TREASURY DEPARTMENT
UNITED STATES PUBLIC HEALTH SERVICE

PUBLIC HEALTH BULLETIN No. 177
JUNE, 1928

EFFICIENCIES OF PAINTERS' RESPIRATORS FILTERING LEAD PAINT, BENZOL AND VITREOUS ENAMEL SPRAYS

By

S. H. Katz, E. G. Meiter, and F. H. Gibson
United States Bureau of Mines

PREPARED BY DIRECTION OF THE SURGEON GENERAL

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EFFICIENCIES OF RESPIRATORS FOR SPRAY PAINTERS[1]

By S. H. KATZ, E. G. MEITER, and F. H. GIBSON

United States Bureau of Mines

INTRODUCTION

This determination of the efficiencies of respirators in protecting spray painters was made through a cooperative arrangement between the United States Bureau of Mines, the National Safety Council, and the United States Public Health Service. An abridged report based on the present paper is included as Appendix II in the Final Report of the Committee of the Chemical Section, National Safety Council, on Spray Coating.[2]

Operators of spray-guns are usually within arm's length of the gun being manipulated and may breathe some spray that fails to lodge upon the surface; also they may breathe vapors of paint solvents and thinners. When using paints that contain lead or other poisonous pigments it is best that the operator of the spray-gun be protected from inhaling the mist. Some paint solvents such as benzol, which has sometimes been used, or thinners, may evolve vapors detrimental to health.

Many paint-spraying operations in factories are performed in booths with strong drafts to exhaust the mists and the vapors through pipes to the exterior. Respirators are frequently worn by operators as additional protection. As to spraying in house painting, W. J. Pitt, secretary for the Spray Painting and Finishing Equipment Manufacturers' Association, informed the writers that—

> Lead paints are not sprayed in interiors of buildings according to present practice; lithopone paints and other harmless ingredients are generally used in interior paints. The hand-brush painter, however, still insists on using lead paints on interiors, but also uses nonlead paints, such as prepared paints, flat wall paints, and mill whites, just as the spray operator does. Varnishes are not to any extent sprayed on or in buildings, but interior modern lacquers are, and more so, daily, as are also enamels. Stains are sprayed on exteriors—seldom, if ever, inside.

Respirators and ventilation are the only protective means for the operator in many spray-painting operations employing the mate-

[1] Submitted for publication Jan. 12, 1928.

[2] Final Report of the Committee, Chemical Section, National Safety Council, on Spray Coating: Issued by National Safety Council, 108 East Ohio Street, Chicago, Ill., September, 1927, 53 pp.

rials dealt with in this investigation, especially those not conducted under factory conditions. Because of the important part respirators are assuming in this industry their efficacy was determined by laboratory tests.

The efficiencies of the respirators were tested similarly with sprays of silica dust in aqueous suspension because vitreous enamels, which include silica as an ingredient, are being applied to sanitary ware (enameled metal bathtubs and the like) by the spray process preliminary to firing.

PROBLEMS PROPOSED

Specific questions proposed by the National Safety Council to be answered through this investigation were as follows:

1. What filtering material, if any, is adequate—
   - (*a*) To reduce the lead content of the air to which a spray coater is exposed from 200 milligrams per cubic meter to 0.6 milligram per cubic meter?
   - (*b*) To reduce the amount of benzol under similar conditions from 2,000 to 75 parts per million?
   - (*c*) To reduce the number of silica particles under similar conditions from 200,000,000 to 100,000 per cubic meter as determined by the Palmer method?
2. How long would a layer of such material function?
3. How do certain typical masks now available measure up to this standard?

The concentrations stated above for lead and benzol should not be construed as those to which spray painters are commonly exposed. They represent more nearly the high concentrations which can quickly cause sickness and are to be considered as extremes.

BRIEF OF FINDINGS

It may be stated as a result of the tests that, in general, the respirators with cotton, paper, or fabric filters remove 90 or more per cent of the lead from air carrying paint mist. These respirators restrain none of the solvent vapors. The addition of a canister or cartridge of activated charcoal to the respirator removes all solvent vapors until the charcoal becomes saturated. The useful life of filters is determined by their increase in resistance, which necessitates changing for fresh filters at intervals of several hours. When charcoal is saturated the cartridge must be exchanged for a fresh one. Canisters of the size used with gas masks may last for weeks before a change is necessary.

The respirators were somewhat less efficient against the silica-dust sprays, but they restrained 24 per cent or more of the dust from the air passed through them; most were more than 50 per cent efficient.

Plate 1.—Respirator with sponge filter

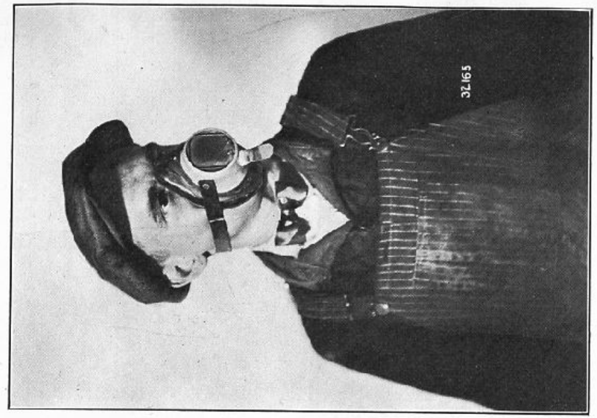

Plate 2 and 2a.—Respirator with filter of thick paper made of cotton fiber

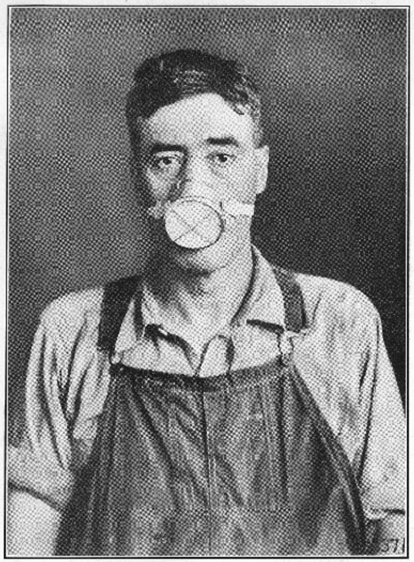

Plate 3.—Respirator with filter of thin paper made of cotton fiber

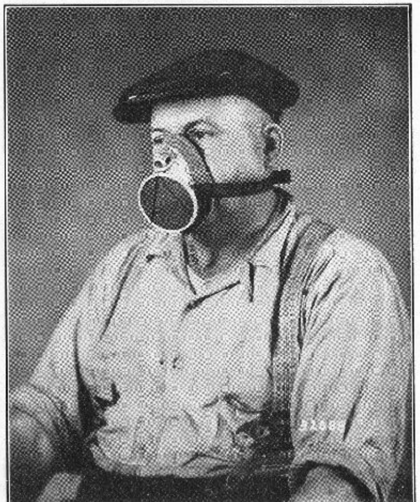

Plate 4.—Respirator with filter of several layers of paper tissue

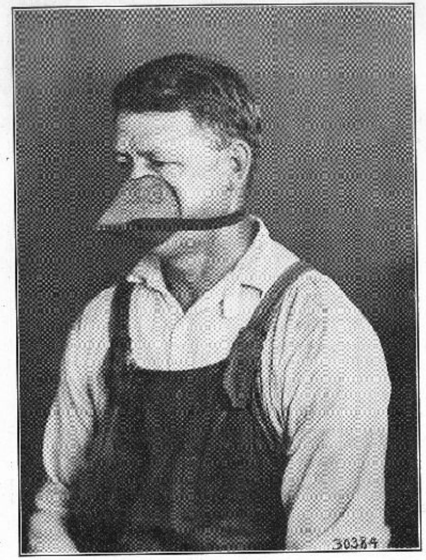

Plate 5.—Respirator with cotton flannel filter

Plate 6.—Respirator with silk gauze and cheesecloth filter

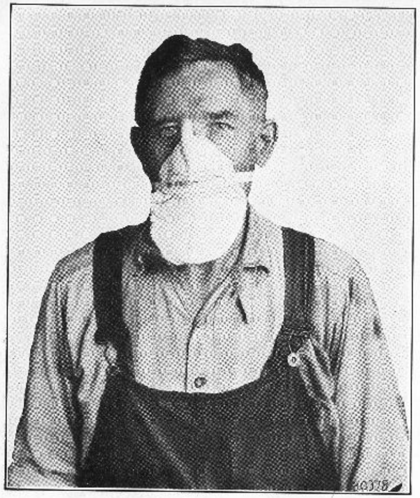

Plate 7.—Respirator with filter of cotton wool between cheesecloths

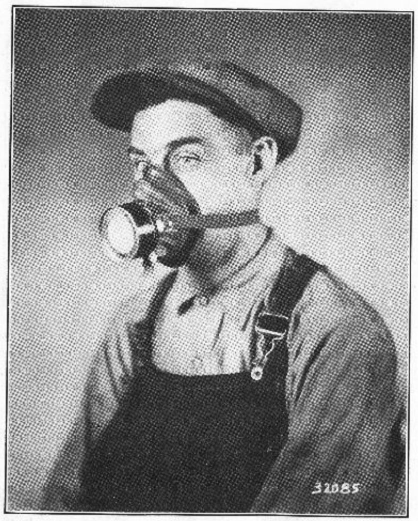

Plate 8.—Respirator with attached cartridge of charcoal and tissue paper filters

This investigation was conducted under the supervision of R. R. Sayers, chief surgeon, and A. C. Fieldner, chief chemist of the Bureau of Mines, to whom the writers are indebted for guidance and counsel. The photomicrographs were taken by A. H. Emery, assistant geologist and petrographer of the Bureau of Mines.

