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Uses and Limitations of RESPIRATORY Protective EQUIPMENT

By PHILIP DRINKER

SCHOOL OF PUBLIC HEALTH, HARVARD UNIVERSITY, BOSTON, MASS.

PREVENTION of dust inhalation by the wearing of cloths, handkerchiefs, and the like over the nose and mouth was practiced in Agricola's time. Such devices, crude as they were, reduced the discomforts of breathing smoky or dusty air. Although the medieval metallurgists lacked our chemical and medical names for their respiratory hazards, they understood the physiologic effects of carbon monoxide, and Agricola's remarks about silicosis among the Carpathian miners showed that this disease was well known.

The invention of the diving suit by Siebe early in the nineteenth century demonstrated that it was perfectly practicable for a man to breathe air blown to him through a hose connected to a blower some distance away. The modern hose mask and the simpler air-line respirators remind one of Siebe's original equipment.

It was not until the close of the World War, however, that industry in general began to appreciate the industrial possibilities of gas masks, dust respirators, and other respiratory protective equipment. In 1911 the U. S. Bureau of Mines began issuing literature on oxygen-breathing apparatus, but it was not until 1919 that the systematic development of modern respiratory protective equipment began.

A respirator is a device for rendering inhaled air respirable. In recent years the word has been applied especially to devices for protection against dust inhalation, but the broader use of the term is preferable. Brown (1)[1] has suggested the following classification of respirators:

- I Supplied-air respirators
  - A Self-contained type
    - 1 Oxygen breathing apparatus
  - B Hose type
    - 1 Hose mask
    - 2 Air-line respirator
    - 3 Abrasive-blasting respirator
- II Air-purifying respirators
  - A Chemical-filter respirator
    - 1 Acid-gas, or type A
    - 2 Organic-vapor, or type B
    - 3 Ammonia, or type C
    - 4 Carbon monoxide, or type D
    - 5 Combinations of 1, 2, 3, and 4
  - B Mechanical-filter respirator
    - 1 Dust, or type A
    - 2 Fume, or type B
    - 3 Mist, or type C
    - 4 Combinations of 1, 2, and 3
  - C Chemical- and mechanical-filter respirator
    - 1 All combinations of A and B above (Group II)

GENERAL REQUIREMENTS

There are several important considerations applicable to all respiratory protective equipment: First, the device must not offer an annoying resistance either to inspiration or expiration; secondly, it must afford a definite degree of protection under well-defined conditions; thirdly, it must be reasonably comfortable, it must not interfere unduly with vision, and it must not be too heavy—all of these items being subject to certain latitude.

The amount of air breathed and the oxygen consumed by the average healthy 150-lb man is given in Table 1.

TABLE 1 AIR BREATHED AND OXYGEN CONSUMED

(After Henderson and Haggard)

	Oxygen consumption, liters per min	Air breathed, liters per min
Rest in bed, fasting	0.240	6
Sitting	0.300	7
Standing	0.360	8
Walking, 2 mph	0.650	14
Walking, 4 mph	1.200	26
Slow run	2.000	43
Maximum exertion	3 to 4	65–100

It was decided in the gas-mask studies carried out during the War that 85 liters per minute represented the maximum amount of air likely to pass through a mask at either inspiration or expiration. Of course no one but the exceptional person, such as a long-distance runner, breathes at 85 lpm for more than a few moments, but half that rate, or 42.5 lpm, is not unusual. Since one inspires approximately one-half the time and expires the other half, the actual minute volume breathed should be doubled,[2] hence the figure of 85 lpm; and it is this figure which is commonly used in measuring resistance. Measurement is made with the aid of simple set-up illustrated in Fig. 1 precisely as one measures pressure differences in air ducts or in chimneys. The muscles which raise and lower the chest in respiration are not strong and easily become tired if overworked. Any serious impediment to inspiration is fatiguing and causes a building up of excessive carbon dioxide in the blood, a desire to breathe rapidly, and a degree of discomfort which quickly may become so distressing as to

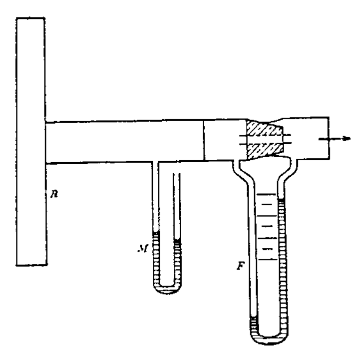

FIG. 1 ARRANGEMENT FOR TESTING THE RESISTANCE TO AIR FLOW OF VARIOUS FORMS OF RESPIRATORS

(R = respirator, M = water manometer, F = flow meter with capacity of 85 liters per minute.)

