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# Control of Environmental Industrial Hazards

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THE HEALTH hazards in industry which, if uncontrolled, may cause occupational illnesses and discomfort, are many and varied. The more common ones may be divided conveniently into seven groups as follows: (1) Atmospheric contaminants (dusts, fumes, mists, gases, vapors and smokes); (2) Heat, cold, high humidity and rapid temperature changes; (3) Radiant energy other than heat; (4) Faulty illumination; (5) Noise; (6) Unsanitary conditions; (7) Fatigue.

All of these factors are capable of control by sound engineering to such degree as to render them innocuous to the industrial worker. It follows then that engineering is the first line of defense in the control of ill health and discomfort of industrial workers.

Fortunately for the engineering profession, the human being is a miraculous organism and can stand considerable mistreatment without showing illness or even discomfort. For this reason, noise, radiant energy, atmospheric contaminants, fatigue, etc., need not be completely eliminated, they need merely to be controlled within certain limits. These limits have been fairly well defined for most of the factors included in the foregoing list, and serve as bench marks for the engineers.

Of the groups listed in the first paragraph, the atmospheric contaminant group is the most important one. Because of its importance and the keen interest taken by labor and management, the engineering control of industrial atmospheric sanitation will be discussed in detail. No further reference will be made to the other health hazards, not because they are unimportant, but because of time limitations.

## Engineering Control of Atmospheric Contaminants

THE OBJECTIVE in controlling dusts, fumes, mists, smokes, gases and vapors is to prevent the amount in the air breathed by the workers from exceeding safe limits commonly called maximal allowable concentrations. They are not truly maximal allowable concentrations, but are the amounts which all but the unusually susceptible workers can endure day in and day out without producing significant effects on their well-being. These concentrations vary from material to material, some being relatively harmful and others being almost innocuous. Knowledge of the safe limits of the materials in question and how the amounts in the air can be measured is important to the engineer in addition to ways and means of reducing the concentrations.

Engineering measures for preventing the inhalation of excessively contaminated air have been discussed by many authors, and there are about as many different classifications of these methods as there are papers on the subject. The principles expounded, however, are always essentially the same. They may be divided conveniently into three main groups as follows, depending upon the avenue of approach:

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1. Eliminating the sources of contamination or reducing the amount: (a) Design, alteration, and maintenance of buildings and equipment; (b) Substitution of less toxic materials; (c) Process or operation changes; (d) Housekeeping.

2. Prevention of contaminant dispersion: (a) Segregation of hazardous processes; (b) Enclosing the hazardous processes; (c) Wet methods; (d) Local exhaust ventilation; (e) Equipment maintenance; (f) Worker education; (g) Housekeeping.

3. Protecting the worker: (a) Equipment alteration; (b) General ventilation; (c) Respirators; (d) Worker education.

The control of an atmospheric health hazard is rarely accomplished by a single measure; it usually involves the use of a combination of methods.

### Eliminating the Source of Contamination

OBVIOUSLY, the most successful approach to the problem of industrial atmospheric sanitation lies in *the design or alteration of plant and equipment* so that the control features are engineered into the structure and machinery. Factories constructed without due consideration to keeping the air clean, and existing plants, preclude the most efficient use of engineering-control knowledge. Much control equipment, installed on "unprepared" machinery even if carefully planned, is makeshift at best and has all the features of the proverbial "sore thumb."

Probably the most important single avenue to better atmospheric sanitation lies in the education of manufacturers of industrial equipment and machinery so that at least the basic elements of control equipment are included as an integral part of each machine which is known to produce or disperse dusts, fumes, smokes, mists, gases, or vapors. Some action in this connection is in progress, but the surface is only being scratched. Some new plants are being laid out with the atmospheric-sanitation problem in mind. Also a few industries which are undertaking industrial hygiene on a long-term basis are slowly mechanizing and modernizing their existing plants to increase production, eliminate arduous labor, and reduce atmospheric pollution. Fully as important as the original design of any piece of equipment is its maintenance. Deterioration, wear, corrosion, abrasion, and shock result in inefficient operation unless maintenance is good. In the smaller industry, maintenance is too frequently left to the user of the equipment. This is not a satisfactory procedure. All maintenance work should be made the responsibility of one man or one department.

A very effective method of control is *the substitution of nontoxic for toxic materials.* The application of this method is very limited in scope because of the basic requirements on which materials are usually selected. It should, however, always receive due consideration since it is both effective and usually inexpensive. Yet, for this very reason, the engineer or chemist must guard against overdoing substitution. It is generally agreed that any material, be it ever so harmful, can be handled safely if properly engineered. This feeling has been verified in practice by the experience of the atomic-bomb plants and the military explosives manufacturing and loading plants.