DESCRIPTION OF RESPIRATORS TESTED

Twelve respirators, representing the different industrial types, were tested. It was impracticable to test every make of respirator but the types included are representative and the findings indicate the results to be expected from the field of respirators as a whole. Of the respirators tested, nine were filters without adsorbents for vapors, three had both filters and activated charcoal adsorbent for solvent vapors.

Plate 1 shows a respirator with a sponge filter. The face cushion is a rather firm but flexible rubber with the edge curved outward so that a surface of rubber rather than an edge is in contact with the face. The body is of sheet aluminum. A rubber flutter-valve underneath permits escape of exhaled air. The sponge is inclosed in the round box at the front, between wire screens. The front screen is removable so that the sponge may be taken out for cleaning or wetting.

Plate 2 illustrates another respirator similar to Plate 1 with the exception of the filter, which is a thick paper made of cotton fiber. Three filters averaged 1.02 millimeters (0.040 inch) in thickness (measured between metal plates). A supply of circular filters 6.11 centimeters in diameter ($2\frac{13}{32}$ inches) accompanies each respirator for changing when resistance is increased by clogging. Filters of cotton felt are also provided with a respirator of this type. (In the tables that follow, the respirator with cotton felt filter is designated as No. 2A.)

Plate 3 is a respirator with a thin paper filter. The papers are made of cotton fiber 0.2 millimeter thick, and are supplied in circles of 8.25 centimeters (3.25 inches) in diameter. The body is of rubber with a thin edge fashioned to lay the inner rubber surface of the respirator against the skin. A wire is attached over the bridge of the nose which may be bent to shape the rubber body into the contour between the nose bridge and cheeks. The paper is held in an adapter of sheet aluminum. This respirator has no exhale valve but the manufacturer provides the respirator with valves if desired.

Plate 4 shows another respirator with paper filter. The body is of aluminum. A pneumatic rubber cushion lays against the face. The exhale valve on the upper side is of the mica-disc type. The paper filter is held by an aluminum ring, brass wire screen, and a spring wire fastener. The filters are of gauzy tissue paper and four or more are used as a filter. Ten papers measured 1.2 millimeters (0.05 inch) in thickness.

Plate 5 is a respirator with a body of fly-screen shaped into a cone and cut at the basal edge to the contour of the face. The screen is covered with two layers of cotton flannel. The flannel is bound over the lower edge and lies against the face. By bending the wire screen it may be shaped to fit various facial contours. There are no valves; inhalations and exhalations pass through the filter.

Plate 6 is a respirator with a body made of pyroxylin fabrikoid. This is cut away in the center and the filter of one layer of fine silk gauze and three layers of cheesecloth is sewed into the opening. At the position over the nose bridge a wire is bound onto the respirator for conforming to the facial contours.

Plate 7 is a respirator of cotton wool quilted between cheesecloths. The fabric is gathered over the bridge of the nose to form a sort of nose pouch. About 5 grams of charcoal granules are spread through the cotton for the purpose of adsorbing solvent vapors, but the amount is insufficient to be of value. The respirators are thrown away when soiled.

Plate 8 is a respirator with small canister or cartridge containing 60 cubic centimeters of granular activated charcoal with filters of gauzy paper tissue and wire screen supports at inlet and exit to the cartridge. Each of the two filters, one at inlet side, one at outlet side of cartridge, consists of 10 papers measuring 1.7 millimeters (0.067 inch) in thickness measured between metal plates. The filter layer in the cartridge measures 6.35 centimeters in diameter and 2.54 centimeters thick (2.5 inches by 1 inch). The cartridge screws into the respirator body, which is similar to that of Plates 1 and 2, and seats against a rubber gasket. The weight with canister attached is 195 grams (6.9 ounces) somewhat heavier than the other respirators described.

Plate 9 is the Bureau of Mines respirator developed to present a large filtering surface with a correspondingly low resistance to breathing, and a high filtering efficiency.[3] These respirators have at present been made and used only in the laboratories of the Bureau of Mines. The filter is of canton flannel either 2 or 3 plies, shaped into a turban for the head. The frame is of spring wire, and there is a lining of pyroxylin which is impervious to air and prevents dust being drawn into the wearer's hair. Between the lining and the filter is a separator about an inch thick made of sterilized, curled hair, like that used by upholsterers; it permits passage of air, with negligible resistance, from all parts of the filter surface to the exit valve on top. The valve prevents back flow of exhaled air. A rubber tube leads the filtered air from the valve down between the eyes, to a nose cap of rubber; only the nose is covered so the wearer can talk as usual or expectorate. A coiled spring in the rubber tube holds the nose cap against the face with a slight pressure and prevents leakage. At the lower side of the nose cap is an exit provided with a rubber flutter valve or check valve for eliminating exhaled air. This respirator weighs about 625 grams (22 ounces) but the weight is not oppressive to the wearer.

[3] Katz, S. H., Smith, G. W., and Meiter, E. G., Dust respirators; their construction and filtering efficiency. Bureau of Mines Technical Paper 394, 1926, 52 pp.

The Bureau of Mines respirator may be rid of accumulated dust by means of compressed air blown through a tube attachment. But the filter can not be changed readily, so it would hardly be serviceable in paint mist. It should be good in vitreous enamel spray.

Plate 10 shows an Army type gas mask used by a spray painter. Masks of this type are now used in numerous industries. The canister shown in detail in Figure 1 is carried in the haversack supported from the neck. It contains 600 cubic centimeters of activated charcoal to serve as an adsorbent for vapors. There are two filters of cotton wool between wire screens and one of Turkish toweling.

Plate 11 shows a Fogler flat felt filter and mask; a canister of charcoal is attached to the filter, or it may be used without the charcoal canister. The Fogler flat felt filter consists of two rectangular pieces of an especially dense woolen felt about 21.6 by 24.1 centimeters (8½ by 9½ inches) by 3 millimeters (one-eighth inch) thick, with a crimped wire screen separator of slightly smaller dimensions between. On the outside of the felts are two similar crimped screens, both of which are covered with canvas. The fabric and felt edges are all thoroughly rubberized and vulcanized together. Each canvas side is perforated by five holes 1 centimeter (0.39 inch) in diameter. A tube about 2.54 centimeters (1 inch) in diameter passes through one canvas and one felt and connects with the central space between the felts. The air, filtering, passes through the canvas or its perforations, filters through the felt to the central space, passes through the exit tube to the canister containing activated charcoal, and then to the mask for breathing. If protection from dust only is required, the canister is omitted.

The large filtering area of the Fogler flat felt filter permits breathing through the highly efficient filter without excessive resistance to air flow or rapid clogging. It is the most efficient of the types so far employed in industry for retaining the very finest suspensoids. A disadvantage is that the filter can not be cleaned of paint that may lodge on the felt and the filters are rather expensive for only a short period of use. Dusts may be blown out with air under pressure.

Plate 12 shows a respirator similar to the one illustrated in Plate 3, but with a small rubber hose connection to the compressed-air line

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of the spray gun. The amount of air delivered to the respirator is regulated by a needle valve. At the respirator the air enters the metal cup which incloses a filter of cotton fiber paper. The paper retains oil droplets or dirt. Two flat rubber check valves, one on each side, are mounted on the rubber body; they provide exits for the air stream. The valves are retained and protected by metal caps, they are replaceable and a supply accompanies each respirator for changing when they no longer function properly, due to paint or deterioration. When an air stream of about 2 cubic feet a minute passes through this respirator, it can exclude all paint and vapors of solvents. The air supply must, of course, be free of distasteful oil vapors from the compressor or air line.

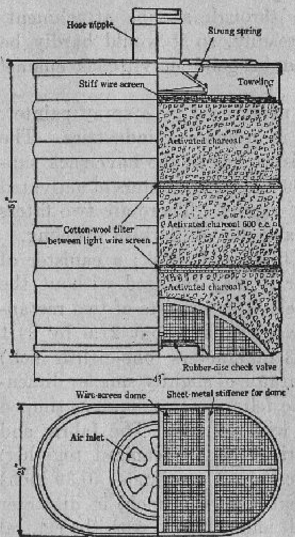

FIG. 1.—Canister of army type gas mask used by spray painters

Plate 13 shows a hose mask or helmet especially for spray painters. The outer covering is a cotton twill which may be separated from the light metal frame for washing. A hose conducts compressed air to the helmet and the air discharges downward over the inside of the eyepieces to prevent fogging. A woolen headpiece supports the weight upon the head. Two cubic feet or more of free air per minute is led into the helmet; the air may be supplied by the compressor for the spray gun. When sufficient air discharges into the helmet the spray-gun operator is completely protected from inhaling mist or vapors. No tests were made with the helmet because it does not filter the air, nor with the respirator shown in Plate 12.