[1] Numbers in parentheses refer to similarly numbered items in the bibliography at the end of this paper.

Contributed by the Safety Committee and presented at a session on Occupational Diseases at the Annual Meeting, New York, N. Y., Dec. 2–6, 1935, of The American Society of Mechanical Engineers.

[2] Actually the respiratory cycle is usually irregular, but for mask testing it is permissible to consider it symmetrical and to ignore the pause at full inspiration or expiration.

FIG. 2 HALF-HOUR OXYGEN-BREATHING APPARATUS—APPROVED BY THE BUREAU OF MINES (2)
(Courtesy Mine Safety Appliances, Pittsburgh, Pa.)

cause the inexperienced wearer of a mask to take it off. It is not difficult to train oneself to breathe against rather high resistances but this training requires the incentive of extreme hazards or the discipline possible in war. It is not a practical peace-time expedient and should not be necessary. For gas masks the Bureau of Mines now allows an inspiratory resistance of 3.5 in. and 1.5 in. to expiration at 85 lpm. In dust respirators the Bureau's schedule permits maximum resistance of 2 in. to inspiration and 1 in. to expiration, all tests being made at the completion of filtering-efficiency tests and not simply when the device is new. These resistances should be lowered from time to time as general improvements in industrial respirators warrant more severe specifications, for it will be found that even 2-in. resistance at 85 lpm is unpleasant for long periods.

Oxygen-Breathing Apparatus. After a fire or explosion such as occurs in mines, rescue work must be quick, and the rescuers must enter atmospheres of unknown composition. Often an added difficulty is dense smoke through which the visibility is poor. Rarely is there any chance for the use of hose-type equipment. In spite of such obstacles there are numerous records of rescues made by men wearing self-contained apparatus for which the wearer carried his own oxygen supply.

A modern oxygen-breathing outfit is shown in Fig. 2. Oxygen is carried in a small steel bottle which leads through a special reducing valve to the breathing bag and then to the face piece. Since an average man engaged in fairly heavy exercise needs 2 to 3 liters of oxygen per minute, the exhaled air of the wearer of oxygen-breathing apparatus must be purified and re-used. Otherwise the man would be able to carry only a few minutes' oxygen supply.

The regenerating and purifying device consists essentially of a container or cartridge of a suitable carbon-dioxide absorber such as soda lime (Na_2OCaO). The oxygen consumed is then made up by the addition of oxygen from the breathing tank.

At altitudes in excess of about 15,000 ft experienced airplane pilots use oxygen-breathing equipment varying from a simple arrangement for giving the pilot an occasional breath of oxygen to complete equipment which must be worn continually. At sea-level pressures, there is no limit to the gas concentration against which an oxygen-breathing equipment protects, although it obviously cannot protect the wearer against gases, like hydrocyanic acid, which are absorbed through the skin.

Hose Mask. In Fig. 3 is shown a hose mask with the wearer carrying out a task for which the device is particularly suited. Here the air hose must be strong enough to be used as a life line in emergencies, must be impermeable to oils, gasoline, and water, and must not collapse under heavy weight. Air is supplied by a hand-operated blower.

As in the case of oxygen-breathing apparatus, there is no limit to the atmospheres in which hose masks give safe protection, saving possible harm through skin absorption. The hose must be of sufficient diameter to let the wearer breathe in case the operator of the pump should have to stop for a short interval. It is found that a safe minimum hose diameter is $^7/_8$ in. It is impracticable to pump air by hand through long lengths of hose and difficult to breathe through more than 150 ft should the air supply be cut off. Therefore, the device is definitely limited to use in places where the blower can be placed within 150 ft of the wearer.

The Bureau of Mines requires that the exhalation valve on the face piece shall not have a resistance at 85 lpm of more than 1.5 in. Because of the danger of the hand-driven blower's stopping occasionally, the inspiratory resistance through the blower, the hose, and face piece should not exceed 2.5 in.

