger, it needs to be taken into account. Safety measures take the form of keeping the air as humid as possible, or in special cases ionized, using electrically conducting belting or suitably earthed collectors, and of bonding all plant to earth to prevent accumulation of charges. It has also been claimed by Wolf (41) that where aluminium foil or powder is produced it can be ignited not only by fire and sparks but also by the effect of light.

In the case of grinding particularly dangerous dusts, such as magnesium, the only safe practice is to prevent any worker being in the mill room whilst grinding is in progress, to which end the grinding mill door should be so interlocked with the electrical control to the grinding mill motor, that unless the door is shut the grinding plant cannot be set in motion, and the door cannot be opened until the current has been switched off and the mill has come to rest.

Above all there needs to be emphasized the vital need for so enclosing, working, and constructing dust grinding and associated plant that large dust accumulations outside such plant on walls, floors, ledges and beams are avoided. Otherwise a primary explosion in the plant (itself perhaps of small intensity) may raise a dust cloud outside the plant, ignite it, and so propagate a disastrous secondary explosion throughout a large area of a factory.

Many of the above methods of protection against inflammable or explosive dusts are statutory requirements under special sections of the Factories Act or under the Electricity Regulations (42), and the physical principles underlying most of them will be self-evident. There is as yet no approach to finality in the design of safeguards and protective measures, since much has yet to be learned concerning dust explosions. Dusts hitherto unsuspected occasionally prove to be explosive under certain conditions. The explosive limits and ignition temperatures of many dusts are not yet known or are not known with certainty; little is known about the best methods of removing 'static' from dust clouds, about the danger of ignition of dust clouds by sparks caused in various ways, about flame arrestors, or about the best methods of safely relieving explosion pressures in long elevator casings or in cyclones. It would be very useful to know the pressure and rate of rise of pressure which develop when the dusts in question explode under various conditions and in varying concentrations and grades of fineness. The physical and chemical mechanism by which dust clouds of various types inflame and explode is also obscure, and methods of inhibiting fires and explosions might well follow from greater knowledge in this sphere. In the investigation of such problems as these and in the furthering of preventive and control measures necessary for the elimination of the health hazards, physicists must play a large and ever increasing part.

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Note on the Preparation and Properties of Metal-coated Mica Condensers.

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ABSTRACT. In this note, the production of stable thin metallic films of low resistance is described, and alternative techniques of cathode sputtering and evaporation considered. Using such films as electrodes, mica dielectric condensers have been prepared with capacitance stabilities of the order one part in one thousand over a period of weeks. This estimate is conservative, as the circuit used for measurement had a stability of the same order. The experimental condensers had power factors between 2 and 5×10^{-4} at 500 kcyc./sec.

Differences between condensers prepared by sputtering or evaporation were negligible.

INTRODUCTION

THE need for stable low loss condensers has, in recent years, become more urgent on account of the improved tuned circuits required for high-frequency electrical apparatus. In many cases it is important to reduce the size of condensers, for a given capacitance, as far as possible, and mica is often used as a dielectric in preference to air.

There are several possible methods of depositing metallic films on mica, viz. (i) by cathode sputtering, (ii) by condensation in vacuo, (iii) by spraying, (iv) by chemical precipitation, and (v) by deposition from colloidal solutions. In this note only the first two methods will be described. Condensers so made have been known for some years, but, so far as the author knows, no details of preparation have been published.

FILMS MADE BY SPUTTERING

The theory of this process is still obscure† and only the experimental procedure will therefore be described. As stable films with high electrical conductivity are required for condenser electrodes, silver and possibly copper appear to be the most suitable metals to be used.

Preliminary experiments with a bell jar (25 cm. × 17 cm. internal diameter) and a 5 cm. square silver

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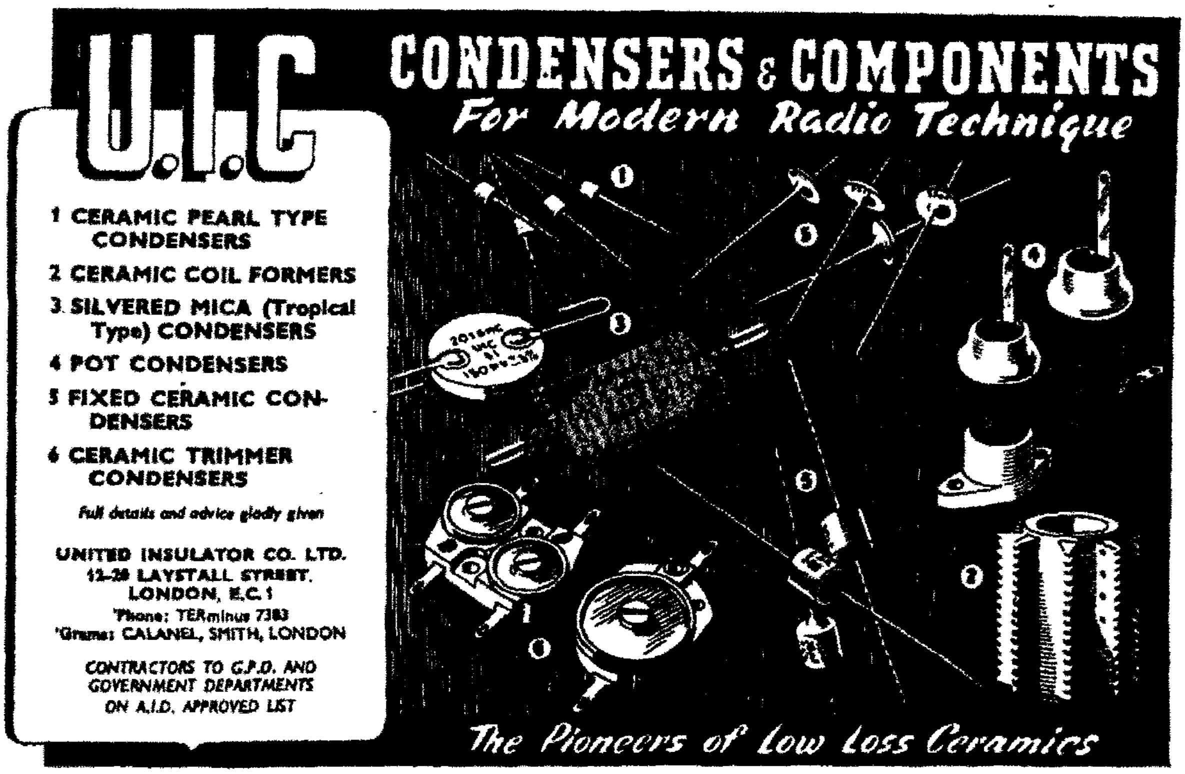
† Langmuir and Kingdon, *Phys. Rev.* **22**, pp. 148, 357 (1923); von Hippel, *Ann. Phys., Lpz.* **80**, p. 672 (1926); *ibid.* **86**, p. 1006 (1928); Cartwright, *Rev. Sci. Instr.* **1**, p. 758 (1930).



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