TESTS OF RESPIRATORS IN PAINT MIST

APPARATUS FOR TESTING FILTERING EFFICIENCIES

The apparatus used to test respirators against paint mist is shown diagrammatically in Figure 2. The mechanical equipment, including air compressor, air receiver, air cleaner, pressure regulator and spray gun, was of standard make. The compressor was rated at 150 pounds working pressure, but when the spray gun was operated the pressure regularly obtained at the trigger of the gun was 20 to 30

Plate 9.—Bureau of Mines respirator

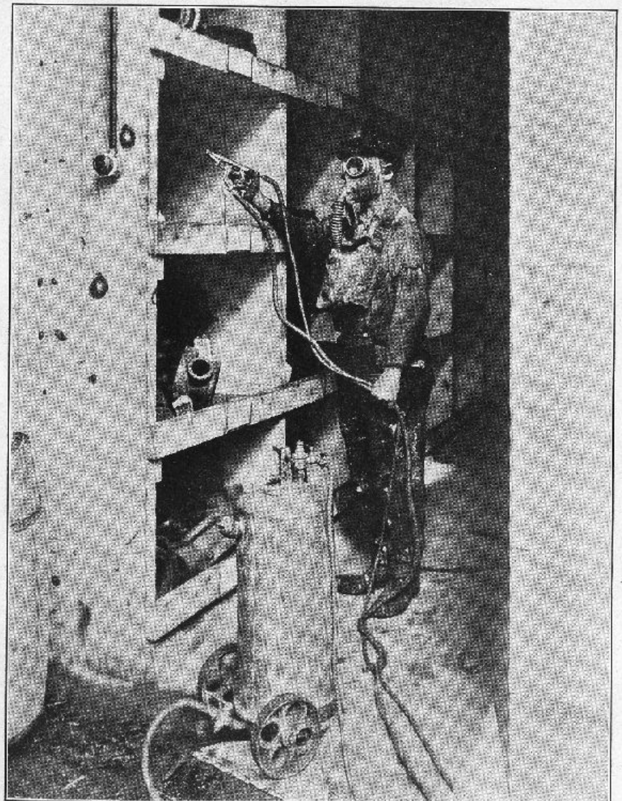

Plate 10.—Army type gas mask used by spray painter

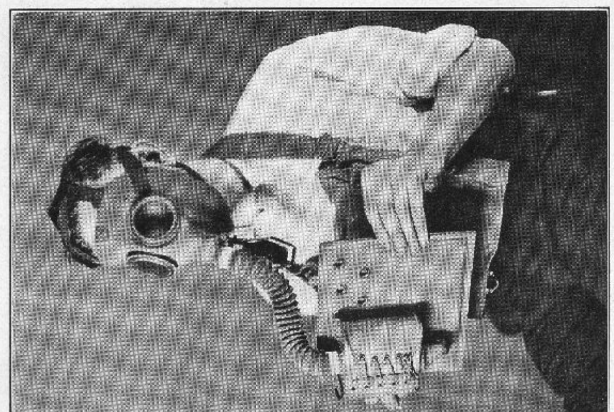

Plate 11.—Fogler flat felt filter canister and mask

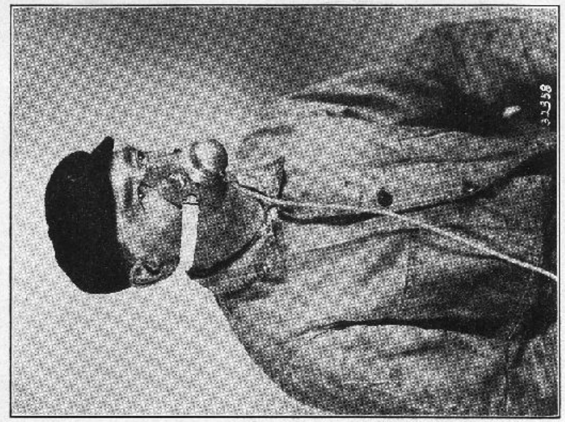

Plate 12.—Respirator with rubber tube to supply fresh air

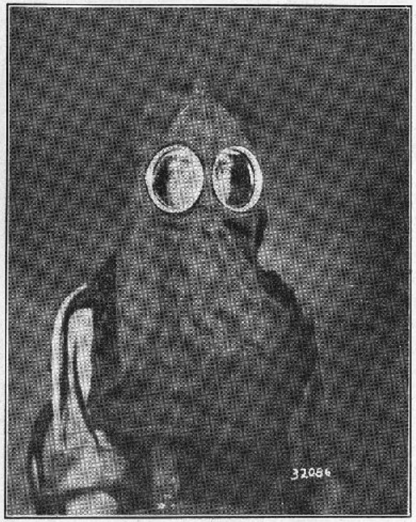

Plate 13.—Helmet with hose to supply fresh air

pounds. This gave a good spray and was ample for the purpose. The gun was supported in a box 30 inches on a side, open on one side which was draped with a cloth curtain. The gun discharged against a sheet-metal plate 9 inches from the nozzle. Paint drippings were caught in a pan. The trigger of the gun was fixed to spray uniformly by means of a metal loop and thumbscrew to depress the trigger. The density of the spray was kept uniform as much as possible by adjustments needed occasionally according to its appearance.

The respirator undergoing test was shielded by baffles from direct approach of spray from the gun. It was mounted in a holder by means of plastecene (modeling clay); the respirator valves were sealed so that all the air passed through the filter, and filtering efficiencies as determined were unaffected by any possible leakage of unfiltered air. The respirator was placed downward on a support so that no paint particles lodged upon it by gravity. Air was drawn through the respirator at the rate of 32 liters (1.13 cubic feet) a minute, the rate of breathing by a man doing vigorous work.

The filtered air passed from the respirator directly into an electric precipitator tube of glass, lined with analytical filter paper. The tube was 2.5 centimeters (1 inch) in diameter and 30 centimeters (12 inches) between inlet and outlet. Operation without the paper (used to catch precipitated paint) showed complete precipitation of paint in the first half length of precipitator tube. The inner electrode was a platinum wire; the outer was copper foil bound around the glass tube; a pressure of 15,000 volts from a transformer was employed. From the precipitator the air passed to a solution of potassium iodide and sodium thiosulphate to remove ozone and oxides of nitrogen, then through a flowmeter to measure the flow rate and to the suction pump.

Tests were run 15 to 60 minutes in order to obtain sufficient lead for chemical determination. After each test the filter paper with its lead was removed from the precipitator; the inner electrode and glass surfaces of the precipitator were thoroughly cleaned and the cleanings put with the filter paper. The filter on the respirator was removed (the respirator was destroyed when necessary) the lead caught thereon and lead caught by the Cottrell precipitator were determined separately by chemical analysis according to the method described later.

The efficiencies of the respirators were calculated from the results obtained thus:

$$\frac{\text{Weight of lead caught by respirator} \times 100}{\text{Weight of lead caught by both respirator and precipitator}} = \text{per cent efficiency.}$$

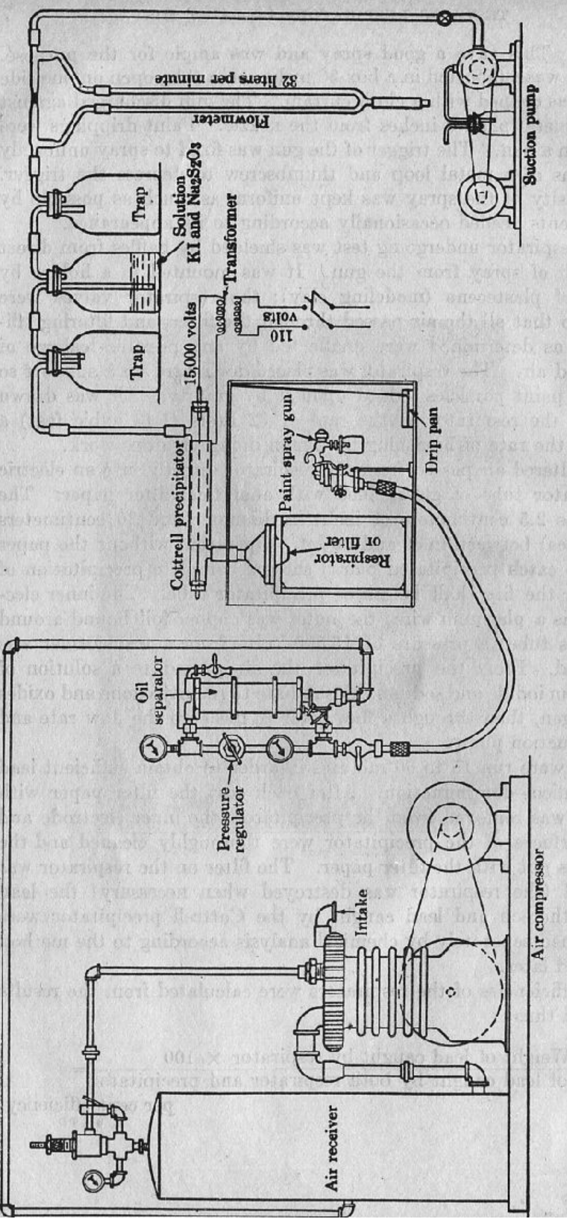

Figure 2. Apparatus for testing filtering efficiencies of dust respirators and filters against paint spray

An effort was made to maintain the concentration of lead in the air before filtering about 200 milligrams per cubic meter as specified by the National Safety Council; but this was not readily attained and considerable variations occurred. However, previous work has shown that the concentration of the suspension in air exerts little or no effect on the efficiencies of the filters.[4]

COMPOSITION OF THE PAINT

The paint used was of the same composition throughout as follows: White lead (paste), 100 grams; linseed oil, 50 cubic centimeters; and benzol, 25 cubic centimeters.

The paste white lead was 91 per cent white lead and 9 per cent linseed oil by weight.

The white lead and benzol were included in the paint because the questions proposed by the National Safety Council for this investigation included white lead and benzol. Other paint materials were excluded because they might increase the difficulties and extend the time and labor of determining lead and benzol.