As substitution of less-toxic materials frequently runs counter to quality control in production it must be recommended with caution, particularly since other methods are available for the adequate control of hazards. Examples of successful substitution of less-toxic materials are the replacement of steel grit for sand in abrasive blasting; artificial abrasive grinding and polishing wheels for sandstone wheels; nonsilica parting compounds for siliceous compounds in foundries; petroleum naphtha or toluol for benzol in the lacquer, ink, and rubber cement industries; Stoddard solvent for carbon tetrachloride, in dry cleaning (special equipment is usually required to comply with fire regulations); quartz-free or low-quartz minerals for sand under mine locomotives; and relatively insoluble lead compounds for lead oxide in paints and ceramic glazes.

*A change in the process* can sometimes be used to eliminate or control a health hazard. Such change frequently involves major changes in other parts of the production line, and this control measure is therefore very limited in scope. Examples are controlling the temperature and speed of chemical reactions so that the rate of mist, gas, or vapor production is decreased; welding, crimping, riveting, or otherwise

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More can be done by *good housekeeping* to eliminate sources of contamination, particularly dusts and fumes, than is commonly realized. In dusty industries or workrooms where dust is continuously settling on all surfaces which approach the horizontal, and collecting on vertical surfaces, good housekeeping in the form of vacuum cleaning, wet washing, and sometimes brushing prevents the material from being redispersed into the air.

The amount of dustiness which is contributed to the air of dusty industries by the continual redissemination of the settled material is sometimes more than 50% of the total dust concentration. Yet this dust can be prevented from getting into the air very readily by constant cleaning. Painting the walls a light color, improving the illumination, and oiling or wetting the floors are effective in promoting good housekeeping. While good housekeeping alone is seldom sufficient to control existing hazards, experience has shown that the housekeeping in most plants is a good index of the industrial hygiene program.

### Prevention of Contaminant Dispersion

MANY INDUSTRIES have operations which produce considerable atmospheric contamination but which require the immediate attention of only a relatively small number of workers. If located indiscriminately throughout the plant or if conducted at certain times, such operations may expose many other workers to a needless amount of atmospheric contamination. By *segregating or isolating these operations*, only those few workers engaged there will be exposed to the hazard, and they may be protected by means of respirators. Also the segregation or bunching of hazardous operations aids materially in the effective application of local exhaust ventilation or other control measures.

The usefulness of this measure is so obvious that examples are scarcely needed. Blasting in mines at the end of the shift so that the gases and dusts will have settled or dissipated by the time the workers return, sweeping and cleaning at night when other workers are not on the job, shaking out foundry castings at night when most workers are off the job, and locating the plating or degreasing tanks in separate rooms are common examples.

*Enclosing an operation* might be considered an extreme form of isolation. The contaminant or contaminated air is prevented from reaching the breathing zone of any workers except in rare instances when one or two men may be exposed within the enclosure. It is superior to segregation or isolation since it acts nearer the source of contamination. In one instance the simple expedient of attaching a loose cover for the containers being filled to the end of a canvas discharge chute from a gyratory screen reduced the dust concentration in the screen room by well over 50%. In another instance a toxic and highly explosive material was transferred from 50 pound to five pound containers in a complete enclosure. The large cans were mounted on a frame in the top of a home-made enclosing device, and after closing the door the contents were dropped into a hopper by rotating the handle. Measured quantities were then dropped into small cans through a dust-tight corrugated hose. Two slide gates served to close and open the top and bottom of the measuring device. Hence by closing the lower gate and opening the upper one the material from the hopper filled the section between the slides which served as the measuring device. By closing the upper slide and opening the lower one the measured quantity of material was charged into the small container. This arrangement reduced the atmospheric concentration of the toxic material from a harmful level to almost nothing.

Process enclosure has been found particularly successful at abrasive-blasting operations, such as barrel and cabinet types of equipment which operate on the batch basis. The equipment is closed tight during the cleaning operation and is open only for charging and discharging after the abrasive blasting has been discontinued. This method of control does not find wide application except in conjunction with local exhaust ventilation which will be discussed later.

*Wetting dust* with water or other liquids is probably the oldest method of control. It was practiced in the pottery industry in Great Britain as early as 1713. Wet drilling and water sprays have been widely employed in mining operations in recent years. The use of water sprays in quarrying operations also has been reported recently. Substantial reductions in the dust concentration have been reported as wet-grinding operations, and as wet-drilling operations in mining, but even then the atmospheric concentrations were still greatly in excess of the maximal allowable concentration.

