Oxygen breathing apparatus

Oxygen breathing apparatus has been in use in fire brigades in this country since about 1912, and compressed-air sets since about 1925. Although atmospheric types of breathing apparatus were still in use in industry it became generally acknowledged that the only suitable breathing apparatus for fire brigade use was the self-contained type with its own supply of oxygen or air to give protection against any known or unknown gas. Accordingly self-contained oxygen and compressed-air sets gradually displaced all types of atmospheric breathing apparatus, and early in the life of the National Fire Service the few remaining atmospheric sets were replaced by self-contained apparatus. The 1-hour self-contained oxygen apparatus became the most widely used.

Oxygen breathing apparatus has not altered greatly over the years, the general principles remaining the same, and successive 'marks' have not provided any radical changes. However, in circumstances where there is a substantial difference between one 'mark' and another, details are given.

1 Specifications

In 1952 a requirement specification for self-contained breathing apparatus for fire brigade use was prepared by the Joint Committee on Design and Development of Appliances and Equipment, a committee of the Central Fire Brigades Advisory Council (England and Wales) and the Scottish Central Fire Brigades Advisory Council. The specification, JCDD/19, defines the term 'breathing apparatus' as an entirely self-contained apparatus which may carry cylinders containing compressed oxygen or air.

Three types of apparatus are covered by the specification:

(1) Oxygen, closed circuit, using a reducing valve (constant predetermined flow);
(2) Oxygen, closed circuit, using a demand valve (with or without a reducing valve); and
(3) Compressed air, open circuit, using a demand valve.

All the apparatus described in the following paragraphs comply with the requirements of that specification,

British Standard (BS 4667) has been prepared for closed-circuit breathing apparatus (Part 1), open-circuit breathing apparatus (Part 2) and fresh air hose and compressed air-line breathing apparatus (Part 3). There is an associated British Standard (BS 4275) which contains recommendations for the selection, use and maintenance of respiratory protective equipment. These standards are expected in due course to supersede JCDD/19.

2 Self-contained oxygen breathing apparatus

A feature of the closed-circuit apparatus is that the supply of oxygen for regeneration purposes is controlled to give a predetermined amount per minute, irrespective of the energy expended, and the duration of the supply is therefore known.

In sets of the closed-circuit type, therefore, the working time can be predetermined within fairly exact limits, which will vary according to the use of the by-pass which is incorporated to make good any temporary shortage of oxygen due to sudden great exertion.

If the supply of oxygen is regulated so that a given amount flows per minute irrespective of the energy consumed, then a breathing bag or other container must be provided in which a reserve can be built up, and the exhaled air must be returned to this reserve. Since lie exhaled air will contain a percentage of carbon dioxide it follows that a means must also be provided for absorbing this gas so that die air is purified before being re-inhaled. Sets employing a circuit of this sort are known as the closed-circuit regenerative type.

The circuit employed by this type of apparatus is shown in diagrammatic form in Fig. 1. A cooler is not an essential feature, but is a desirable addition as a certain amount of heat is generated in the circuit. This circuit from the breathing bag to the mouthpiece and hack in an endless circle is common to all types of regenerative apparatus.