DETERMINATION OF LEAD

The lead caught on filters and in precipitators was determined by methods described by the United States Public Health Service.[5] Briefly, the method is as follows:

Filters, papers, or cellulosic substances, bearing the lead, are ashed in a muffle furnace at 550° ± 20° C., then dissolved in 1:1 hydrochloric acid solution, filtered and washed. Neutralize with sodium hydroxide, acidify with dilute acetic acid till color of thymol blue indicator changes, then add slight excess. Heat to boiling and precipitate lead as chromate with potassium chromate solution, adding slight excess. Keep hot for one hour, then digest overnight. Filter off lead chromate, wash with hot water. Then transfer precipitate to beaker or flask with water and finally by treating filter with 1:2 hydrochloric acid, add potassium iodide and titrate with standardized sodium thiosulphate solution with starch indicator. Calculate data to metallic lead.

This simple method was sufficient when the lead was contaminated only by the small amounts of ash material from cotton or high-grade filter papers. When considerable ash was present the lead was precipitated as sulphide, redissolved, and determined as before. Complete details are given in the reference cited.

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[4] See footnote 3, p. 4.

[5] Anon., Fairhall (chromate) method for minimal amounts of lead in fecal specimens: Ind. & Eng. Chem., vol. 18, April, 1926, pp. 431–432.

EFFICIENCIES OF RESPIRATORS IN PAINT MIST

FILTERING LEAD PAINT MIST

Table 1 lists the efficiencies of the respirators in restraining lead contained in the paint spray; the respirators are numbered in the table to correspond to the figures picturing them.

TABLE 1.—*Efficiencies of respirators filtering lead in paint mist from spray gun. Rate of air flow, 32 liters a minute. Time of testing, 31¼ minutes giving 1 cubic meter of filtered air*

Test No.	Number of respirator[1]	Filter material	Resistance to air flow at 85 liters per minute, inches of water		Average amount of lead in air, milligrams per cubic meter	Filtering efficiency of respirator per cent	Remarks
			Start	End			
807	1	Sponge	0.3	0.3	395	84	Sponge was wet before test.
809	2	Cotton paper	1.0	2.5	558	98.7	1-ply paper in filter.
818	2	do	1.0	1.6	397	97.3	Do.
819	2	do	1.1	2.0	417	98.3	Do.
808	3	do	.15	.5	359	96	Do.
816	3	do	.2	.6	374	96	Do.
817	3	do	.5	.9	353	98.3	2 plies of paper in filter.
814	4	Gauzy tissue paper	.5	.8	498	92	4 plies paper in filter.
815	5	Cotton flannel	.2	.4	458	95	2 plies cotton flannel in filter.
811	6	Silk gauze and cheesecloth.	.05	------	450	74	1-ply silk, 3 plies cheesecloth.
812	7	Cotton wool	.2	.2	351	94	Cotton between cheesecloth, 109 square centimeters of filter was exposed.
810	2A	Cotton felt	.7	1.7	551	97.9	
820	2A	do	.5	1.2	417	97.5	
821	2A	do	.7	1.2	394	97.7	
813	8	Gauzy tissue paper	3.5	4.4	524	99.7	Cartridge with charcoal and 2 filters each of 10 plies.
847	10	Cotton wool	3.6	3.9	76.1	99.7	The Army type gas mask canister contains 2 cotton filters, 1 of toweling and 600 cubic centimeters charcoal.
848	10	do	3.6	3.9	71.3	98.8	Do.
850	10	do	3.4	3.6	75.3	99.6	Do.
851	10	do	3.4	3.5	50.6	99.3	Do.
852	10	do	3.6	3.8	65.7	99.7	Do.

[1] Numbers correspond to the numbers of figures showing the respirators.

Filtering efficiencies range from 74 per cent for respirator No. 6 with filter of silk gauze and 3-ply cheesecloth to 99.7 per cent for the No. 8 cartridge with two filters each of 10-ply gauze tissue paper. The sponge respirator No. 1 was 84 per cent efficient. All the others ranged above 94 per cent efficiency. The efficient respirators thus restrain nearly all of the lead in paint mist from air filtered through them.

These tests do not consider possible leakage of unfiltered air when respirators are worn due to poor fit upon the face, leaky valves, or other leaks. On the other hand, greater weights of lead (but not greater percentages) were caught on the respirator filters under the test conditions than may be expected in similar circumstances in practice, because the volume of air filtered (32 liters per minute, which is an excessive breathing rate) is greater than the volume inspired under ordinary painting practice. This leakage may be eliminated in respirators fitted with care by shaping to the facial contour of the wearer and careful adjustment. Leakage at valves or other places may sometimes occur. Care should be taken that valves are in good condition and function well. As leakage can annul the benefits of an otherwise good respirator, it is important that the wearer be careful to eliminate all leaks.

Table 1 also gives the resistances of the respirators to air flowing at 85 liters a minute before and after the paint had lodged upon them. Most have less than 4 inches of water throughout; 4 inches is a maximum tolerable resistance.[6] Only one respirator, No. 8, with the cartridge filter, exceeded 4 inches; at the end of the test it showed 4.4 inches. Respirators tend to increase in efficiency as well as resistance with increase in deposited material on the filter; hence it is the increase in resistance rather than any filtering deficiencies developing with use that determine the useful life of a filter. Most of the filters had deposits of lead ranging from 351 to 558 milligrams deposited in 31¼ minutes of testing (the gas mask canisters had 51 to 76 milligrams) without developing excessive resistance. As the concentrations of paint mist were higher than customarily encountered by spray painters, it appears that any of the filters can serve at least for a period of hours or a day before change is needed.

BENZOL VAPORS

The filters of fabric or paper have no capacity whatever for restraining benzol vapors (or any similar vapors); activated charcoal absorbent is needed for that purpose. Two of the respirators, No. 7 and the No. 8 cartridge respirator, contained activated charcoal, also the canister of the Army type gas mask, No. 10. These were tested against benzol vapor in air at a concentration of 2,000 parts per million and air flow of 32 liters a minute, by methods used previously for testing canisters against gasoline vapors.[7] The respirator, No. 7, with about 5 grams of charcoal granules interspersed through the cotton showed no noticeable restraint of the benzol vapors at all, for the reason that the quantity of charcoal was insufficient and it was too irregularly dispersed. The No. 8 cartridge restrained the benzol for 19 minutes before a leakage of 75 parts per million benzol appeared in the effluent air. An Army canister, No. 10, containing 600 cubic centimeters of high-grade activated charcoal lasted 250 minutes under similar conditions. In actual service the concentrations of solvent vapors are mostly much less than under the test conditions, so that the useful life of adsorbents for vapors is many

[6] Schedule 14A, Procedure for establishing a list of permissible gas masks: Bureau of Mines, Aug. 25, 1923, 15 pp.

[7] Katz, S. H. and Bloomfield, J. J., Gas Masks for Gasoline and Petroleum Vapors: Tech. Paper 348, Bureau of Mines, 1924, 37 pp.

times longer; in fact, the writers have known canisters containing 600 cubic centimeters of activated charcoal to last for weeks in daily service of spray painters.

FILTERING EFFICIENCIES OF FABRIC FILTERS

The filters in the various respirators can not be very well compared for filtering qualities because of their different filter areas, part coverings, and different environments. Several filtering materials were therefore compared under uniform conditions by holding them in a special holder or flange. Figure 3 shows the flange. Exactly 100 square centimeters of filter area is exposed. Several plies of fabric or paper can be clamped together. They were backed, when necessary, by a screen to prevent bulging from air pressure. Table 2 gives the results of the tests, including the filtering efficiencies, duration of the tests, resistance to air flow (at 85 liters per minute) both before and after the paint was deposited on the filter, the average concentration of lead in the air and the average concentration of benzol in the air.

TABLE 2.—*Efficiencies of various fabrics filtering paint mists. Filter area, 100 square centimeters; rate of air flow, 32 liters per minute*

Test No.	Fabric	Number of plies	Period of testing, minutes	Resistance to air flow at 85 liters per minute, inches of water		Average concentration of lead in air, milligrams per cubic meter	Lead filtering efficiency, per cent	Average concentration of benzol in air, parts per million
				Start	End			
822	Cheesecloth, 31 by 36 threads per inch, 42 grams per square yard	2	15	0	0	406	18	560
823	do	3	15	0	0	504	23	600
824	do	4	15	.02	.02	447	34	740
825	do	5	20	.02	.02	432	39	550
781	do	10	62½	.02	.02	253	51	550
826	do	10	31¼	.02	.02	421	68	640
782	do	20	62½	.05	.05	207	74	590
796	Muslin, 66 by 66 threads per inch, 130 grams per square yard	1	62½	.2	.6	328	67	780
797	do	2	62½	.2	.7	381	87	820
783	do	4	62½	.6	1.6	181	95	610
798	do	6	62½	.7	1.7	321	97.6	800
784	do	8	62½	1.1	2.1	228	98.7	770
804	do	12	31¼	1.7	2.8	346	99.2	1,360
785	do	16	62½	2.2	3.3	218	99.4	960
794	Canton flannel, 44 by 76 threads per inch, 143 grams per square yard	1	62½	.1	.2	391	85	900
786	do	2	44	.1	.2	313	92	1,120
795	do	3	62½	.2	.6	428	96	980
787	do	4	40½	.4	.5	194	97.9	1,120
788	do	8	62½	.9	1.0	154	99.2	530
803	do	8	31¼	.9	1.0	540	99.5	1,120
799	Cotton felt, 131 grams per square yard, thickness 0.84 millimeters	1	62½	.1	.1	368	82	1,010
800	do	2	62½	.1	.1	249	91	960
801	do	4	31¼	.1	.3	250	97.0	740
802	do	6	31¼	.4	.4	334	98.5	1,100
792	Filter paper, S. & S. No. 589, black label	1	42½	2.5	22.8	151	98.8	500
793	do	2	53¾	4.9	41	181	99.6	690
806	do	3	31¼	6.3	44	281	99.9	780
789	Absorbent cotton, between cheesecloths, 348 grams per square yard	1	62½	.1	.2	146	96.8	480
790	do	2	62½	.6	.6	165	99.0	470
805	do	3	31¼	1.0	1.0	451	99.5	1,310
791	do	4	62½	1.2	1.2	183	99.5	420