It has been found safe for men to enter empty tank cars, shallow manholes, and the like with hose masks without blowers. The wearer then breathes through a gas-proof hose and is safe as long as the inspiratory resistance of the hose is low and the inlet of the hose remains in clean air. Such an arrangement does not dispense with the need of a strong hose which can serve as a life line in the event of some mishap to the wearer

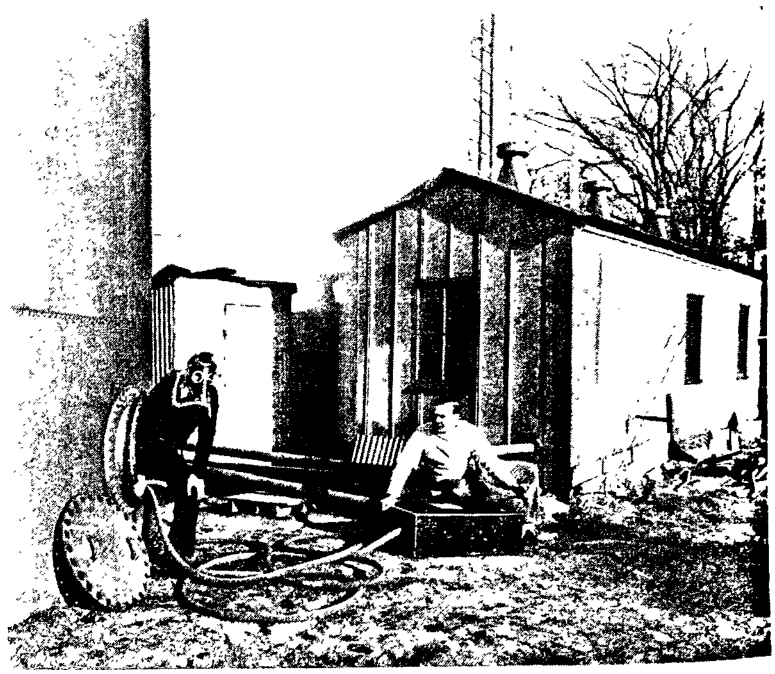

FIG. 3 HOSE-MASK EQUIPMENT—APPROVED BY BUREAU OF MINES (3)
(Courtesy Davis Emergency Equipment Company, Inc., New York, N. Y.)

of the mask, nor should it dispense with an observer outside the zone of danger.

Air-Line Respirators. The positive-pressure respirator, Fig. 4, worn in such jobs as paint spraying, is an outgrowth or simplification of the hose mask. It is adapted to all work in which there is no severe hazard to the wearer should he remove the device momentarily. That is, it should not be used in dangerous atmospheres to which the hose mask or the oxygen-breathing apparatus is especially suited. Air-line respirators are much less expensive than hose masks, the air line may be of small-bore compressed-air hose, and no life line is needed. If the air supply is cut off, the wearer simply removes his mask and moves out of the polluted air.

In general, air-line respirators can be worn for long periods, as they are light and there is little discomfort to the wearer. As yet there are no specifications for these respirators, but their effectiveness can be judged satisfactorily by requiring the wearer to spray an emulsion of black pigment in water, and after some 15 or 20 minutes' typical spraying work, comparing his nasal discharge and sputum with specimens taken before spraying.

Abrasive-Blasting Respirators. One of the severest dust hazards is abrasive blasting of sandy castings with sand as the abrasive cleaner. Of less danger is blasting with steel shot, but neither process should be permitted unless the blaster wears a respirator of the general type shown in Fig. 5. The device must protect the workman against flying particles and should be supplied with air at sufficient pressure and volume to insure a slight but constant positive pressure at the nose and mouth.

FIG. 4 AIR-LINE RESPIRATOR
(Courtesy Willson Products, Inc., Reading, Pa.)

Unfortunately, abrasive blasters are often the least intelligent workmen in the plant. It is not at all uncommon to see the blaster finish a job, open the doors of the blasting chamber, take off his helmet and then blow the loose material off the castings, thus making it certain that he will breathe dust he should avoid and that his helmet and his own head are well bathed in dust. Obviously, he will breath this dust when he puts on his helmet again.

FIG. 5 ABRASIVE-BLASTING RESPIRATOR
(Courtesy W. W. Sly Manufacturing Company, Cleveland, Ohio.)

Respirators suitable for this work can be made in various forms. The essential specification is that the wearer receives air substantially as clean as that from the compressed-air line. Tests demonstrating this fact should be made under practical blasting conditions—tests such as that suggested for air-line respirators are quick and will eliminate many poor abrasive-blasting respirators, but final acceptance of a blasting respirator should rest upon a practical demonstration in which the air within the device is sampled and compared with that from the air line.