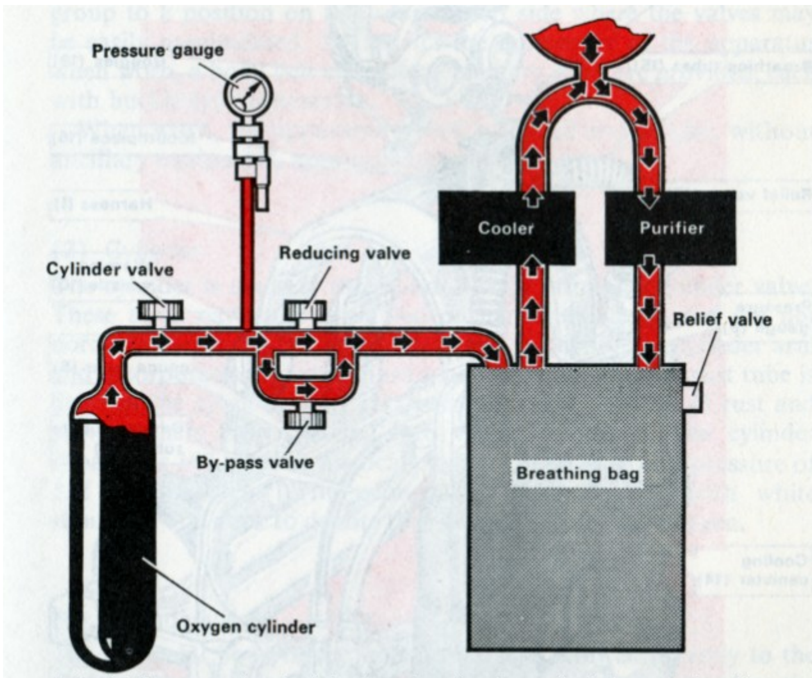
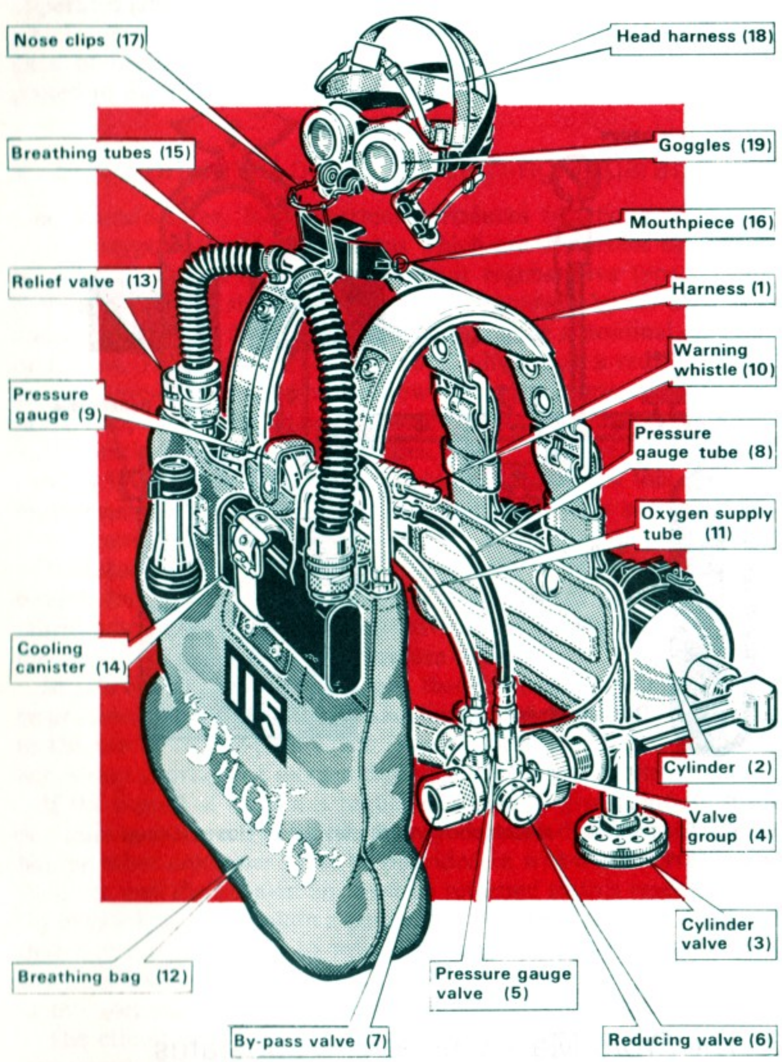


Fig.1 Diagramatic sketch showing the layout of closed-circuit regenerative apparatus

The high pressure of the oxygen in the cylinder has to be reduced before the oxygen can safely be fed into the breathing circuit, and a means of reducing pressure is an essential feature of all breathing apparatus employing compressed gases. This may be done by a pressure-reducing valve which in some types of apparatus is augmented by a demand valve operated by the breathing action of the wearer.

3 The Proto Mark V breathing apparatus

The oxygen breathing apparatus most commonly employed for fire brigade work is the Proto, a closed-circuit set having a nominal duration of 1 hour which uses a constant predetermined flow reducing valve. A diagrammatic view of the apparatus is shown in Fig. 2.



Fi Fig. 2 Diagrammatic view of the *Proto* Mark V breathing apparatus

a. Description of the set

In the following description of the set, the various items are numbered in the same sequence as the numbers in Fig. 4.2.