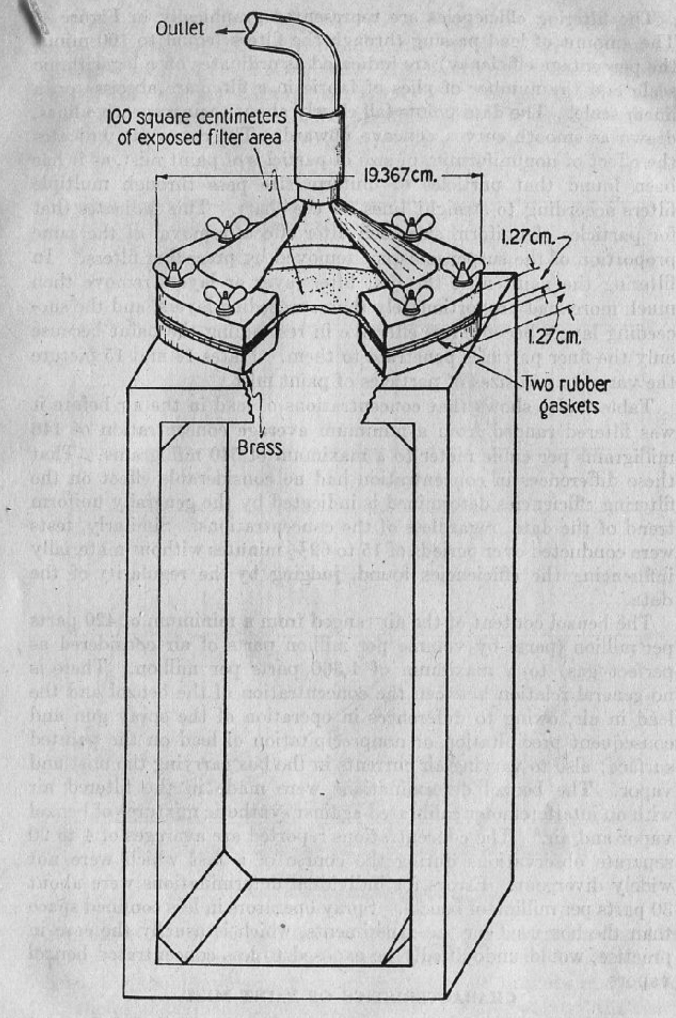

Fig. 3. Flange or holder for fabrics used in determining the filtering efficiencies of the fabrics.

The filtering efficiencies are represented graphically in Figure 4. The amount of lead passing through the filters (equal to 100 minus the percentage efficiency) are indicated as ordinates on a logarithmic scale and the number of plies of fabric in a filter are abscissa on a linear scale. The data points fall closely about their respective lines, drawn as smooth curves, concave upward. The concavity indicates the effect of nonuniformity of size of particles of paint mist, as it has been found that particles of uniform size pass through multiple filters according to straight lines on the chart. This indicates that for particles of uniform size each filter effects removal of the same proportion of the suspensoids not removed by preceding filters.[8] In filtering the paint mist the first filter layer or layers remove then much more lead proportionately than succeeding layers, and the succeeding layers become less effective in restraining the paint because only the finer particles penetrate to them. Plates 14 and 15 picture the variations in sizes of particles of paint mist.

Table 2 also shows that concentrations of lead in the air before it was filtered ranged from a minimum average concentration of 140 milligrams per cubic meter to a maximum of 540 milligrams. That these differences in concentration had no considerable effect on the filtering efficiencies determined is indicated by the generally uniform trend of the data, regardless of the concentrations. Similarly, tests were conducted over periods of 15 to 62½ minutes without materially influencing the efficiencies found, judging by the regularity of the data.

The benzol content of the air ranged from a minimum of 420 parts per million (parts by volume per million parts of air considered as perfect gas) to a maximum of 1,360 parts per million. There is no general relation between the concentration of the benzol and the lead in air, owing to differences in operation of the spray gun and consequent precipitation or nonprecipitation of lead on the painted surface; also to varying air currents in the box carrying the mist and vapor. The benzol determinations were made in the filtered air with an interferometer calibrated against synthetic mixtures of benzol vapor and air.[9] The concentrations reported are averages of 4 to 20 separate observations during the course of a test which were not widely divergent. Errors for individual determinations were about 30 parts per million of benzol. Spray operators in less confined space than the box used for the experiments, which is usually the case in practice, would undoubtedly be exposed to less concentrated benzol vapors.

CHARACTERISTICS OF PAINT MIST

The efficacy of filters in restraining suspensoids in air is influenced greatly by the size and nature of the particles. To determine the character of the particles of paint mist floating in the air at the respira-

[8] See footnote 3, p. 4.

tor filters, some were caught on "cover glasses," such as are used with microscope slides, by rapidly moving the glasses in the mist under the filters undergoing test. The paint mist particles upon the glass were examined under a microscope. Plates 14 and 15 show particles of mist with included pigment at two magnifications. On the former, one large-scale division represents 100 microns (1 micron = $\frac{1}{25000}$ inch = $\frac{1}{1000}$ millimeter); on the latter, one large-scale division

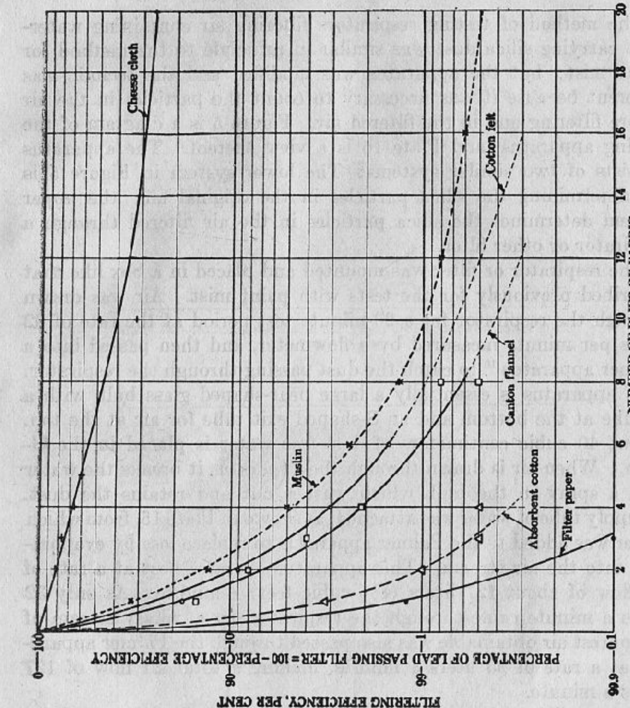

FIG. 4.—Efficiencies of various multiple fabric filters in filtering lead from paint spray.

represents 20 microns. Plate 14 at the smaller magnification shows a larger field and includes a common variety of droplet sizes. It is seen that the droplets range from about 4 to 60 microns in diameter. Particles of pigment appear inside most of the droplets; the size of pigment particles is shown best on Plate 15. They range in size from about 1 to 4 microns. The oil liquid about the pigment particles increases the particle size and aids the filters in retaining the

[9] See footnote 7, p. 11.

lead. It is evident that the larger the droplets the more easily they are retained by a filter. Thus, the larger droplets lodge on the foremost filter layers together with some of the smaller droplets and leave some smaller droplets to penetrate with the air streams. As a result, less and less is caught by succeeding filter layers.

TESTS OF RESPIRATORS IN WATER-MIST CARRYING SILICA DUST

APPARATUS USED

The method of testing respirators filtering air containing water-mist carrying silica dust was similar in principle to the method for paint mist; but the apparatus was modified and the technic was different because it was necessary to count the particles in the air before filtering and in the filtered air. Figure 5 is a diagram of the testing apparatus, and Plate 16 is a view thereof. The apparatus consists of two similar systems: The lower system in Figure 5 is for determining the silica particles in the original air; the upper system determines the silica particles in the air filtered through a respirator or other filter.

The respirator or filter was mounted and placed in a box like that described previously for the tests with paint mist. Air was drawn through the respirator for a 20-minute test period at the rate of 32 liters per minute measured by a flowmeter, and then passed into a Palmer apparatus [10] to catch the dust passing through the respirator. This apparatus is essentially a large pear-shaped glass bulb with a U-tube at the bottom and an S-shaped exit tube for air at the top. About 40 cubic centimeters of dust-free water is placed in the U-tube. When air is drawn through the apparatus it breaks the water into a spray in the bulb which washes out and retains the dust. A supply tube of water was attached, as shown in Plate 15, from which water was added to the Palmer apparatus to replace loss by evaporation into the air stream. This apparatus operates best at a rate of air flow of about 127 liters (4½ cubic feet) a minute. As only 32 liters a minute came through the respirator, an auxiliary stream of the purest air obtainable was also passed through the Palmer apparatus at a rate of 95 liters a minute, making a total air flow of 127 liters a minute.

The auxiliary air was taken from the dead end of a tunnel for service pipes in the building, at a point about 60 feet from the nearest tunnel opening, which was a trapdoor usually kept closed. The air was filtered through a layer of fabrics closing one side of a tight box. This filter was about 28 by 30 centimeters (11 by 12 inches) in area and was made from outside to inside of 1 ply each of canton flannel, cotton felt, a paper made of cotton fiber, canton flannel, and finally

[10] Palmer, G. T., A New Sampling Apparatus for the Determination of Aerial Dusts: Amer. Jour. Public Health, vol. 6, 1916, pp. 54–55.

