Articles on the removal of carbon monoxide with special reference to carbon monoxide gas masks: part II: self-contained respirators

Ruedy, R.

https://doi.org/10.4224/21273323

NATIONAL RESEARCH COUNCIL OF CANADA

ARTICLES ON THE REMOVAL OF CARBON MONOXIDE WITH SPECIAL REFERENCE TO CARBON MONOXIDE GAS MASKS

PART II

SELF-CONTAINED RESPIRATORS

BY

R. RUEDY

RESEARCH PLANS AND PUBLICATIONS SECTION

OTTAWA

FEBRUARY, 1941

PRICE 25 CENTS

N.R.C. NO. 983

SELF-CONTAINED RESPIRATORS

(OXYGEN BREATHING APPARATUS)

Introduction

During the last war it became necessary to adapt a large number of portable oxygen respirators, originally designed for mine rescue work, to military uses either as gas masks or for the immediate treatment of soldiers poisoned by gas. Gas masks and carbon monoxide masks fail to protect when owing to combustion or explosion the oxygen content of the atmosphere drops to three-fourths or one third of the normal fraction, or when the carbon monoxide percentage exceeds two or three. Protection by oxygen breathing apparatus, designed nowadays for two hours' use, must be provided wherever serious fires or sustained air and gas attacks are to be expected. During the last war the volume of oxygen consumed in respirators by German forces alone amounted to about 100 million litres. Protection against carbon monoxide is not complete without oxygen breathing apparatus. In several countries an increasing number of firemen, miners and civilians are being trained in the use of oxygen equipment.

Principles of Construction

In the different types of oxygen breathing apparatus, the mouth, the lungs and the air path in the device supplying oxygen form a closed circuit that has practically no communication with the outside atmosphere. The nose is closed with a clip. The consumption of oxygen and the production of carbon dioxide depend in a considerable measure on the constitution and the state of nutrition of the user but above all on the amount of work performed.

An adult at rest breathes about 500 litres (17 2/3 cu.ft.) of air each hour. Of the nearly 21% of oxygen in the air about one-fifth is taken up in one breath by the blood so that about 25 litres of oxygen are consumed per hour in quiet breathing (o.4 litre per minute.) During times of great exertion the requirement increases tenfold. Oxygen apparatus for an hour's use is therefore designed to provide 120 to 150 litres of pure oxygen.

The air exhaled from the lungs contains 2.6 to 6.6 per cent of carbon dioxide; it has moreover become saturated with water vapour. A large fraction of the carbon dioxide and water vapour are absorbed by chemicals placed in the oxygen circuit of the respirator.

Oxygen is procured in one of three different ways: (a) the use of compressed oxygen in bottles made of special carbon steel or light metal (b) the use of liquid oxygen and (c) from chemicals acted upon by the products of breathing, carbon dioxide and water vapour.

(a) Respirators using compressed oxygen

Main types

Oxygen equipment depending on the use of compressed gas was designed around 1853 by the great physiologist, Theodor Schwann, professor at the University of Liège, Belgium. His "Aerophor" was provided with a bottle of compressed oxygen, a reducing valve, a manometer, a breathing bag for the reception of the exhaled air, and a regeneration cartridge for the fixation of carbon dioxide, that is, it had the five essential parts found in recent equipment. H. A. Fleuss in England followed with his design at a time when the manufacture of high pressure containers had made good progress. The Fleuss Proto and the more recent Fleuss-Davis apparatus are used in Britain.

An innovation, abandoned after a few years, was Dräger and Girsberg's injector (1901), which used the oxygen issuing from the small tank, at the rate of two litres per minute, for setting up a continuous flow of air in the breathing circuit, at the rate of 16 litres per minute, and in modern types at 60 litres per minute. The use of the injector method creates a zone of suction which is unsafe in the presence of leaks.

In the United States the disastrous mine explosions during 1907 led to the introduction and study of oxygen breathing apparatus. Existing models were improved and replaced by the Gibbs, the Paul, and more recently the McCaa breathing apparatus designed by men in charge of rescue work.

Air circulation

In the self-rescuer instrument constructed by Dräger and Tübben for mine rescue work and used in over 100,000 units during the poison gas attacks, in the war of 1914 to 1918, the air passed through the same hose and the same bag from and to the lungs, oxygen being admitted at regular intervals. No breathing valve was provided. The instrument weighed about 10 pounds and provided oxygen for ½ hour.

In the oxygen breathing equipment used nowadays the oxygen from the high pressure bottle passes through the main closing valve and the small opening, 4/1000 to 6/1000 inch, of the pressure reducing valve, into a rubber tube and a metal tube, then through the admission valve into the breathing bag.

The seat of the reducing valve is connected to a lever arm controlled by a diaphragm and a spring, or by a copper bellows. Contraction of the spring closes the valve seat when the pressure on the side towards the breathing bag is higher than 2 1/3 or 3 lb. When the pressure is relieved by oxygen consumption and flow of oxygen into the bag the valve opens again.

In the breathing bag the oxygen mixes with the exhaled air that has been purified by a caustic substance. It is then drawn through the inhalation tube and valve into the lungs. The air breathed out and containing oxygen, carbon dioxide and water vapour is forced through the exhalation valve and tube to the bottom of the regenerator cartridge, where the carbon dioxide is absorbed, and finally into the breathing bag. Parts of the circuit are in contact with cooling surfaces.

A by-pass valve, which is independent of the main closing valve, connects the oxygen bottle with the inhalation tube. When the by-pass valve is opened oxygen is admitted directly to the breathing bag.

The weight of the oxygen equipment is relatively high, owing to the high pressure bottles of special carbon steel; for a volume of two litres the container weighs 4.3 kg., the oxygen 0.42 kg. More recently, however, containers made of an aluminum-copper-silicon alloy (94:4:2 parts, called LAUTAL) have been manufactured and approved in some countries; the weight is reduced to 2.65 kg.

The compressed air shall be at least 98% pure, and in particular cases 99.8% pure.