(1) The harness

The apparatus is carried in a lightweight Terylene harness placed over the shoulders of the wearer. The front part, which is carried on the chest, supports and gives protection to the rubber breathing bag. A small leather pouch protects the pressure gauge from damage and retains it in a readily accessible position for periodic inspection by the wearer during operations. The rear part of the harness is worn on the back and supports the oxygen cylinder which is secured by two quick-release metal bands. The cylinder arm brings the valve group to a position on the wearer's left side where the valves may be easily manipulated. To restrict the movement of the apparatus when worn, a body belt and complementary strap are provided, each with buckle-type fasteners.

When worn, the apparatus is well balanced and weighs, without ancillary equipment, approximately 12.2 kg.

(2) Cylinder
The cylinder is made in three parts - body, arm and cylinder valve. These three parts are assembled during manufacture and are not normally dismantled. The cylinder valve is part of the cylinder arm and incorporates a fibre or hard plastic seating. An anti-rust tube is fitted in the cylinder body to arrest any small particles of rust and prevent them from passing into the valve group. The cylinder capacity is 187 litres of medical oxygen compressed to a pressure of 132 atmospheres. The cylinder is painted black with white shoulders and neck to denote that it contains medical oxygen.

(3) Cylinder valve
The gunmetal body of the cylinder valve is screwed securely to the outlet of the cylinder arm. The operating components, including the fibre or hard plastic seated valve, fit into the valve body. The valve is operated by a small hand wheel which is turned in an anticlockwise direction to open. Under normal working conditions the cylinder valve should be kept in the fully-open position at all times.

(4) Valve group
Attached to the cylinder arm by means of the main union is the valve group. The main union is a large serrated threaded female connector which connects on to the mating outlet of the cylinder valve. A projecting hexagonal spigot in the valve group fits into a similarly shaped recess provided in the cylinder valve outlet. This ensures the correct positioning of the valve group in relation to the cylinder and prevents movement when connected. The union is a pneumatic one requiring only hand pressure to effectively tighten. Gas tightness is effected by a small neoprene '0' ring which fits into a small groove on the spigot. A small sintered metal filter plug prevents dust and foreign matter from entering the central column of the valve group.

The valve group is composed of three valves:

(i) Pressure gauge valve;
(ii) reducing valve;
(iii) By-pass valve.

(5) Pressure gauge valve
Under normal operational conditions the pressure gauge valve remains open. It is fitted as a safety device and is intended to be used in an emergency only to isolate the pressure gauge, warning whistle and pressure gauge tube when some defect or fracture causes a serious oxygen leak. In such circumstances the valve must be immediately closed in order to conserve the oxygen supply. It is lever-operated, requiring only a quarter-turn to close (see Fig. 5).

(6) Reducing valve
As its name suggests this valve reduces the high-pressure oxygen delivered from the cylinder to a lower breathable pressure. It is set to deliver 2.5 litres per minute throughout the full duration of the set and works automatically, requiring no attention from the wearer. The operation of the reducing valve is described in section (b) (page 8).

(7) By-pass valve
The by-pass valve is an emergency valve which when operated supplies the wearer with an immediate additional supply of oxygen, e.g. when because of strenuous work the wearer finds that 2.5 litres of oxygen per minute provided by the reducing valve is insufficient for his requirements, or in the event of the oxygen supply being reduced or cut off due to a defect in the reducing valve. The by-pass valve is also used in the 'starting-up' procedure to fill the breathing bag, or during operational use as a means of replacing the warm exhaled breath of the wearer by flushing the bag with cool oxygen direct from die cylinder. It is press-button operated and must always be used with discretion. Incorrect or careless use may seriously reduce the duration of the set.

(8) Pressure gauge tube
A pressure gauge tube from the pressure gauge valve to the low cylinder-pressure warning whistle and pressure gauge is provided to bring the gauge to an easily readable position. It is made of stout flexible `Techalon' tubing, approximately 460 mm long. Both ends are fitted with female connections; that which fits to the reducing valve has a metal-to-metal seating and the end connected to the low-cylinder-pressure warning whistle is fitted with a fibre washer.

(9) Pressure gauge
The pressure gauge is of the bourdon tube type and is calibrated in atmospheres and minutes. Each division represents 10 atmospheres or 5 minutes. A red line at 120 atmospheres indicates 60 minutes duration.