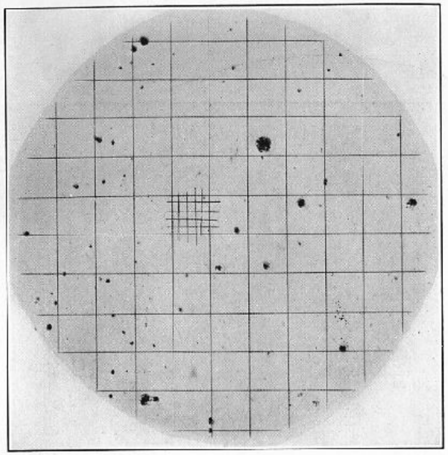

Plate 14.—Photomicrograph of paint mist droplet showing range of droplet sizes

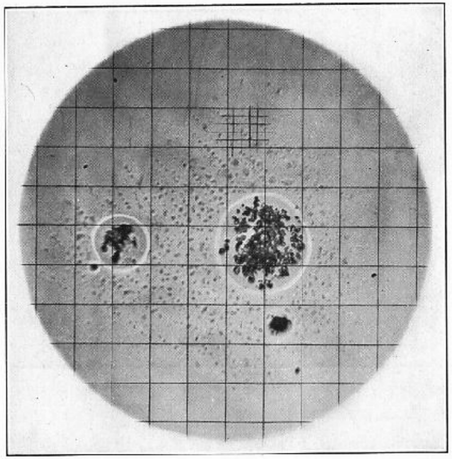

Plate 15.—Photomicrograph of a large paint mist droplet showing pigment particles within the droplet

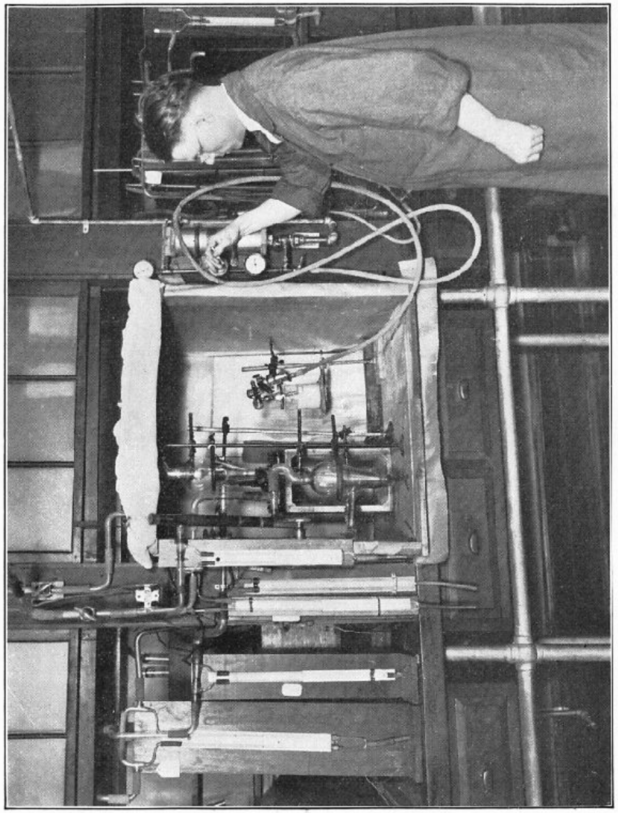

Plate 16.—Apparatus for testing respirators filtering water-mist-bearing silica dust

a support of fly screening. Special tests with the Palmer apparatus of the air through this filter showed 3 dust particles per cubic centimeter (3,000,000 per cubic meter), which was regarded as constant and deducted in calculations of efficiencies of the respirators.

All of the air from the Palmer apparatus was drawn into a motor-driven suction pump. The flow rates were controlled by means of

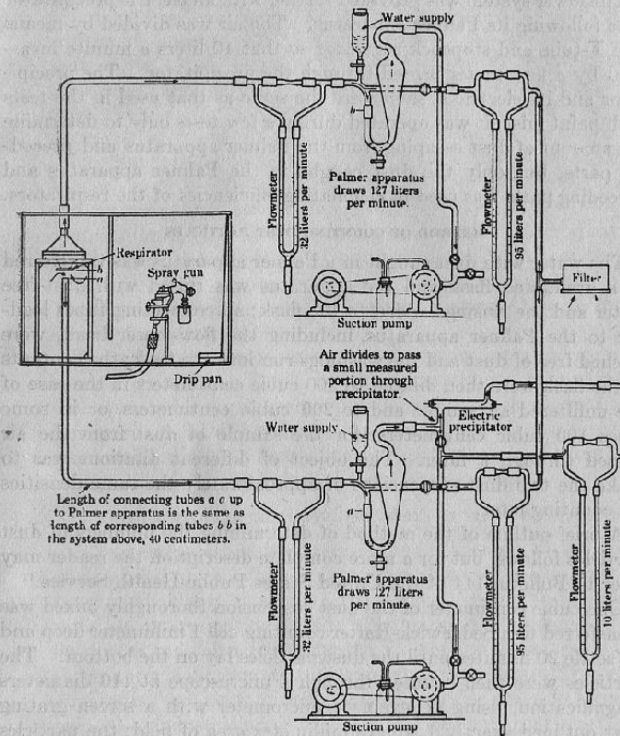

FIG. 5.—Diagram of the apparatus for testing respirators filtering water-mist-bearing silica dust.

three valves or cocks on the connecting tubes, as indicated in Figure 5.

The system for determining the dust in the original air in the box (the lower system in fig. 5), was identical with that described up to and including the Palmer apparatus, except that the filters and their holder were omitted at the inlet end. The inlet was under and about 1 inch from the respirator filter to assure air of equal dustiness for both systems. The flow meter and length and diameter of connecting tubes were identical because some dust precipitates on the walls of the tubes, especially after passing through the restriction of the flow meter where turbulence causes marked precipitation. All of this dust was washed from the tubes after each test and included for determining efficiencies with that caught by the Palmer apparatus.

The lower system was provided further with an electric precipitator tube following its Palmer apparatus. The air was divided by means of a T-tube and stopcock regulator so that 10 liters a minute measured by a flow meter passed through the precipitator. The precipitator and its electric system were the same as that used in the tests with paint mist; it was operated during a few tests only to determine the amount of dust escaping from the Palmer apparatus and preceding parts, but only the dust caught in the Palmer apparatus and preceding parts was used in calculating efficiencies of the respirators.

METHOD OF COUNTING DUST PARTICLES

The water with dust caught in a Palmer apparatus was transferred to a graduated flask and the apparatus was rinsed with dust-free water and the rinsings added to the flask; all connecting tubes leading to the Palmer apparatus, including the flow-meter head, were washed free of dust and the washings run into the flask; the contents of the flask were then diluted to 500 cubic centimeters in the case of the unfiltered air sample and to 200 cubic centimeters, or in some cases 100 cubic centimeters, for the sample of dust from the air passed through a filter. The object of different dilutions was to make the two dust suspensions of approximately the same densities for counting later.

A brief outline of the method of determining the numbers of dust particles follows, but for a more complete description the reader may refer to Bulletin 144 of the United States Public Health Service.[11]

One cubic centimeter of the dust suspension thoroughly mixed was transferred to a Sedgewick-Rafter counting cell 1 millimeter deep and let settle 20 minutes until the dust particles lay on the bottom. The particles were then counted through a microscope at 110 diameters magnification, using an eyepiece micrometer with a screen grating that outlined exactly 1 square millimeter area of field; the particles viewed in the outline represented those originally present in 1 cubic millimeter. The dust particles in one-fourth square millimeter were counted, making a total count usually ranging from 70 to 150. In some instances when the filters removed much of the dust the counts were somewhat less. Five counts were made, including the center and each corner of the cell, and the average was used in calculations. The particles were nearly all less than 5 microns diameter and the particles counted ranged from that size down to the low limit of vision, about one-half to one-fourth micron in diameter; most particles were about 1 micron in diameter.

[11] Katz, S. H., Smith, G. W., Myers, W. M., Trostel, L. J., Ingels, M., and Greenburg, L., Comparative Tests of Instruments for Determining Atmospheric Dusts. U. S. Public Health Service, Bulletin 144, 1925, 69 pp.

METHOD OF MAINTAINING DUST CONCENTRATIONS IN AIR

Included with the silica particles were the particles always present in the room air; a special test of room air with a Palmer apparatus showed 16 particles per cubic centimeter. As the dust concentrations in the air of the box when spraying was in progress ranged on the average from 160 to 700 particles per cubic centimeter, the room dust was not very important. The room dust, however, was unavoidably included with the silica dust desired in the tests.

In some instances when respirators or filters were known to be efficient in restraining dust, the amount delivered by the spray gun was increased to raise the number of particles in the filtered air for counting purposes. The suspensions of dust in water sprayed were always in concentrations of 1 gram of air-floated silica dust (called "Silica smoke," in the trades) to 100 cubic centimeters of water. The dust suspension was kept evenly suspended in the water by stirring from time to time.

The suspensions used in applying vitreous enamels are of higher concentrations than the 1 per cent just cited. As the spray gun was operated near its minimum delivery for these tests, the low concentration of silica in water was used in order to maintain low concentrations of the dust in the air of the box, according to conditions outlined for the tests, as stated in this paper.