Field of application

Modern portable oxygen breathing apparatus has proved its worth in the fight against stubborn fires. In fighting a fire at the Mannesmann Coal Mines at Gelsenkirchen in the Ruhr district, between 29 March and 12 May 1938, about 250 Draeger oxygen respirators and 10 Audos instruments were used by the men during the worst hours of the fire, in an atmosphere at 50°C. and rich in carbon monoxide, carbon dioxide and nitrogen. On the most critical night 700 oxygen fillings had to be made and the same number of alkali cartridges replaced. The average number of oxygen fillings and cartridges was 100 per day. The length of time during which the different oxygen respirators were in actual use added up to 10,000 hours. No accident occurred.

Of the Draeger oxygen breathing instruments used, 250 were of the 1924 type, giving 2.2 litre per minute, increased, if necessary, by admitting oxygen through the by-pass valve, and 100 units of the 1934 model, yielding 1.5 litre oxygen per minute, increased automatically, if needed, by a valve responding to the depth of breathing. A special alkali cartridge (L 46) was designed during the fire for work at high temperature.

Several thousand self-contained mine rescue oxygen breathing apparatus have been sold in the United States. The Bureau of Mines owned about 300 sets in 1934.

About 3,150 portable two-hour oxygen breathing units were available in German mines at the end of 1937. Of this number 2,000 were Draeger models 1924, 500 Draeger 1934, 300 Draeger 1936, 200 were Audos (1925 to 1927 models), and 150 Audos 1932. About 1,100 units were in actual use during 1937 for rescue work.

The rescue workers called Draegermen in Nova Scotia are not equipped with portable Draeger apparatus. Modern oxygen breathing apparatus is not intended for use at temperatures below zero.

(b) <u>Liquid oxygen breathing apparatus</u>

Unless liquefaction plants are operated in the neighbourhood, the field of application of liquid oxygen breathing apparatus is limited, since condensed oxygen can be stored for a limited time only without considerable losses.

According to the Peace Commission, 136 liquid oxygen plants were used by Germany during the war of 1914-1918 in northern France; they yielded five million pounds of liquid oxygen , used mainly for explosives. Portable plants furnishing 3 to 5 litres of liquid oxygen per hour proved to be useful. One litre of liquid oxygen means about 875 litres of gaseous oxygen.

Liquid oxygen equipment is suitable for military aviation; its use eliminates the high pressure steel bottle which is a hazard when the aeroplane is hit by projectiles. Respirators are resorted to when flying above 4,500 metres (15,000 feet).

In the apparatus worked out by the Heylandt Gesellschaft fur Apparatebau, Berlin-Mariendorf, the liquid oxygen is stored in an evacuated double-walled metal flask. The inner cavity is closed at the top by means of a solid stopper. The oxygen is forced through a syphon to the top of the bottle where side tubes lead it to the vaporization chamber that surrounds the neck of the flask. A special valve admits the oxygen to the air bag. The exhaled air escapes into the surrounding atmosphere. Before the start of the aeroplane the valve is set so that it begins to function at a certain altitude.

(c) Equipment using chemicals as sources of oxygen

Two groups of instruments are available and used to some extent in Europe though not admitted in mine rescue work: (1) equipment in which oxygen is set free by the exhaled air (2) equipment in which the evolution of oxygen is independent of breathing.

Manufacture of oxygen by the products of respiration

M. Bamberger and F. Böck were among the first to apply the action of the products of breathing, carbon dioxide and water vapour, upon alkali peroxides, to the construction of respirators (Zeits. ang. Chemie 17:1426-1437. 1904). The reactions are represented approximately by the formulas

$$2Na_2O_2 + 2H_2O = 4NaOH + O_2$$
$$4NaOH + 2CO_2 = 2Na_2CO_3 + 2H_2O$$
$$2Na_2O_2 = 2Na_2CO_3 + O_2$$

A cartridge filled with sodium peroxide combines the function of the alkali cartridge and the oxygen bottle in compressed oxygen respirators. Cartridges with sodium potassium peroxide yield a greater volume of oxygen than sodium peroxide alone.

The Pneumatogen apparatus by Bamberger and Böck, the Drägeron equipment (Draeger), the Proxylen of the Hanseatische Apparatebau and other types of chemical respirators were not a success, despite the amount of scientific and practical studies devoted to their improvement.

The Auer Gesellschaft and the Scheideanstalt took out numerous patents on the sensitization of the active masses. Addition of copper and manganese, and partial hydratation (about 6% water) increase the response of the mass to the exhaled gases. The slow start of the oxygen evolution remains, however, a drawback; it is necessary to breathe lightly for a time, at complete rest, until the instrument has started to work. In order to shorten the period of waiting a small oxygen container can be added (Drägerogen 1928), or a special chemical oxygen cartridge used. More recently the chemical mass has been improved at the Scheide Anstalt; cautious hydratation of the whole substance is obtained by adding $Na_2O_2 \cdot 2H_2O$ or steam; the product is then briquetted and granulated (NEU PROXYLITH). The mass contains 4 to 9 molecules H_2O upon 12 molecules Na_2O_2, and is perfectly stable after having been heated to a temperature between 50° and

120°C.(Brit. Patents 280,554; 305,101; 319, 393; 320,985 Swiss Pat. 134,784; 141,234; 142,021 F.P. 645,275; 672,272). Respirators containing the improved chemical mass are used on board ship. The rate of response is increased greatly by inserting a small carbon dioxide cartridge into the circuit; a pressure exerted on the cartridge releases four litres of carbon dioxide and hastens the production of oxygen.

A fundamental disadvantage of the chemical oxygen apparatus is the lack of correspondence between the time when the need for more oxygen is greatest, and the increase in the rate of oxygen delivery. While the use of potassium sodium peroxide gives one molecule of oxygen for each molecule of carbon dioxide, in order to produce more oxygen at a given moment carbon dioxide would have to be exhaled first at a greater rate. An increase in the output of carbon dioxide, however, is possible only if more oxygen is available from the first, and a vicious circle results if no proper measures are taken.

Instruments in which the production of oxygen is independent of the rate of breathing.