It was suggested by Bloomfield and Greenburg (4) that air flows of at least 6 cfm per helmet were required but it is now recognized generally that less than 6 cfm often suffices. However, in estimating air flows to be supplied to blasting respirators at least 6 cfm per man should be allowed. No harm results from using too much air within the helmet while too little may result in negative pressures during inspiration. One can notice momentary pressure drops by the sensation on the ear drums, and the wearer should be taught to turn on enough air so that he can not notice this change even on taking a deep breath.

Air Purifiers. In most mines and in most dusty plants compressed air is available, but is apt to be wet and smell objectionably of oil. Also it may be unpleasantly cold when expanded directly into a respirator.

It is not difficult to clean, dry, and warm compressed air so that it is suitable for breathing. Various expedients can be adopted, one of which is shown in Fig. 6.

Plants having no compressed air would do well either to install compressors in which the intake air has no contact with oil or else to use a rotary compressor capable of delivering air at a pressure of 10 to 20 lb per sq in. Obviously, the air supplied should be free from harmful dusts. Accidents in which the intake of oil-lubricated compressors has been contaminated with the exhaust gas from gasoline-driven motors or in which some of the lubricating oil has been converted into carbon monoxide are much more common than is generally supposed.

Chemical-Filter Respirators or Gas Masks. The Bureau of Mines has detailed specifications for the construction and performance of gas masks which protect against any gas or against any combination of gases. In Fig. 7 is shown a so-called "all-service mask" which protects against any combination of gases as well as against smokes and dusts.

In general the most important ingredient in gas-mask canisters is activated carbon, about 8–14 mesh in size. Carbon of high adsorptive capacity is now obtainable and is controlled by exacting specifications. It is effective against dilute concentrations of such organic gases and vapors as gasoline, and has an appreciable effect against organic acids such as formic or acetic. Furthermore, a mask approved against mercury vapor contains charcoal as the essential air purifier.

Of next importance is an alkaline absorbent such as soda lime, which reacts with acid gases such as carbon dioxide, sulphur dioxide, and hydrogen sulphide. Ammonia can be caught by silica gel (6) and by the special reagent, cupramite, which is activated carbon or pumice impregnated with copper sulphate (7). Carbon monoxide is not directly absorbed by any reagent but is converted by a special catalyst, hopcalite (8), into carbon dioxide and that in turn is caught in soda lime. One of the important difficulties in carbon-monoxide adsorption is dissipation of the heat generated when the carbon monoxide is oxidized to the dioxide. This heat loss is realized by passing the oxidized gas through a special radiator on top of the canister.

In general, gas masks will not protect against concentrations exceeding 2 to 3 per cent of the inspired air and of course they will not make up for oxygen deficiency. Their life lasts only as long as the ingredients of the canister retain their required efficiency. Some masks, such as that shown in Fig. 7, are obtainable with timing devices which are actuated by the wearer's respiration and thus show when the canister should be renewed.

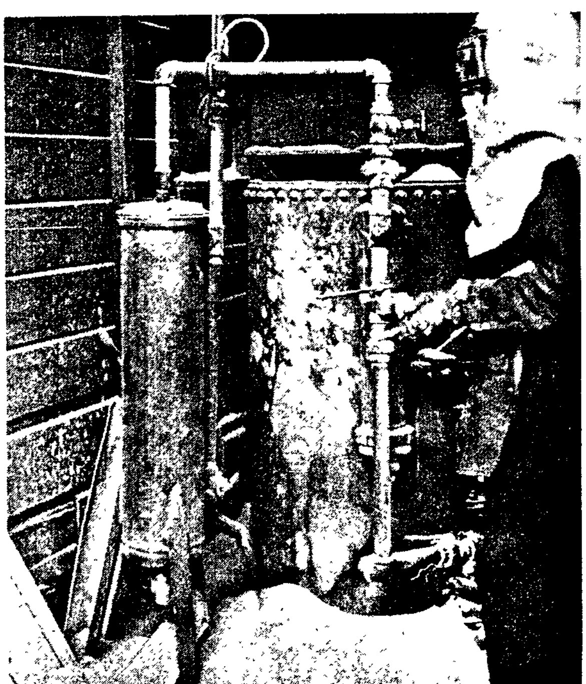

FIG. 6 AIR-PURIFIER
(Courtesy E. D. Bullard Co., San Francisco, Calif.)

FIG. 7 ALL-SERVICE MASK—APPROVED BY BUREAU OF MINES (5)
(Courtesy Mine Safety Appliances Company, Pittsburgh, Pa.)