The effectiveness of wet methods for dust control depends upon two factors—wetting the dust, and proper disposal of the wetted dust. Some dusts are hard to wet and unless wetted will not be captured. Even if the dust is wetted satisfactorily, it is necessary to collect and dispose of the wetted material before the liquid evaporates and the dust is again redispersed by air currents, walking, or blasting. In certain mines, for example, the dust from the wet-drilling operations settles out as the water flows away, and collects also as water droplets on the walls from where it is readily redispersed. Even though wetting of the dust must be recommended with discretion, it has been found an effective dust control aid in rock drilling, blasting, crushing, screening, materials transfer, foundry shakeout, core knockout, and abrasive blasting, and the addition of moisture to molding sand decreases greatly any amount of dust produced while making molds.

*Local exhaust ventilation* is probably the most important single method of preventing industrial atmospheric pollution. Yet the principles involved and the bases for adequate design are so poorly understood that a large percentage of the installations made in recent years are unsatisfactory or inefficient. The design of good local exhaust systems is a specialty requiring knowledge not normally possessed by any engineering group including ventilating engineers, unless they have received special training in this field. This is neither the time nor the place, however, to discuss the details of this most important subject; they have been covered adequately elsewhere.[1,2,3] Suffice it to mention briefly the method of operation and to cite a few examples of operations at which local exhaust systems are used.

Local exhaust systems function by removing the contaminant or grossly contaminated air as close as practicable to the point where it is released or generated. This is done by producing air currents in the area of contaminant escape of such direction and magnitude as to carry the highly contaminated air into the exhaust hood which is located as close as possible to, or around, the source of contamination. The more nearly the hood encloses the source of contamination, or the closer it can be located to the source of contamination, the smaller will be the required exhaust rate to capture the contaminant effectively. Hood shape and location are of the utmost importance and deserve considerable study and head-scratching on the part of the designer. In addition to the hood, a local exhaust system includes piping or ductwork, an exhauster (usually a centrifugal fan), and usually a collector. The contaminated air is moved through the piping to the collector and the filtered air is then discharged to the outside of the exhauster. The design of the hood and piping, and the selection of collectors and exhausters are complete studies in themselves and will not be covered here.

Examples of the satisfactory use of local exhaust systems are numerous. Some are welding; granite surfacing; pickling and plating tanks; wood working equipment; grinders; buffers and polishers; and spray painting booths.

Like all other types of equipment, that are employed to control health hazards they require *constant checking and maintenance.* It should be included with other equipment in the cleaning and maintenance schedule. Dust collectors, fans and in many instances ductwork require periodic cleaning to obtain satisfactory operation. Bent hoods and leaky or damaged ductwork and enclosures should be repaired promptly. Blast gates and dampers, if used, should be locked in position, but even then they need constant watching to see that the setting is not altered by the workers and that the balance of the system is not thereby disturbed. Only too frequently management invests substantial capital in good control equipment and then, either through complacency or lack of understanding proceeds to forget all about it until faced with a case or epidemic of occupational illnesses. The answer, and the only way to protect their investment, is periodic checking and maintenance just as is done with production equipment.

Very few if any measures or installations for the control of atmospheric pollution are

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sponsibility it is to select them and supervise their use and care. Each and everyone assigned this responsibility should study some of the literature on this subject.[1,6,7,8] Examples of places where respirators may be used satisfactorily are spray painting; abrasive blasting; cutting metal coated with lead paints by means of oxyacetylene torches; welding; handling dusty materials; clean-out operations; shaking out operations in foundries; and housekeeping or other cleaning and sweeping.

The *education of the worker* for his protection is fully as important as to prevent the creation of unnecessary dust, fumes, mist, gases, or vapors. He must be told which contaminants are harmful and sold on the idea of avoiding the higher concentrations. Careful and continuous education is necessary to get workers in the habit of standing upwind of all operations which produce or release considerable material, such as spray painting, welding, cleanout and other maintenance operations, and handling bulk materials; also to keep his face as far from the point of operation as possible, or out of the line of throw or movement of the contaminant.

## Examples of Results Obtained

IN CONCLUSION, I should like to cite one or two examples of the results achieved in decreasing occupational diseases through engineering. After all, "the proof of the pudding is in the eating."