In the 1929 NASZOGEN Apparatus of the Inhabad Company, Berlin, oxygen is supplied by the decomposition of a specially prepared briquette of chlorate-perchlorate (Brit. Pat. 341,975 1929). The addition of catalyzers e.g. cobalt oxide, and reducing metallic powders, allows the chlorate to furnish oxygen as soon as the temperature has reached 300°C. A knock produces local heating and starts the reaction at one point; the reaction then spreads through the entire mass and gives 2.5 litres of oxygen per minute for about half an hour. The breathing bag is large; it holds 5 to 7 litres and constitutes a reserve needed during times when strenuous work has to be performed. Half-hour briquettes (80 litre oxygen) weigh 0.5 kg., a one-hour briquette (150 litre oxygen) 0.8 kg., a two-hour briquette (320 l. oxygen) 1.6 kg. The approaching exhaustion of the briquette is indicated by the odour of camphor. The briquettes are claimed to be bullet-proof.

Information on improvements in oxygen breathing apparatus is presented in special Information Circulars of the United States Bureau of Mines (No. 7030 (1938), 7086 (1939) and 7130 (1940 in the periodical: "Draeger Hefte", issued by the Draeger Work, Lubeck, Germany, "Gasmaske", published since 1929 by the Deutsche Gasglühlicht Auer Gesellschaft (Degea) Berlin, and journals devoted to chemical warfare. A German film "Army (oxygen) breather" illustrates the use of portable oxygen breathing apparatus in the protection of soldiers and civilians during air raids.

The testing, methods are outlined in Information Circular 7130 of August 1940 and in: Self-contained oxygen breathing apparatus, a handbook for miners, U.S. Bureau of Mines. Government Printing office 1934.

List of Recent Articles

1. BALLA, K. Note on completely closed oxygen rescue apparatus. Montan. Rundschau 26: 1-3. 1934.

   Details of Degeo-Audos respirator.

2. BANGERT, Fritz. Draeger alkali cartridges for oxygen respirators. Draeger Hefte 199: 3990-3992. 1938.

   Use of an improved caustic material L 46 in the cartridge eliminates the formation of a caustic liquid. The empty spaces left in the old type cartridge for the reception of caustic liquid can be filled with grains of caustic material. An increase in the power of absorption is obtained and the device for holding the liquid in the upper part of the cartridge can be dispensed with unless the cartridge is used in an upright position. The new material responds equally well in a warm or in a cold atmosphere. It is placed on a few dozen sieves with regularly spaced horizontal cylindrical bulges, one above the other so as to form a vertical channel. The material absorbs not only CO_2 but also the normal amount of H_2O formed during breathing. The carbonate formed at the surface of the grains forms an impervious crust when the cartridge is allowed to cool so that cartridges once used are not satisfactory for a second use (in contrast with the filling used by the U.S. Bureau of Mines).

3. BECK, Theodor. History of the development of respirators. Südd. Apotheker Ztg. 74: 248-254; 258-265. 1934.

4. BENDER, K. New Draeger Oxygen Inhalation Equipment. Draeger Hefte 195: 3782. 1938.

   The instrument is to be used for the transport of injured men through CO gases in a mine.

5. BENDER, K. Testing the performance of the new Alkali cartridges L 46. Draeger Mitteilungen No. 40: 1-3. 1938. (Supplement to Draeger Hefte No. 195)

In two tests two cartridges taken at random removed the CO_2 produced during work amounting to 100,000 kg.m.(0.365 horse power hour). The use of a new oxygen flask holding 2.6 l. and filled with oxygen at 200 atm. pressure(520 litre oxygen) changes the oxygen respirator Model 160A for mines from a two-hour apparatus to a six-hour apparatus giving one quart oxygen per minute.

6. BÖCK, F. A new pneumatogen apparatus "1910 Model Back Type." Oesterr. Z. Berg. Hüttenw. 5 and 6: 59-69; 77-83. 1911.

Improvements in a breathing apparatus that depends on the regeneration of exhaled air by means of alkali peroxides (German Patent 168,717, March 3, 1904; 176,506 of April 23, 1905, and 208,565 of June 6, 1908 by Max Bamberger, Friedrich Böck and Friedrich Wanz, Vienna.

The history of regenerating apparatus with gaseous oxygen is reviewed in an article by Gustav RYBA, Oesterr. Z. Berg. Huttenw. 60: 427-431. 444-447. 458-462. 472-475. 487-489. 505-508. 546-547.

7. BOOTHBY, Walter M. Otis O. Benson and W. Randolph Lovelace. Emergency oxygen unit for use in parachute escape, or in case of failure of regular oxygen supply. J. Aviation Medicine 11: 59-66. 1940.

8. DAVIS, R.W. Gorman. Respirators. Chemistry and Industry 17: 334-336. 401. 1939.

A satisfactory respirator will stop at least 94% of a dust cloud composed of dust particles of 0.1 to 0.2 micron diameter with a maximum initial resistance to inhalation of ¾ inch water at an air flow of 85 l. per minute. The Home office has approved certain types of self-contained oxygen breathing apparatus (not mentioned in the article).

9. DEWEY, Bradley. Production of gas defense equipment for the army. Another creditable chapter of American manufacturing achievement during the war. J. Ind. Eng. Chem. 11:185-197. 1919.

With a sentence mentioning oxygen,inhalators, a mechanical apparatus for administering oxygen to gassed persons.

10. DRÄGER, Heinrich. New Dräger self-rescuer for one hour service (oxygen breathing apparatus). Draeger Hefte 183: 3094-3095. 1936.

11. DRÄGER, Heinrich. Development work of the Draeger Plant in the mining field. Draeger Hefte 202:4158-4161. 1939.

Two improvements were aimed at: creation of apparatus leaving sufficient oxygen after two hours of strenuous work, and reduction of weight for two-hour equipment in order to bring it nearer to the weight (11.55 kg.) of the army oxygen respirator.

The increase of the oxygen reserve was accomplished by using two-litre flasks of light steel filled at 200 atmospheres pressure and tested each year. The constant flow of oxygen through the valve amounts to 2.1 litre per minute; a valve controlled by respiration increases the flow if necessary (Model 160 B). The equipment weighs 17.65 kg., that is 0.85 kg. more than Model 160 A of 1934.

Model B.G. 181 (1.5 l. flask at 200 atm.) of reduced weight yields 1.5 litre of oxygen per minute; the alkali cartridge is freely exposed and surrounded by a paper or felt wrapper to be kept moist in order to promote cooling. A properly cooled cartridge absorbs 50% more CO_2.