Chemical-Cartridge Respirators. There are many jobs in which some protection against gases is welcome but the lack of such protection does not involve a serious risk. In Fig. 8 is shown a cartridge-type respirator which is used for protection against low concentrations of such gases as gasoline and sulphur dioxide, and in certain paint-spray jobs.

Obviously, such a device is cheaper than an air-line respirator or gas mask and attracts purchasers accordingly. It is not a substitute for either of these devices and should never be used for protection against severe hazards. In its favor are its extreme simplicity and the readiness with which expended cartridges can be renewed.

Mechanical-Filter or Dust Respirators. These devices are intended to protect only against particulate matter and are not to be used against gases. As the result of the formulation by the Bureau of Mines of an approval schedule (9), dust respirators have been improved greatly and now are available in efficient forms with low resistance to breathing, Fig. 9.

Dust respirators, unlike the filters of commercial dust collectors, must be highly efficient at the outset—they cannot rely upon usage or dusting to plug the pores of the filter substance and thus improve the dust catching. It is not an easy matter to catch such substances as finely divided lead fume or fine quartz dust and still have a device through which the untrained wearer can breathe with reasonable comfort.

In general the filter materials now in use in the approved respirators are of wool felt or of specially impregnated paper (10) or various combinations of the two. Air velocities through the fresh filters are about 20 fpm compared to 2 to 6 fpm used in commercial filter cloths for dust collection. It is generally recognized in practical respirator manufacture that thin filter

FIG. 8 CHEMICAL-CARTRIDGE RESPIRATOR
(Courtesy Willson Products, Inc., Reading, Pa.)

substances plug rapidly. If they are used in respirators, provision for frequent changes of filters is necessary. Thick filters of wool felt; on the other hand, plug slowly but are too expensive to discard and are cleaned by compressed air or by shaking.

There is every reason to believe that better filtering materials will be made, and it is important to note that the Bureau of Mines' requirements permit the greatest latitude in the selection and manufacture of the filters. It is probable that the Bureau's resistance requirements, which are now more severe than those for gas masks, will be made still more severe in the future.

Nonapproved Dust Respirators. There are many dusty jobs for which less effective dust respirators are suited. The Bureau's stamp of approval has in the eyes of many an unwarranted legal significance which has yet to be upheld in court. Some firms, driven panicky by the present silicosis-dust racket, have even gone so far as to stock up with "approved" respirators so that they might be able to show they have on hand the best respirators made in case they find themselves defending a dust-compensation lawsuit.

There is not the slightest reason to use the best respirators against flour, cocoa, limestone, cement, and many other dusts. It is more to the workman's interest to give him a less elaborate device which may be less effective but which is also more comfortable, Fig. 10. Indeed, there are jobs with high quartz-dust exposure in which it would be much better to provide the men with nonapproved respirators which the men would wear than to supply approved devices which remain in the stock room or are worn only in the presence of superiors.

DISCUSSION

It can be said of all the mechanical-filter-type or dust respirators that they are a poor substitute for dust control. Ultimately it is not an economy to supply workmen with air-line respirators or with dust respirators instead of installing the proper dust-control equipment. Further, the time is not far off when the courts and compensation boards will make short shrift of the employer who lets his men work in dense clouds of dust, regardless of what the dust is.

In general the employer would do well to try some of the dusty jobs himself, wear the men's respirators, and thus decide whether or not it would be better to install dust control instead of respirators. However, dust respirators are centuries old; they have a legitimate place in industry, and are an important aid in the prevention of dust inhalation, but they are not a substitute for dust prevention and never should be used as such.

This sort of criticism does not apply with the same force to the other types of respirators. Oxygen-breathing apparatus, gas masks, and hose masks are all used in emergencies, usually resulting from accidents. Hose masks may be used routinely, but they are sold in single units while dust respirators are apt to be sold and used by the gross. Also, air-line respirators and abrasive-blasting respirators are often applicable to situations