DUST CAUGHT IN THE DIFFERENT PARTS OF THE TEST APPARATUS

It had been desired to determine the efficiencies of the respirators on the basis of the Palmer apparatus alone. Because dust precipitated unavoidably in some of the parts preceding the Palmer apparatus, a determination of the amount of dust lodging in (1) the flowmeter and tubes preceding the Palmer apparatus, (2) the electric precipitator following the Palmer apparatus, and (3) the Palmer apparatus, was made in some special tests in order to ascertain the amounts of dust lodging in the aforementioned parts as compared with the Palmer apparatus and the general efficiency of all of these parts. Table 3 gives the result.

TABLE 3.—*Dust caught in Palmer apparatus and other parts of dust-determining apparatus*

Dust caught in—	Dust particles per cubic centimeter of air entering	Percentage of total dust caught
Palmer apparatus	524	58
Flowmeter and tubes preceding Palmer apparatus	246	27
Electric precipitator	141	15
Entire apparatus	911	100

The Palmer apparatus caught 524 particles from each cubic centimeter of air passed through, while 141 particles per cubic centimeter failed to lodge in the Palmer apparatus and were carried to the electric percipitator, where they were retained. The electric precipitator retained all dust entering with the air, as judged by the precipitation occurring all in the foremost part of the tube. Based on the numbers of dust particles in the air entering the inlet tube, 58 per cent were caught in the Palmer apparatus, 27 per cent in the flowmeter and tubes preceding the Palmer apparatus, and 15 per cent in the electric precipitator. This special test showed the Palmer apparatus 79 per cent effective in retaining the silica particles in water mist that entered it from the conduits. The efficiencies of the respirators and filters were calculated on the basis of the dust caught in the two Palmer apparatuses and the tubes conducting the dusty air to them, on the assumption that each Palmer apparatus would be fully effective in retaining all the dust precipitated in the conduits preceding them.

Both systems of Palmer apparatus and conduits were considered to have equal percentage efficiencies in retaining the dust passed into them. Provided this is true, the efficiencies of respirators determined by the method employed may be considered as real efficiencies in restraining the silica dust in the water mist.

FILTERING EFFICIENCIES OF RESPIRATORS IN WATER-MIST CARRYING SILICA DUST

Table 4 lists the filtering efficiencies of the different respirators against water-mist carrying silica dust. The table describes the filters in the respirators, states the resistances to air flow before and after testing against silica dust sprayed with water into air for a 20-minute period, states the average dustiness of the air as particles per cubic centimeter, and gives the filtering efficiencies determined.

TABLE 4.—*Efficiencies of respirators filtering silica dust in water mist from spray gun. Rate of air flow, 32 liters per minute; period of testing, 20 minutes*

Test No.	Number of respirator [1]	Filter material	Resistance to air flow at 85 liters per minute, inches of water: Start	End	Average amount of dust in air, particles per cubic centimeter [2]	Filtering efficiency of respirator based on numbers of particles, per cent	Remarks
892	1	Sponge	0.25	0.20	190	24	Sponge was wet before test.
888	2	Cotton paper	.70	.75	399	59	1 ply paper.
889	2	do	.65	.70	393	62	Do.
890	2	do	.60	.65	421	61	Do.
885	3	do	.30	.35	309	55	1 ply paper in filter.
886	3	do	.35	.35	334	57	Do.
887	3	do	.55	.60	265	73	2 plies paper in filter.
896	4	Gauzy tissue	.35	.35	318	45	4 plies paper
897	4	do	.55	.60	487	66	Do.
981	5	Cotton flannel	.20	.20	434	62	2 plies flannel.
5001	9	Canton flannel	1.70	1.70	509	80	2 plies flannel built into a cap. This respirator had been used considerably; it was freed of dust before testing by means of compressed air.
5003	9	do	1.45	1.45	546	90	3 plies flannel built into a cap. This respirator was new and unused.
893	6	Silk gauze and cheesecloth.	.10	.10	205	40	1 ply silk, 3 plies cheesecloth.
898	6	do	.05	.05	405	37	1 ply silk, 2 plies cheesecloth.
899	2A	Cotton felt	.10	.10	343	72	
900	7	Cotton wool	.15	.15	162	59	Cotton between cheesecloth; 109 square centimeters of filter was exposed.
894	10	do	3.40	3.55	415	95	Canister contains 2 cotton filters, 1 of toweling, and 600 cubic centimeters of charcoal.
895	10	do	3.50	3.55	321	96	Do.
5002	12	Dense wool felt				99.2	

[1] Numbers correspond to the numbers of figures showing the respirators.
[2] For particles per cubic meter, multiply by 1,000,000.

Increases in resistance were usually negligible because the dust deposited upon a filter was exceedingly small in amount; the maximum increase was 0.15 inch for one of the gas-mask canisters. The average dustiness of the air during the tests ranged from 162 particles per cubic centimeter to 546 particles. Filtering efficiencies showed a minimum of 24 per cent for a respirator with a sponge filter and 99.2 per cent for a Fogler flat felt filter.

The efficiencies are usually a little higher than those determined for similar respirators filtering dry silica dust in air.[12] This must be partly due to the effect of droplets of water around some of the particles, which lodge more readily upon the filters and retain their included dust particles, and it may be partly due to the effect of water in causing agglomeration of dust particles included in droplets when the water evaporates, leaving larger particles composed of several adhering small particles floating in the air.

It seems assured that the particles as filtered were mostly dry because a test made with a konimeter,[13] which impinges air with included dust at high velocity from a small orifice upon a glass plate,

[12] See footnote 3, p. 4. [13] See footnote 11, p. 18.

failed to show appreciable dust upon a clean glass plate, which was examined microscopically. Had the dust been wet or the air very humid the dust would have precipitated upon the plate, together with some moisture. A test with a petrolatum-coated glass plate in the konimeter showed the dust. There were appearances of a few water droplets with a number of dust particles included, or of agglomerated particles, although agglomeration was not determined with certainty. The minute water droplets would last only a very short time in the air before evaporation, because the laboratory air had only about 50 per cent relative humidity, like that of average indoor air in factories in winter, and the amount of water sprayed was very small.

It appears then that unless the spraying is done in a very humid atmosphere, or so much water is sprayed that the air becomes very humid before the droplets of water mist are evaporated, the respirators filter dust particles which have become dry and will be only moderately more efficient in restraining the sprayed silica dust than when the dust is dispersed in air in originally dry condition. If the air in which spraying is done is very humid, higher efficiencies of respirators against sprayed silica dust than those reported herein may be expected. However, tests were not made in humid atmospheres to confirm this. Thus, these tests show efficiencies of respirators under adverse conditions of humidity, which conditions usually predominate, and the protection afforded by respirators worn by sprayers of vitreous enamels will usually correspond to the efficiencies determined.

FILTERING EFFICIENCIES OF FABRIC FILTERS IN WATER-MIST CARRYING SILICA DUST

A series of tests with fabric filters of 100 square centimeters area and composed of various numbers of plies or layers of filters was made with silica dust sprayed in water, analogous to the tests with paint mist previously described. Table 5 lists the results; the filtering efficiencies of the various filters with increasing numbers of plies of fabric are presented graphically in Figure 6. The muslin and filter papers were identical with those reported in Table 2; the other materials in Table 5 were purchased as nearly like those in Table 2 as were available at the time but they were not identical.

TABLE 5.—*Efficiencies of various fabrics filtering silica dust in water mist from spray-gun. Filter area, 100 square centimeters; rate of air flow, 32 liters per minute; period of testing, 20 minutes*

Test No.	Fabric	Number of plies	Resistance to air flow, inches of water		Average amount of dust in air, particles per cubic centimeter	Filtering efficiency of respirators based on numbers of particles, per cent
			Start	End		
877	Cheesecloth, 27 by 30 threads per inch, 36 grams per square yard	2	0.00	0.00	571	15
878	do	4	.02	.02	299	35
879	do	8	.03	.03	368	44
880	do	16	.04	.04	371	58
881	do	32	.07	.07	168	62
871	Muslin, 66 by 66 threads per inch, 130 grams per square yard	1	.10	.10	314	44
872	do	2	.20	.20	408	58
873	do	4	.40	.40	296	71
874	do	8	.80	.80	367	81
875	do	16	2.00	2.05	337	92
867	Muslin (bleached), 68 by 75 threads per inch, 90 grams per square yard	1	.85	1.40	219	69
868	do	2	1.25	1.65	271	84
869	do	4	4.20	5.40	284	95
870	do	8	6.85	7.55	321	97.4
871	do	16	17.45	18.40	768	99.6
853	Canton flannel, 44 by 76 threads per inch, 159 grams per square yard	1	.10	.13	306	51
854	do	2	.25	.30	569	62
855	do	4	.45	.50	94	77
857	do	8	1.35	1.35	212	85
858	do	16	3.10	3.10	304	93
856	Cotton felt, 90 grams per square yard, thickness 0.69 millimeters	1	.05	.10	341	44
859	do	2	.10	.10	315	51
860	do	4	.15	.15	321	58
861	do	8	.35	.35	137	74
862	do	16	1.15	1.15	390	88
863	Filter paper, S. & S. No. 589, black label	1	2.25	3.15	337	97.9
864	do	2	4.15	5.15	387	98.2
866	do	3	6.55	7.35	512	98.9
865	do	4	10.15	11.05	521	99.7
882	Absorbent cotton between cheesecloth, 403 grams per square yard	1	.20	.20	280	74
883	do	2	.60	.60	402	89
884	do	4	1.85	1.85	324	97.9

The efficiencies of fabric filters in increasing numbers of plies filtering silica dust with water mist in air are similar to those found with paint mist as indicated by the curves in Figure 6 when compared to those in Figure 4. Instead of straight lines generally found when testing filters against dry silica dust of uniformly sized particles dispersed in air,[14] the graphs are curved through the range of small numbers of plies, then tend to straight lines. As with the paint mist, the curves must be due to more dust proportionally being caught on the first filters because of the inclusion of agglomerates and dust particles held in water droplets. When the large, easily removed particles are eliminated the individual particles of nearly uniform size tend toward a straight line upon the logarithmic chart.