12. DRINKER, P. Uses and limitations of respiratory protective equipment. Mech. Eng. 58: 171-175. 175-176. 1936.

13. ENGELHARD, Hermann and Karl PÜTTER. Moisture in respirators with one or two-way breathing. Zeits. Elektrochemie 39: 687-690. 1933.

14. FERGUSON, R.H. Equipment shows progress in respiratory protection. Nat. Safety News 28: 37-38. 71-72 (Oct.) 1933.

15. FLÖRKE, Wilhelm. Research with breath filters. Z. phys. Chem. Unterricht 51: 27-29. 1938.

Simple precautions are indicated, to be taken in determining the breathing resistance.

16. FORBES, J.J. and G.W. Grove. Protection against mine gases. U.S. Bureau Mines Miners' Circ. 35: 1-52. 1937.

17. FORSTMANN, R. Development of oxygen respirators in mining. Glueckauf 75: 805-809. 1939.

18. GARSAUX. Oxygen inhalers for aviation at high altitudes. La nature 54, I, 193-196. 1926.

19. GRAHAM, J.I. Respirators for absorbing CO. Colliery Guardian 128: 1635-1636. 1924.

Tests to determine the efficiency of the Burrell All-Service canister and Mine Safety Appliances Self-rescuer. (The construction of the carbon monoxide self-rescuer is described by A. C. Fieldner, S. H. Katz and D. A. Reynolds (U.S.A.) Bureau of Mines, Repts. of Investigations, No. 2591 (10 p.). 1924.)

20. GROVE, G. W. Refilling small cylinders. Chem. Ind. 46: 322-324. 1940.

21. HAASE-LAMPE, Wilhelm. Oxygen and air respiratory devices. Chem. Zeitg. 45:117-118. 142-146. 1921. C.A. 15:1363. 1921

Descriptions with diagrams of German types of oxygen and air supply instruments: Portable breathing apparatus for oxygen - Group (a): Injector apparatus (Draeger and Westphalia, each in 2 sizes for 1 or 2 hr. service, helmet or mouth breathing. Group (b), without injector (1) Draeger-Tuebben for mouth breathing, ½ hr. service (2) Navy respirator for mouth breathing, ½ hr. (3) Army Oxygen breather (Model HSS 1916) for mouth breathing 1 hr. (4) Oxygen protection SS apparatus in 1, 2 and 3 hour sizes for mouth breathing (5) Magirus helmet respirator for O_2 and differing from all other types by having in place of a caustic cartridge an excess of oxygen. Group (c) using liquid air (Aerolith (1906) and Draegerolith (1920) for 2 hr. service. Group (d) apparatus for generation of oxygen, 1 hr. size (Oxylith of Jaubert or Perolit cartridge of the Scheideanstalt).

There are three types of air-supplying respirators (Koenig, Magirus and Westphalia), all with helmets and tubes for pumps.

22. HAASE-LAMPE, Wilhelm. Use, care and storage of the Army Oxygen Breathing Apparatus(with 19 illustrations). Draeger-Hefte 198: 3936-3944. 1938. (also Gasschutz und Luftschutz 1938).

The Army Oxygen Respirator supplies the wearer for one hour with the necessary oxygen. It must be used when the ordinary gas mask is no longer sufficient protection, that is, in closed rooms where lack of oxygen threatens, when the products of breathing reach high concentrations, or in the presence of poisonous gases not absorbed by gas masks. The oxygen respirator is carried in the same way as a knapsack. A gas mask has to be connected with the oxygen respirator after removal of the inhalation valve rubber plate and complete tightening of the exhalation valve of the mask since the oxygen apparatus has separate valves; these do not allow the used air to mix with the inhaled air into which a steady stream of oxygen flows.

The cover supplied for the oxygen respirator hose can be used for closing the exhalation valve of the gas mask. The nozzle of the respirator admits 1.5 litre oxygen per minute from a one-litre oxygen tank; the respiratory control increases the supply during strenuous work to 2 litres per minute. When the manometer indicates 20 atm., the oxygen reserve has dropped from 150 to 20 litres, and will be exhausted in about ten minutes.

Before being put to use the apparatus must be emptied by breathing in order to remove about eight litres of nitrogen present in the hollow spaces of the equipment and likely to distend the breathing bag after the admission of oxygen.

A 35-mm. film (784 meter long) and a 16-mm. film are available to illustrate the use of the Army Oxygen Breather in air defence training.

The German respirator must not be allowed to reach temperatures below freezing. Neither CO masks nor oxygen respirators with their alkali cartridge can be expected to work properly at low temperatures. The respirator must be placed while warm in an insulating box (No. 199. p. 4021) before it is taken out in freezing weather.

23. HAASE-LAMPE, Wilhelm. Oxygen the helper. Draeger Hefte 200: 4035-4049. 1939.

About 1,000 million litres of oxygen were used in the war of 1914 to 1918 for the treatment of soldiers poisoned by gases, in trenches and in hospitals. Oxygen treatment apparatus and respirators for this purpose were designed in 1916 by Bernhard Draeger.

Experience has shown that air containing 40% to 80% of oxygen breathed for hours on end at normal pressure, produces no disturbance as far as respiration is concerned.

Modern military respirators and oxygen treatment apparatus are described.

24. W. HAASE-LAMPE (with E. Naujoks, H. Stelzner, Gerh. Stampe, Fritz. Bangert, Franz Hollmann, K. Bender and H. Rullmann) Draeger-Gasschutz im Luftschutz (Draeger Gas Protection in Air Raids). Eighth edition, enlarged. Lubeck. H. G. Rahtgens 1939.

Reprint of the technical section of the 1939 Draeger Gas Protection Almanac (Respiration in air raid shelters, Draeger shelter ventilator, tests on gas masks, new gas detector model 16. Use, storage and upkeep of universal oxygen breathing apparatus. Draeger alkali cartridges, disinfection.

(See also W. Haase Lampe, The oxygen rescue methods and gas protection Vol. I, II (1923) and III Construction of apparatus, 1929, Rahtgens G.M.B.H. Lübeck).

25. HALDANE, J.S. Report upon smoke helmets prepared for use in the London Fire Brigade 1913.

26. HANCOCK, W. Time factor and other points of importance in use of self-contained breathing apparatus. Institn. Min. Eng. Trans. 87. 49-60 (discussion 60-67) 1934. Eng. Ind. 937. 1934.