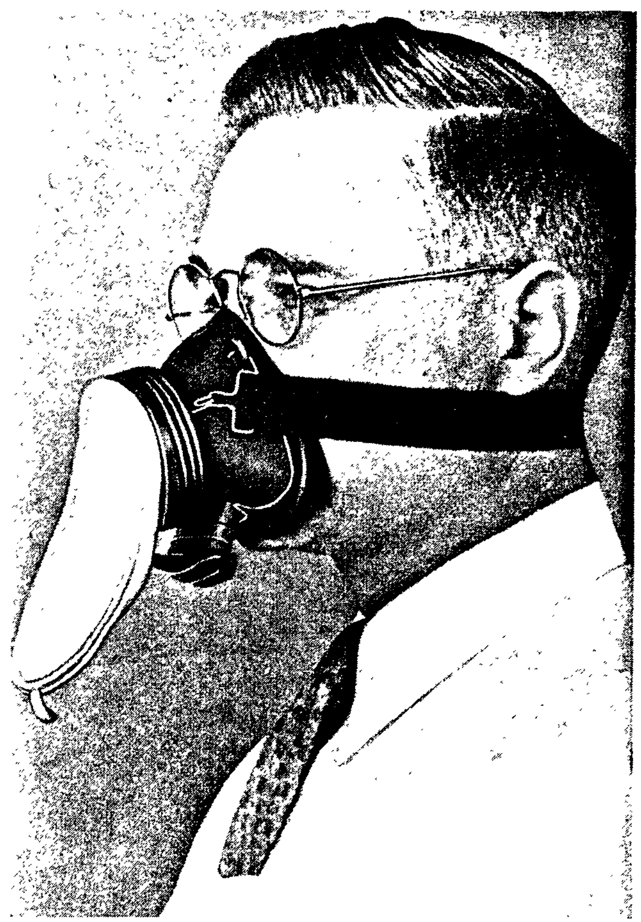

FIG. 9 DUST RESPIRATOR FOR USE AGAINST LEAD AND SILICA DUST (8)—APPROVED BY THE BUREAU OF MINES
(Courtesy Willson Products, Inc., Reading, Pa.)

in which the employer conscientiously has taken *all reasonable precautions* to prevent dustiness.

At the present writing there are United States Bureau of Mines' specifications for approval of all of these devices except the air-line and abrasive-blasting respirators. The American Standards Association and the Bureau of Mines are now preparing specifications for this complete list. The United States Navy and Army have further specifications for various types of equipment. The purpose of all such specifications—certainly those of the Bureau of Mines—is to insure a product adequate for the protection needed, without putting undue restraint upon the respirator manufacturer's ingenuity.

Care of Respirators. Because of their special construction and the composition of the chemical ingredients of various of these devices, their deterioration is fairly rapid. Companies like the utilities using them in considerable quantity maintain a regular repair service which sees that all equipment is inspected regularly and all is in first-class condition before being reissued. Generally, the firms which sell respirators furnish reliable directions for storing, cleaning, sterilizing, and repairing all equipment.

In conclusion the author wishes to make clear that equipment of the type described in this paper ages rapidly—today's new models will appear on tomorrow's museum shelves. The Bureau of Mines' approval, desirable as it is, does not tell the purchaser which is the best equipment but merely insures him that the approved article is what might be called "first-grade." Testing these devices is a service offered by the Bureau for the help of industry and it is to industry's advantage to patronize this service.

REFERENCES

1 "Respiratory Protective Devices," by C. E. Brown and W. P. Yant, Trans. National Safety Council, 1935, p. 135.

2 "Procedure for Establishing a List of Permissible Self-Contained Oxygen-Breathing Apparatus," U. S. Bureau of Mines, Schedule 13A, Jan. 21, 1930.

3 "Procedure for Testing Hose Masks for Permissibility," U. S. Bureau of Mines, Schedule of April 28, 1927, and supplement of August 20, 1934.

4 "Sand and Metallic Abrasive Blasting as an Industrial Health Hazard," by J. J. Bloomfield and L. Greenburg, *Journal Industrial Hygiene*, vol. 15, 1933, p. 184.

5 "Procedure for Testing Gas Masks for Permissibility," U. S. Bureau of Mines, Schedule 14D of May 9, 1935.

6 U. S. Patent 1,586,327.

7 U. S. Patent 1,559,980.

8 "The Removal of Carbon Monoxide From Air," by A. B. Lamb, W. C. Bray, and J. C. W. Frazes, *Journal, Industrial and Engineering Chemistry*, vol. 12, 1920, p. 213. See also U. S. Pat. 1,345,323.

9 "Procedure for Testing Filter-Type Dust, Fume, and Mist Respirators for Permissibility," U. S. Bureau of Mines, Schedule 21 of August 20, 1934.

10 U. S. Patents 1,798,164; 1,814,190; 1,818,155.

FIG. 10 DUST RESPIRATOR FOR USE AGAINST DUSTS SUCH AS ZINC OXIDE, COCOA, FLOUR, AND SODA ASH
(Courtesy Willson Products, Inc., Reading, Pa.)