On the whole, the filters are less efficient against silica dust spray than against the lead paint spray, but are more efficient than similar filters against silica dust dispersed into air in a dry state.[14] The dense filters give very high efficiencies; 4 plies of high-grade chemical filter

[14] See footnote 3, p. 4.

paper restrained 99.7 per cent of the dust; the loose texture cheese cloth shows lowest filtering efficiency, but even this material built up into a layer of sufficient thickness can produce very efficient filters,[15] although they may be impracticable because of their thickness.

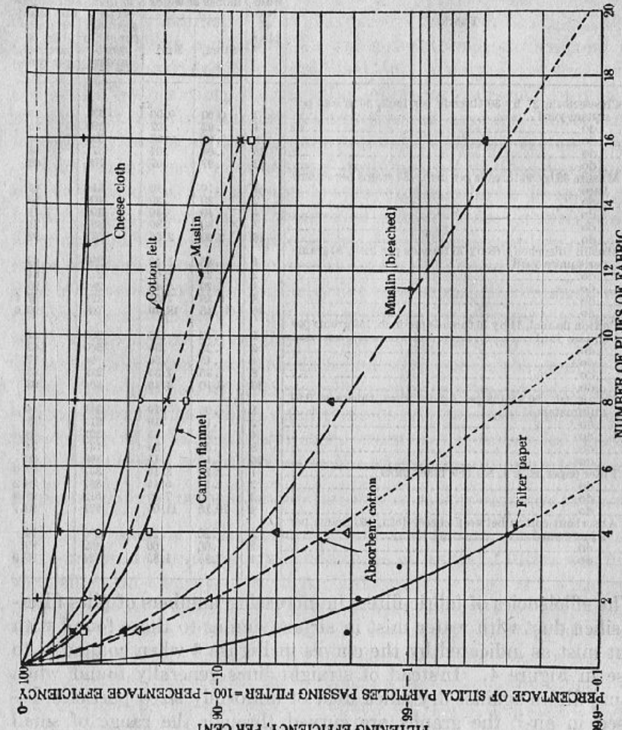

FIG. 6.—Efficiencies of various multiple fabric filters in filtering silica dust sprayed with water into air.

DISCUSSION AND CONCLUSIONS

The questions concerning paint spray proposed when this investigation was undertaken were the following:

1. What filtering material, if any, is adequate—
   (*a*) To reduce the lead content of the air to which a spray coater is exposed from 200 milligrams per cubic meter to 0.6 milligram per cubic meter?
   (*b*) To reduce the amount of benzol under similar conditions from 2,000 to 75 parts per million?

[15] See footnote 3, p. 4.

2. How long would a layer of such material function?
3. How do certain typical masks now available measure up to these standards?

The answers numbered to correspond to the questions are:

MATERIAL ADEQUATE FOR FILTERING PAINT SPRAY AND BENZOL

1. (*a*) Only one filter material (tested as such without respirator setting) equaled the specification during the tests conducted—that is, 3 plies of high-grade chemical filter paper. The figures of question 1 (*a*) state an efficiency of 99.7 on a percentage basis. Several filters tested close to this. The following gave 99 per cent or more: Muslin, 12 and 16 plies; canton flannel, 8 plies; absorbent cotton, 3 and 4 plies; and filter paper, 2 and 3 plies; 6 plies of a cotton felt tested 98.5 per cent efficiency. Had sufficient time been available the tests would have been extended. Under the circumstances it appears permissible to extrapolate the average curves the short extent remaining to the efficiency of 99.7 per cent in order to estimate the number of plies of the different filters producing that efficiency. The extrapolations are shown by dotted lines in Figure 4; they indicate that 99.7 per cent efficiency may be developed by filters of the absorbent cotton in 5 plies, canton flannel in 13 plies, felt in 16 plies, and muslin in (probably) 30 plies. The necessary cheesecloth can not be estimated from the insufficient data available, but a large and probably impracticable number of plies would be necessary.

1. (*b*) Activated charcoal filters can reduce the amount of benzol in air from 2,000 to 75 parts per million or less. A sufficient quantity must be provided; 60 cubic centimeters of the charcoal was found adequate for a period of 19 minutes; under test conditions 600 cubic centimeters lasted 250 minutes. Under conditions prevailing in painting practice considerably longer life may usually be expected.

FILTERING EFFICIENCY AND RESISTANCE DUE TO PAINT

2. Filters for restraining paint mist will function continuously without decrease in efficiency and as long as the resistance to air flow remains tolerable. In general filtering efficiency tends to increase rather than decrease as deposits gather upon filters, but resistance increases at the same time. Gas masks of the Army type may be worn when the resistance does not exceed 4 inches of water. However, the amount of work the wearer can do is reduced unless the work does not require much physical exertion. The capacity of a man for hard work while wearing a gas mask (Army type) is only one-half that without the mask. Respirators with resistances not exceeding 2 inches of water may be worn indefinitely without breathing distress during hard work. With these criteria it may be stated that the filters will function until resistance to breathing through

clogging with deposited paint becomes excessive, which should be a period of hours or even a working day for all the filters tested, excepting possibly the chemical filter paper and the muslin in 16 plies. Only one ply of the chemical filter paper, with resistance of 2.5 inches, could be tolerated at all in a respirator (three plies were needed to test as much as 99.7 per cent efficient); 16 plies of muslin filter have a resistance of 2.2 inches of water; when fresh, both of these might be used in respirators by paint sprayers for probably an hour or two before clogging necessitates change.

EFFICIENCY OF CERTAIN MASKS IN PAINT SPRAY

3. Only the Army type gas mask and the Number 8 respirator with cartridge filter tested 99.7 per cent efficient against the lead in paint spray. Also these are the only two which meet the specifications for benzol, lasting, respectively, 250 and 19 minutes; the others have no capacity for benzol. In filtering the lead the Number 6 respirator with filter of 1-ply silk gauze and 3 plies of cheesecloth was 74 per cent efficient. A sponge filter respirator was 84 per cent efficient. All of the others were 94 per cent or more.

In actual service Army-type gas masks worn by spray painters have been known by the authors to last two weeks or more before needing a change of canister. All of the industrial respirators would probably serve for a day or longer.

Among the questions concerning vitreous enamel spray proposed when this investigation was undertaken were the following:

(*a*) What filtering material, if any, is adequate to reduce the number of silica dust particles under spray-coating conditions from 200,000,000 per cubic meter to 100,000, as determined by the Palmer method?

(*b*) How long would such a layer function?

(*c*) How do certain typical masks now available measure up to this standard?

The answers corresponding are:

MATERIAL FOR FILTERING SILICA-DUST SPRAY

(*a*) No practical filter was found capable of reducing the silica particles from 200,000,000 per cubic meter to 100,000. This represents a filtering efficiency of 99.95 per cent and the highest efficiency attained was 99.7 per cent for a filter of 100 square centimeters area composed of four layers of a chemical filter paper of high quality. This filter, however, had a resistance of 10 to 11 inches of water to air flowing at the rate of 85 liters per minute, which is much too high for use in a respirator. If a resistance of 3 inches of water is taken as a maximum to be tolerated in a dust respirator, the efficiencies given by filters included thereto were as follows:

Material and plies	Resistance, inches of water	Efficiency, per cent
Cheesecloth, 32	0.07	62
Muslin, 16	2.0	92
Muslin, bleached and closely woven, 2	1.25	84
Canton flannel, 16	3.1	93
Cotton felt, 16	1.2	88
Chemical filter-paper, 1	2.3	97.9
Absorbent cotton (403 grams per square yard), 4	1.9	97.9

A filtering efficiency of 90 per cent under the conditions thus appears to be excellent for filters of tolerable resistance, although a few filters can exceed 90 per cent.

FILTERING EFFICIENCY AND RESISTANCE DUE TO SILICA DUST

(*b*) The filters just mentioned would probably function throughout a working day of eight hours if used in respirators by spray-coaters applying vitreous enamels, except in the case of the filter paper. During 20-minute periods of testing no noticeable increase in resistance occurred in the fabrics; a filter paper increased 0.9 inch of water through clogging with dust. As resistance determines the period of usefulness of a filter, rather than filtering efficiency which increases with use, a paper of the type tested could be used probably about an hour, until resistance increase would necessitate changing to a fresh filter. For this reason the fabric filters appear more practicable.

EFFICIENCY OF CERTAIN MASKS IN SILICA-DUST SPRAY

(*c*) No respirator equaled the specifications stated for filtering efficiency; the most efficient respirator was the gas-mask type equipped with a Fogler flat felt filter which gave 99.2 per cent. Next came the gas mask with a canister holding two filters of cotton wool; it was 95 per cent efficient. A Bureau of Mines cap-type of respirator was 80 per cent efficient. Commercial respirators of the pig-snout type ranged in efficiency from 24 per cent for one with a sponge filter to 73 per cent for a respirator with two plies of a cotton paper filter. The pig-snout respirators are not all very efficient in restraining very fine silica dust under spray-coating conditions; the better ones can restrain about half or a little more of the dust in the air as breathed, and so can be of real benefit. The Fogler flat-felt filter is much superior as a filter and it should be preferred under very hazardous dust conditions.

The foregoing conclusions are derived only from laboratory tests with chemical apparatus. They are believed to be correct for present-day respirators free from leakage, used under spray-coating conditions as outlined. Their application must, however, be confirmed by further observation in actual use.

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