In the gold mines of South Africa, dust concentrations averaged about 150 mg/m$^3$ before a program of control was begun and the reported incidence of miners phthisis was about 30%. About seven years after the dust control program was started the atmospheric dust level had been reduced to about 5 mg/m$^3$. The incidence of miners phthisis began falling about nine years after the dust control program was started and reached a level of about 2% approximately seven years after the dust level had been reduced to 5 mg/m$^3$. In this instance, the incidence of illness had been reduced from about 30% to 2% by reducing the atmospheric dust content from 150 mg/m$^3$ to 5 mg/m$^3$.[9]

An effective industrial hygiene program was launched in the government-owned explosives manufacturing and loading plants late in 1942—about one year after Pearl Harbor. The atmospheric concentrations of TNT were on the ascent at that time and continued to increase until about April, 1943 when they began to decline, the decline continuing until the close of the war. Periodic medical reports from these plants show that the incidence of lost-time cases because of TNT poisoning, of mild TNT poisoning cases, and of medical transfer from TNT exposure paralleled the atmospheric dust and fume levels very closely. The figures in this instance are somewhat as follows.

The peak concentration of TNT was about 2.7 mg/m$^3$ in April 1943 and the peak incidence of lost-time, mild, and medical transfer cases was about 21, 640, and 450, respectively, in terms of cases per thousand man years of exposed employees. The peaks of the cases occurred about July, 1943. By the end of 1944 the average atmospheric TNT concentration had been reduced to about 1.0 mg/m$^3$ and the corresponding incidence of TNT cases was 1, 80, and 85.[10] Engineering measures alone, of course, were not responsible for this entire reduction. The personal hygiene program, and the periodic medical examinations contributed substantially.

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foolproof. Much depends on the attitude of the worker. A cooperative, interested, and well-trained worker can accomplish much with any control equipment, whereas the indifferent, lackadaisical, untrained worker produces the maximal amount of atmospheric contamination with any control device.

The solution lies in the *education of the worker*. This is an unending task and becomes very discouraging if labor turnover is high. Nevertheless it is the key to the really successful operation of atmospheric sanitation equipment. As a rule the labor turnover will be much less if the working conditions are good. Therefore, proper education of the worker is the first step in a chain of events which lead to a satisfactory educational program. To be successful the education of the worker must begin the day he is employed. If he is permitted to begin his work without proper instruction in the performance of his tasks he will form faulty habits of operation which require much effort to undo. On the other hand the educational program must not cease as soon as the worker has been trained in the correct procedure of doing his job. It must be continued throughout his period of employment to keep him on his toes and to prevent him from falling into a faulty routine. Examples of what can be accomplished in atmospheric sanitation by worker education are unnecessary—they are quite obvious. Any operation (whether it be provided with control equipment or not) which produces or releases an atmospheric contaminant can be done, and should be done, in a manner which results in the escape of as little material as possible into the workroom air.

*Good housekeeping* will serve to prevent the dispersion of atmospheric contaminants. However, it is considerably more important in eliminating sources of contamination as was discussed previously in that connection.

### Protecting the Worker

MOST INDUSTRIAL machinery or equipment which produces or releases harmful contaminants can be *engineered either in the original design or by alteration of existing installations* to decrease the worker's exposure. In many instances, however, the reduction of exposure is not sufficient to eliminate the hazard, and other control measures are needed. Yet there are some operations where the principle may be applied to render the worker's exposure harmless. Examples are the use of mirrors and/or extensions on operating handles to permit the worker to stand clear of the escaping contaminant; arranging all hot processes so that the operator stands beside rather than above the process; and locating a fan diagonally to the rear and to the side of the worker to blow the relatively clean workroom air through his breathing zone and to carry the highly concentrated contaminant from the operation he is doing away from him, or locating the terminal of a supply duct between the operator and the source of contamination to blow the contaminated air away.

*General ventilation* is second in importance only to local exhaust ventilation. It is particularly well adapted to certain contaminants and to certain sources of contamination but is unsatisfactory for others. Unlike local exhaust ventilation, it does not prevent the contaminant from escaping into the general workroom air, it merely dilutes the contaminated air of a given room or building with sufficient clean air to keep the concentration of contaminant in the room air from building up to a harmful level. Like local exhaust ventilation, general ventilation is misused a great deal by people who do not understand the fundamental principles of contaminant control. Major sources of contamination, especially if near to workers, cannot be controlled effectively by general ventilation; the dilution rate required to effect a safe concentration in the workers' breathing zones is so great as to be prohibitive. Minor and scattered sources of relatively harmless contaminants, on the other hand, may be controlled effectively and economically by general ventilation.

The subject of atmospheric sanitation through general ventilation is a very large and complex one. For further information on it, the reader is referred to treatises on the subject of which there are many.[1,4,5]

*Respiratory protective devices* have a distinct place in the field of occupational disease control. That they are a last line of defense can hardly be denied. Nevertheless, where they should be used, how they should be selected, and how they should be used and maintained is not understood adequately by some of the people whose re-