(10) Low-cylinder-pressure warning whistle
The low-cylinder-pressure warning whistle is fitted between the pressure gauge and the pressure gauge tube and is pre-set to actuate when the cylinder pressure drops to 30 atmospheres (15 minutes) or below. It sounds automatically and continuously to warn the wearer that it is time to withdraw to fresh air (see Chapter 10 on the `Operational Procedure for the use of breathing apparatus'). In doing so the whistle consumes approximately 2 litres of oxygen per minute. This means that the safety margin of the set is cut from 15 minutes to approximately 10 minutes.

(11) Oxygen supply tube
This tube leads from the low-pressure side of the valve group to the oxygen inlet connection on the breathing bag. It is made of non-kink flexible rubber and has female connections at each end. The valve group connection is a metal-to-metal one and the breathing bag connection is fitted with a fibre washer. To prevent it catching on projections when the set is worn, the tube is looped around the gooseneck of the cooling canister before connection with the breathing bag.

(1 2) Breathing bag
The breathing bag (Fig. 3) is constructed of strong vulcanised India-rubber. It is divided into two compartments by a rubber curtain crossing diagonally from front to rear and extends from the top to within about 25 mm of the bottom. To prevent complete deflation of the bag, 6 mm square rubber ribs are fitted internally, front and rear. At the top of the bag two moulded rubber blocks, which are stuck in position, hold four metal connections, two at each side. Those on the wearer's left are for connecting to the oxygen supply tube and to the cooling canister; both communicate with the rear compartment. The connections on the right are for the exhaling and relief valves respectively; these communicate with the front compartment.
The breathing bag is charged with 1.6 kg of granulated soda-lime absorbent (Protosorb), which is divided equally between the front and rear compartments and occupies the space in

the bottom of the bag to a depth of about 75 mm. This more than covers the communicating space at the foot of the curtain, between the front and rear compartments, and ensures that any gas moving from front to rear compartments must pass through the absorbent. To prevent undue movement of the absorbent when the wearer is working in awkward positions, e.g. on his side, the bag is 'waisted' about 150 mm from the bottom. This helps to contain the absorbent.

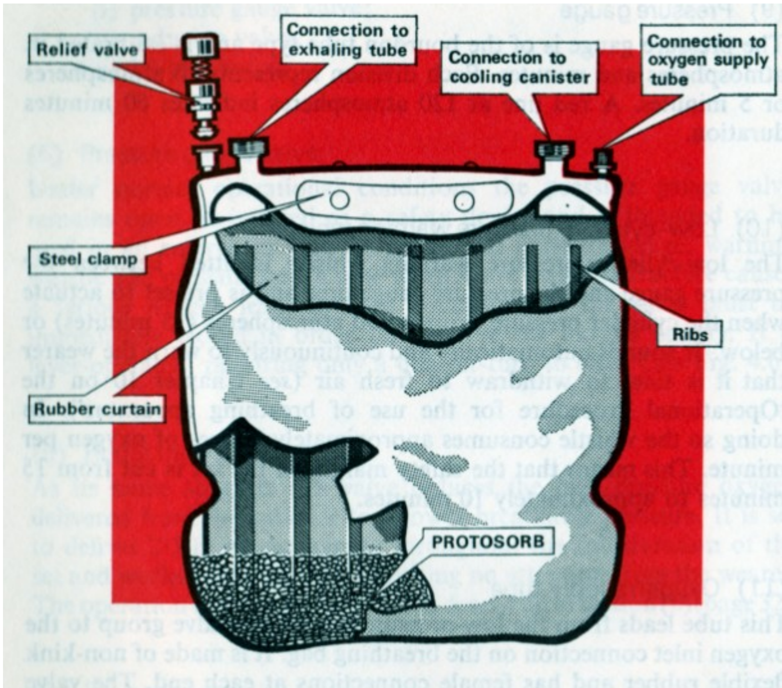


Fig. 3 The *Proto* Mark V breathing bag

A small diffuser is fitted on the oxygen inlet inside the bag for the purpose of diffusing the oxygen delivered to the bag from the oxygen supply tube. This spreads the blast of high-pressure oxygen when the by-pass valve is used and prevents the disturbance of Protosorb dust which might cause discomfort to the wearer. The opening at the top of the bag enables the absorbent charge to be replaced; this opening is closed by two clamps and a rubber washer, the whole being kept gastight by wing nuts. Attachments to support the bag are provided on the wing nuts.