Experiments to ascertain how long four trained rescue men could be expected to survive, assuming that they were entrapped with a full supply of compressed oxygen. It is desirable that each rescue man shall acquire the art of feeding himself at correct intervals (several minutes) with fresh puffs of oxygen and that he shall clear his bag and lungs of nitrogen with every fall of 40 atmospheres pressure, and that he shall learn to acquire the most comfortable position. A two-hour supply of oxygen may then be made to last for 10 or 12 hours.

The instruments tested were: Proto breathing apparatus, Novita Apparatus, with a 10.5 cu.ft. cylinder charged with pure oxygen at 120 atm. pressure, a Novox apparatus, a Carbetha fitted with a sylinder charged with two pounds of liquid CO_2, supplying a reviving mixture of air and CO_2.

27. HEINRICHS. Development of the construction details of the modern gas mask. Z. ges. Schiess Sprengstoffw 29: 27-30. 182-187. 248-250. 1934. C.A. 28: 6881. 1934.

Filter, oxygen apparatus and the chemical oxygen apparatus are described.

28. HETZEL, K.W. Skin breathing in relation to protection against poisonous gases. Gasschutz Luftschutz 2:236-239. 1932.

The probability of poisoning through skin is negligible with CO and CO_2, not necessarily with HCN, H_2S and aniline.

29. HLOCH, Albert. Chemical reactions in the oxygen respirator mask. Z. ges. Schiess Sprengstoffw. 25:379-381. 422-425. 1930. C.A. 25: 1924. 1931.

As fillers the alkali peroxides Na_2O_2, K_2O_4, $KNaO_3$ do not furnish sufficient O_2; hence a small auxiliary O_2 container is necessary. Other objections are: (1) the high temperature of the air entering the lungs and (2) the high breathing resistance of the canister.

A newer type of filler contains alkali chlorates (Z. ang. Chemie 43: 732-734. 1930); the reaction which furnishes O_2 is started by a kind of ignition which results in an initial burst of O_2; the reaction then continues at a rate sufficient for the needs of respiration.

30. HLOCH, Albert. The oxygen-evolution process in the new chemical gas mask. Z ang. Chemie 43: 732-734. 1930.

The older gas masks of the type that had oxygen supplied from chemicals suffered from several defects, such as; high temperature (60° C.) of inhaled air, caking of mass and high breathing resistance, lag of 2 or 3 minutes, failure at temperatures below freezing. In the new mask, the NASZOGEN of the Inhabad Co., Berlin, a rod of $KClO_3$ with a catalyst develops O_2 at the rate of 2½ litres per minute for 30 minutes, at 300° C., the O_2 being filtered to remove KCl dust, and passed into the KOH container in the closed breathing circuit where CO_2 is absorbed. Advantages over peroxides are quick starting and uniform evolution according to the equation

$$KClO_3 = KCl + 3O_2/2 + 9.8 \text{ k.cal.}$$

The rate of oxygen supply corresponds to the requirements of a man walking at the speed of 4 miles per hour; a breathing bag of 7 litre volume is filled with oxygen at the start of the operation; it supplies the excess volume of air required during periods of greater exertion(assumed to be two periods of five minutes each). The heat of reaction tends to accelerate the decomposition after it has been started by a knock against one end of the $KClO_3$ rod; compounds added to the chlorate cause heat absorbing reactions to take place so that the rate is reduced to 2½ litres of oxygen per minute after the first minutes of rapid decomposition. Oxygen is set free even at -40°C.

The temperature of the inhaled air is relatively low. The fixation of the breathing products on the KOH cartridge generates about 126 k.cal. per hour (when walking 4 miles per hour) so that the air leaves the cartridge at a temperature of 120°C. It is necessary to cool this air to 50°C. When sodium peroxide is used the heat of reaction increases the heat set free to 400 k.cal. per hour, whereas the production of oxygen from chlorates adds only 130 k. cal. per hour, but since this heat is generated outside the circuit proper, not more than 2 or 3 k.cal. are added to the 2.5 litres of oxygen per minute.

31. HLOCH, A. The regeneration of respiratory air with alkali peroxides in gas protection apparatus. Ang. Chemie 46: 45-47. 1933. C.A. 27:1419. 1933.

Na_2O_2 is not suitable for complete regeneration.

$KNaO_3$ (Na_2O_2 + K_2O_4) and K_2O_4 will serve the purpose theoretically but practical difficulties exist.

Chemical oxygen sources reduce the weight of the apparatus by one-fourth and the price by one-tenth in comparison with compressed oxygen supply.

The respiration quotient R, that is, the ratio between exhaled CO_2 and O_2 consumed in the same breath varies between 0.8 and 1.0 (Douglas, Haldane, Henderson, Phil. Trans. 203:245-249. 1913), exceptionally it rises to 2.0 when extraordinary output is furnished. Chemical regeneration must be conducted in such a way that the ratio between CO_2 fixed and O_2 evolved is not over 0.8 in normal breathing. For

$$Na_2O_2 + CO_2 = Na_2CO_3 + O_2/2$$
$$Na_2O_2 + H_2O = 2NaOH + O_2/2$$

the quotient is equal to 2, that is, two molecules of CO_2

are required in order to obtain one molecule of O_2, whereas the exhaled air furnishes but 0.8 molecule CO_2. The contribution made by H_2O vapour, which saturates the exhaled air at 31°C., corresponds to the same ratio 2. Each molecule CO_2 and each molecule H_2O is capable of generating one molecule oxygen. The joint action of CO_2 and H_2O gives a quotient equal to 1.7. The use of hydrated peroxides suffers from the drawback that the relation between expired air and oxygen need is no longer maintained. There is one possible solution, however, the reaction of K_2O_4 (quotient equal to 2/3) or of $KNaO_3$ (quotient = 1). Whether the output obtained in practice is satisfactory remains to be studied.