(13) Relief valve
When the wearer's oxygen consumption is less than the 2.5 litres per minute provided by the set, the bag becomes overfilled and consequently breathing is difficult. The relief valve at the top of the bag enables the wearer to discharge surplus oxygen from the bag to atmosphere. It is a small mushroom type valve which is operated manually.

As an alternative to the manual-type relief valve, an automatic type may be supplied with the set. This valve operates automatically when the pressure of oxygen in the breathing bag reaches a predetermined level. This type of valve is recommended for use with sets fitted with certain types of face mask.

The cooling canister (Fig. 4.4) is fitted between the breathing bag and inhaling valve and is designed to cool the oxygen immediately before inhalation by the wearer. It consists basically of two canisters, one inside the other. The small inner one contains the chemical cooling agent — approximately 285 g of calcium chloride—which at normal temperature is in crystalline form.

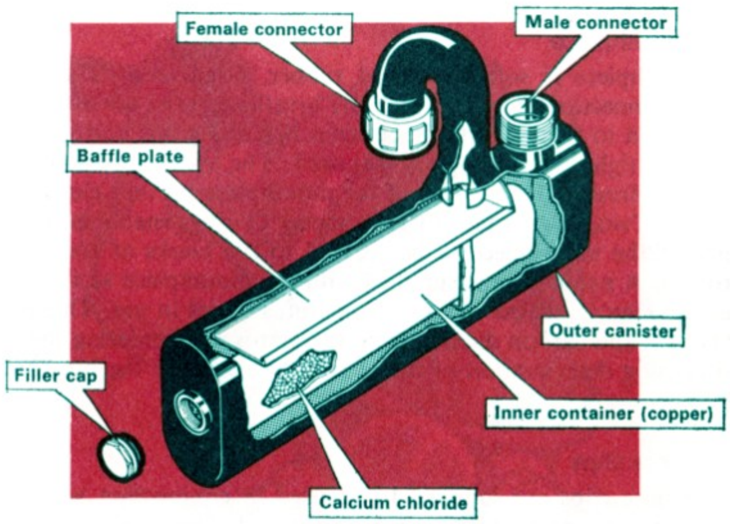


Fig. 4 Cooling canister fitted to the *Proto* set

As the oxygen passes into the larger outer canister and circulates round the smaller container, cooling is achieved by means of radiation and by the latent heat of fusion of the calcium chloride, which liquefies at 30°C. The charge does not deteriorate with use and in maintenance requires only topping up. After a set has been used, cold water should be circulated through the cooler for a short time to restore the chemical to its crystalline form.

(15) Breathing tubes and valves

The 25 mm diameter breathing tubes are 228 mm in length; they are corrugated to provide flexibility and a certain amount of elasticity, and to prevent collapse of the tubes, ensuring the wearer of an adequate supply of oxygen at all times. Spring-loaded mica non-return valves are fitted at the lower ends of the tubes. On inhalation, both valves lift, the inhaling valve opening and the exhaling valve closing. On exhalation the action is reversed, the inhaling valve closes and the exhaling valve opens. In this way, oxygen circulating in the set travels in one direction only. Mica is used in the manufacture of these valves because it is light in weight, it is unaffected by heat, and moisture does not affect the movement of the valve.

(16) Mouthpiece

The mouthpiece is soft vulcanised rubber, fitted to a 'Y'-shaped tubular connection-piece to which the breathing tubes are attached. It is shaped to fit comfortably between lips and gums and is completely gastight when properly adjusted. The two rubber nipples projecting from the inner part of the mouthpiece prevent closing of the teeth. Two, or alternatively four, metal 'D' rings enable the outer flange of the mouthpiece to be secured to the hooks of the head-hardness. A nylon plug is supplied with the mouthpiece so that the aperture may be sealed when the apparatus is not in use. This prevents dust and carbon dioxide from the atmosphere entering the set and causing deterioration of the absorbent charge in the breathing bag.

(17) Nose clips
Spring nose clips are supplied to be used in conjunction with the mouthpiece to prevent the wearer from inhaling noxious fumes through the nose. They are adjustable to suit any nose.

(18) Head-harness
The head-harness is made from a light but sturdy plastics material, and is designed rather like a scrum-cap. It is readily adjusted to suit the wearer and short straps with hooked ends connect with the 'D' rings of the mouthpiece supporting it in the correct position. The light nature of the strapping enables a fire helmet to be worn without discomfort.