32. HLOCH, A. Production of gaseous oxygen from active oxysalts. Chem. Zeitg. 57: 553-554. 1933.

Oxygen is a by-product of several industries and available at a low price. Its manufacture from chlorates costs about three times and its manufacture from alkali peroxides ten times as much as its production from liquid air. Shipping costs for compressed oxygen are high, however, and allow oxygen produced from chemicals to compete where small quantities are required for special purposes (occasional welding and cutting, respiration). In air raid shelters the production of oxygen has to be combined with the absorption of CO_2. Sodium peroxide with chloride of lime, pressed into cubes (Jaubert's Oxylith) has acquired importance; oxygen is set free when water is added, according to $Na_2O_2 + Ca(OCl)Cl + H_2O = 2NaCl + Ca(OH)_2 + O_2$. The I. G. Farben manufacture Oxygal which is placed into a retort and ignited; 1 kg. of Oxygal produce 240 l. oxygen, the gas may be obtained at a pressure of 15 atm. Chlorate and perchlorates containing catalysts (MnO_2, Fe_2O_3) and a diluting mass (diatomite, pumice) are used as briquettes (Jaubert, Zeiss); the oxygen is contaminated by chlorine unless the reaction is slowed down by endothermic processes.

In respirators the Pneumatogen used during the last war was replaced by Proxylen (sodium potassium peroxide containing 6% water) and the reaction temperature reduced from 200°C. to a temperature at which the grains are no longer apt to form a cake. With chlorates the oxygen is produced independently of the products of respiration.

33. HOFF, C.V. New Auer Company high-capacity cartridges for mine oxygen respirators. Gasmaske 9:110-114. 1937. C.A. 32: 1007. 1938.

The cartridges show considerably increased absorption of CO_2 and a better utilization of available O_2. Reduction of the temperature of the respired air has not been obtained.

34. HOLLMANN, F. Description of the Dräger self rescuer models 180 and 200. Draeger Hefte 183: 3096-3098. 1936.

Model 180 is a one-way breathing apparatus. Model 200 is a closed system apparatus.

35. HOLLMANN, F. The new Dräger oxygen-breathing apparatus model 210. Draeger Hefte 187:3331-3336. 1936. C.A. 31: 2312. 1937.

36. HOLLMANN, Franz. Draeger Universal Testing Instrument for oxygen respirators. Draeger Hefte 195: 3783-3785. 1938.

In the instrument using a water column the water frequently runs out during the transportation from storage to destination. The new instrument uses five membranes in series in place of the water column; a lever indicates the movement of the membranes. Pressure differences of 1 mm. water column give an unmistakeable deflection (these are differences of the order of 1/10,000 atm.). Since human breathing produces a pressure of up to 1,000 mm. water column, the membranes had to be made strong enough to withstand such pressures.

The same instrument serves for the determination of constancy of flow, leaks, pressure exerted by the high pressure valve and pressure required for working the respiration valves.

The instrument weighs about 10 lbs.

37. JAUBERT, George F. Respirators with alkali peroxides (oxylith). Compt. Rend. Ac.Sc. 197: 484-486. 1933.

Cartridges with granulated or pressed alkali peroxides without water are suitable for regenerating the exhaled air, in particular Na_2O_2(oxylith S), $KNaO_3$ (oxylith PS), K_2NaO_5 (oxylith PPS). A cartridge containing 181 g. of K_2NaO_5 yields 216 l. oxygen. Cartridges with dry peroxide last indefinitely; they are not combustible but powerful oxidation agents and combustible substances must be kept away.

38. JAUBERT, George F. Protection (against gas warfare) by means of self-contained equipment and shelters.

Mém. compt. rend. soc. ing. civils France. 87:305-372.1934

An address dealing exhaustively with self-contained equipment in which the air is continually regenerated and recirculated.

39. JAUBERT, George F. Respiratory quotient and regeneration of air in a closed circuit by peroxides (Oxylith). Gaz Combat. Défense pass. Feu-Séc. 1:27-44. 151-165. 252-267. 1935.

Substances theoretically suitable for the production of oxygen by means of exhaled air, in the presence of catalyzers, are: Na_2O_2 (oxylith S), $KNaO_3$ (oxylith PS), K_2NaO_5 (Oxylith PPS), K_2O_4 and Li_2O_2. Of these only Oxylith PPS can be stored without decomposition.

40. JONES, A.I. Treatment of casualties from lung irritant gases with particular reference to the use of oxygen and carbon dioxide mixture. J. Ind. Hygiene 22: 235-243. 1940.

41. KATZ, S.H. and J.J. BOURQUIN. Comparison of gas masks, hose masks, and oxygen breathing apparatus. Bur. Mines Repts. of Investigations No. 2489 (5 p) 1923.

42. KINNEY, S.P. Atmospheric conditions and physiological effects produced on trainmen by locomotive smoke (in tunnels). Bureau Mines Repts. Investigations No. 2494 (15 p) 1923.

A respirator to cover the nose and mouth and to be attached to the air-line of the train is illustrated and described.

43. KRAUSKOPF, F.C. Laboratory preparation of oxygen and of chlorine. J. Chem. Educ. 12: 293-294. 1935.

44. KRUTZSCH, J. and H. KAHLE. Chem. Fabrik 7:452-453. 1934.

45. KUPTSCHINSKI, P. Closed respirators. Chimija i Oborona 10:10-12. 1934.

Description of oxygen respirators with special details on German apparatus.

46. LEGENDRE, René and Maurice NICLOUX. Mask to aid in the artificial inhalation of oxygen. Compt. rend. 176: 335-337. 1923.

47. LEMCKE, Walter. Fixation of carbon dioxide in oxygen respirators. Gasmaske 9: 107-109. 1937. C.A. 32: 1007. 1938.

Caustic soda performs satisfactorily as CO_2 absorbent in a closed-circuit O_2 respirator but requires too much space. Ordinary soda lime utilizes the space more efficiently but is less effective as an absorbent and saturates the air with moisture. The Auer Co. has combined the advantages of the 2 absorbents in their new high capacity cartridges.

48. LÖHNER, L. The physiology of breathing with gas masks. Wien. klin. Wochschr. 50:749-753. 1937. C.A. 32: 1805. 1938.

The respiratory cycles in different levels of activity are discussed.

49. MARCILLE, R. Apparatus for defense of toxic gases. Compt. rend. 192: 382-384. 1931. C.A. 25: 1924. 1931.

Respiration takes place in a closed bell. The expired air is passed into a soda solution which absorbs CO_2, the diminished volume of air is supplemented by pure O_2 from a small tank of compressed gas. The apparatus weighs 10 kg. and maintains comfortable respiration for one person for 2 to 3 hours.

50. MARK, Hermann. War chemistry. Atti X ° congr. intern. chim. 1: 313-336. 1938.

51. MATAGRIN, Am. Gas masks and respirators. Rev. chim. ind. 42: 209-214. 237-244. 264-271. 1933.

52. MIUKHILENKO, Y.I. Action of salts on the decomposition of sodium peroxide by water. J. Russ. Phys. Chem. Soc. 53: 350-356. 1921. C.A. 17: 3143. 1923.

The reaction $Na_2O_2 + H_2O = 2NaOH + O + 16$ k.cal. soon stops, but the presence of small amounts of certain salts induces the reaction to proceed to completion to varying extents. The use of compressed sticks of a mixture of Na_2O_2 with a catalyzer (powdered copper) in the cartridges of oxygen-yielding masks is recommended.

53. PARKER, D.J., G.S. McCaa, and E.H. Denny. Self-contained oxygen breathing apparatus, a handbook for miners, revised in 1933 by G. W. Grove. 1934. 307 p. 45 fig.

Detailed information on construction, testing, use, and care of five types of approved two-hour apparatus by W. E. Gibbs (approved 1920), James W. Paul (approved 1920), Fleuss-Davis (1924) (a redesign of the Fleuss-Proto by the Seibe-Gorman Co. of London, England), G.S. McCaa (1925), Draeger (1924). W. E. Gibbs devised his apparatus while employed by the U.S. Bureau of Mines; James W. Paul directed the mine rescue work of the Bureau from 1910 to 1915, and G.S. McCaa was mine safety and district engineer for the Bureau from 1918 to 1929. The McCaa two-hour equipment and McCaa half-hour equipment is manufactured by the Mine Safety Appliances Company, Pittsburgh, Pa.

The types used differ in the design of frames, valves, mouthpieces, breathing bags, tubes and in the arrangement of the circulatory system.

The construction of each apparatus is described according to the following headings: Oxygen bottle, reducing valve, breathing bag, regenerator, cooler, mouthpiece, air circulation and 16 tests (for excess moisture, tightness of valves and pressure tube, breathing bag, air tightness, bypass tube).

54. PAYNE, H.M. Development of oxygen rescue and revival apparatus. Met. Chem. Eng. 9: 224-225. 1911.

55. POGGI, R. Determination of oxygen produced by peroxides. Annali chim. appl. 22: 493-496. 1932.

The volume of oxygen obtainable from Na_2O_2 and similar products used in respirators is determined in a bulb similar to the one used in Schroetter's method of CO_2 determination by adding diluted H_2SO_4 (1:4) to the active mass.

56. QUADT, Eberhard. The (German) army oxygen breather. Gasmaske 10: 10-13. 1938. C.A. 32: 3856. 1938.

This respirator is used when the filter-type army mask is not applicable, i.e. when O_2 in the air is below 15%.

57. RYBA. G. Lungen automatische Gas Tauchgeräte and O_2 Wiederbeleber, System Audos. Union Verlagsbuch handlung Teplitz-Schonau.

58. SCHMID, Franz. The Spasny inhalator apparatus. Montan. Rundschau 21:412-415. 1929. C.A. 24: 1166. 1930.

A description of apparatus containing KOH-cartridge, O_2 cylinder, reducing valve and accessory parts, designed for life-saving work and use in mines.

59. SCHRENK, H.H. Testing respiratory protective equipment for approval. Bureau of Mines Information Circular No. 7130 August 1940.

A brief review is given of the method of approval applying to respiratory equipment by the U.S. Bureau of Mines.

Seven kinds of oxygen respirators were approved between the years 1920 and 1940 (two in 1920, one each in 1924, 1925, 1929, 1931 and 1937). "Mechanically oxygen-breathing-apparatus has improved greatly and present equipment is lighter in weight." The oxygen breathing apparatus introduced into the United States from Europe about 1907 or 1908 came into wide use with the creation of the Bureau of Mines in 1910 which assisted in the development of American types.

60. SCHUSTER, H. Influence of gas mask (Dräger model GM 40) on the wearer during rest and work. Arbeits physiol. 9:351-365. 1936.

61. SCHWENNINGER, O. Gas masks (gas protection apparatus) with closed circuit. Z. Ver. deut. Ing. 74: 338-342. 1930.

Various forms of German breathing apparatus are described in which oxygen is supplied in tanks or from chemicals. The respiration controlled oxygen breather AUDOS built by Hanseatische Apparatebau and the breather with PROXYLITH filling are described.

62. SMOLCZYK, E. Chemical oxygen respirators. Gasmaske 3: 117-121. 1931.

Description of the Degea Proxylin instrument.

63. SMOLCZYK, Ed. Respiratory protection. Gasmaske 8:109-117. 1936. C.A. 30: 8426. 1936.

A moving-picture film is described which illustrates filter-type gas masks, O_2-breathing apparatus, fresh air or hose masks, and military equipment.

64. STAMPE, G. and E. Horn. The method of operation of sodium peroxide respiration apparatus. Serial experiments I and II. (I) Z. angew. chemie 42: 776-779. 1929. (II) Z. ges. Schiess Sprengstoffw. 24: 234-237. 1929.

With one subject 64 minutes were required on the average, with another 58 minutes for O_2 from one charge of PROXYLITH (950 gr.) to fall below 15% and CO_2 to rise above 3%. Catalysts render the evolution more uncertain. Partial drying of the cartridge content through $CaCl_2$ gave better regulation. Cartridges filled to about 22 cm. showed optimum efficiency.

65. STAMPE, G. Requirements for a chemical oxygen breathing apparatus. Z. ges. Schiess Sprengstoffw. 24: 360-363. 1929. C.A. 24: 1166. 1930.

It is shown on physiological grounds that an oxygen breathing apparatus containing an active agent of the Na_2O_2 type must generate more oxygen than corresponds to the amount of CO_2 in the exhaled air, hence some of the moisture must also be utilized as a source of O_2.

On the assumption that this problem could be solved, the sequence of the physiological process of oxidation requires that O_2 from a small container should be supplied first before the tissues can give off the CO_2 which the active agent in the mask requires to produce O_2.

Experimental work should be carried out to determine the correct time intervals required for the bodily gas exchange before a final decision can be rendered on the feasibility of a chemical breathing apparatus.

66. STAMPE, G. What to expect from a chemical oxygen respirator. Draeger Hefte 139: 1616-1620. 1929. Arbeits physiologie 2: 233-240. 1929.

67. STAMPE, G. Draeger CO gas mask canister. Draeger Hefte 177: 2818-2820. 1935.

68. TJUTJUNOW-ORSKI, I. Kip I, isolating O_2 mask. Chimija i Oborona 12: 10-12. March 1936.

69. WEINER, J.S. Ventilation of air raid shelters. Nature 146: 733-737. 1940.

See also Ventilation for Buildings in conditions of blackout. B.S.S. BS/ARP 31, issued July 1940 (Light and Lighting 33:140-141. 1940).

70. YANT, W.P. Bureau of Mines approved devices for respiratory protection. J. Ind. Hygiene 15: 473-480. 1933.

PATENTS

1. CERSTVIK, Stephen (to Bendix Aviation Corporation). Oxygen regulator. U.S. Pat. 2,197,922, of 23/4/1940.

   Means responsive to changes in the atmosphere and regulating amount of oxygen.

2. DEGEA, A.G. (Auer gesellschaft) Cartridge for respirators. Brit. Pat. 413,979 of 16/8/1934. French Pat. 767,760 of 24/7/1934.

   The filling consists of NaOH or KOH in the shape of ball, oval or egg shapes, of different sizes.

3. DRÄGER, Heinrich Otto, and Gerhard Karl Emil Heinrich STAMPE. Method for the manufacture of an absorption mixture for respirator cartridges. U.S. Pat. 1,826,329 of 6/10/1931.

   A homogeneous water-free mixture of Na_2O_2 and NaOH is capable of absorbing water vapour and carbon dioxide and evolving oxygen.

4. GERSON, Kurt, A. Oxygen evolving composition for use in gas masks. Brit. Pat. 414 210. Ger. Pat. 638 136. 17/11/1936. U.S. Pat. 2,068,485. 19/1/1937.

   (Alkali peroxide is mixed with not more than $\frac{1}{4}$ mol. water and heated).

5. Gold und Silber SCHEIDE ANSTALT, formerly Roessler, Frankfurt on Main. Manufacture of oxygen yielding mass for use in respirators. Ger. Pat. 607,301 of 21/12/1934. addition to 606,676 of 7/12/1934 and 587,115, 1934.

   Alkali peroxide is used in finely ground form, and 9 to 23, preferably 10-15 parts of water are added, the mixture is cooled while water is added, and then heated to improve its stability.

   Also Swiss Pat. 153,814 of 16/6/1932. French Pat. 708,230 of 21/1/1929. 665,275 (Brit.Pat. 320985)

6. I. G. FARBEN INDUSTRIE A.G. Frankfurt. Production of pure O_2 in respirators. F. Pat. 807,355 of 16/6/1936 issued 11/1/1937. O_2 cartridge F. Pat. 804 898 of 4/11/1936.

7. I. G. FARBEN (A. Hloch, inventor) Respiratory apparatus for generating oxygen by thermal decomposition of an oxygen evolving substance. Ger. Pat. 673 094 of 16/3/1939.

8. JAUBERT, George F. Oxygen-evolving composition. Brit. Pat. 450 377 of 16/7/1936.

   A product for the regeneration of vitiated air in closed respiratory apparatus consists of spongy anhydrous Na_2O_2 having an activating substance in the form of a dried colloidal preparation coated on the outer surface of the Na_2O_2 fragments by simple adsorption. The Na_2O_2 is obtained by the oxidation of Na and has an apparent density of 0.3 to 0.5. Suitable activators are CuO or mixtures of Cu and Mn or Fe oxides, obtained by desiccating precipitates obtained as colloidal gels.

9. HLOCH, A. Mass for the production of a mixture of oxygen and carbon dioxide free from CO of constant composition. Ger. Pat. 649 770 of 8/9/1937.

   Carbonates which give off CO_2 at 800°C. are added to the substances giving off oxygen e.g. 75 parts $KMnO_4$, 22½ parts iron powder, 7 $MnCO_3$ with 10% water. The mixture is pressed at 150 kg. and shaped into bars. When heated the substance produced an O_2 stream containing 10% CO_2 until the chemical reation proper starts.

10. LALLEMANT, Henri, René Gustave TRAIZET and Edmond PILLET. Respiration cartridge. French Pat. 785,135 of 2/8/1935. French Pat. 785,186 of 3/8/1935.

    The starting difficulties are overcome by forcing water vapour or fog into the cartridge before the respirator is used or by adding water to the mass contained in a small container.

    In order to prevent disagreeable dryness of the regenerated air a spongy mass is added to the cartridge.

11. LEU, Charles. Means for regenerating air. Swiss Patent 183 561 of 1/7/1936.

Pulverized Na_2O_2 with addition of $CuSO_4$, or CuO, is mixed with a porous granulated material and a salt containing water of crystallization forming about 10% or 20% of Na_2O_2, e.g. $Na_2CO_3 . 10H_2O$.

12. LEVY, Leonard A. and Robert H. Davis. Oxygen evolving composition. Brit. Pat. 462,321 of 8/3/1937.

A composition, particularly for use in respiratory appliances, that evolves O_2 by the action of moisture and CO_2 contained in air comprises an alkali peroxide, a hydrate of a caustic alkali, a catalyst adapted to accelerate the evolution of O_2 from the H_2O_2 produced from the alkali peroxide e.g. Na_2MnO_4, and an oxide or hydroxide of an alkaline earth metal.

The H_2O of hydration of the caustic alkali must not react with the alkali peroxide but is normally reactive with moisture and CO_2.

The alkaline earth oxide or hydroxide decomposes the bicarbonate formed into carbonate and also acts as a binder for the composition, e.g. $Na_2O_2$3, $NaOH.H_2O$ 3 . Na_2MnO_4 7, and CaO 45.

13. ROESSLER and HASSLACHER Chemical Corp. (Walter Zisch, assignor) Material for respirators. U.S. Pat. 1,878,359 of 20/9/1932

An alkali peroxide free from water and an alkali peroxide dihydrate, the dihydrate containing about 1/3 to 1 molecule of water of crystallization for each molecule of peroxide, are thoroughly mixed.