(19) Goggles
Protection for the eyes is afforded against smoke and irritant gases by the use of goggles. The frames are made of soft moulded rubber and the eyepieces are non-splinter. The goggles are held in position by a quick-adjusting elastic head-band. Eyepieces should be treated on the inside with anti-mist preparation to prevent condensation during use.

b. Action of the reducing valve

Oxygen enters the reducing valve (Fig. 5) at the main union, passes through the small sintered bronze filter (1) and makes its way along the central column (2). It escapes through the inlet jet (3), which is set at right angles to the central column, and begins to fill the upper half of the reducing valve (i.e. the space above the rubber diaphragm (4)). Further progress is checked by the back-pressure disc (5), the 0.33 mm diameter orifice which allows only a limited amount of oxygen to escape to the low-pressure side of the set.

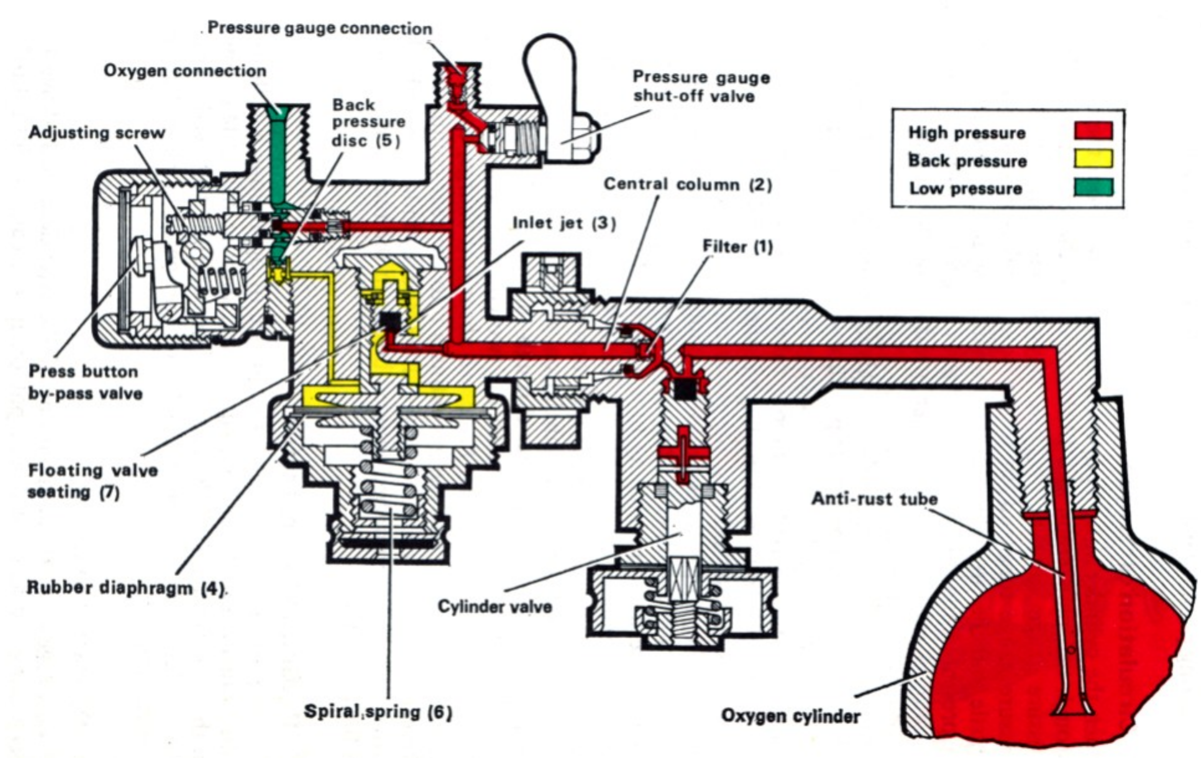


Fig. 5 Diagrammatic arrangement of the Proto Mk5 reducing valve

As a result of the restriction to the flow caused by the back-pressure disc, a back pressure builds up in the upper half of the reducing valve. When it has reached sufficiently high proportions (about 2 atmospheres), this back pressure, acting on the large area of the diaphragm, forces the diaphragm with all its attached components in a downward direction, thus slightly compressing the spiral spring (6) and causing the floating valve seating (7) to baffle the inlet jet, thereby restricting the flow of oxygen from the central column. The leak of oxygen through the small hole in the back-pressure disc reduces the pressure against the diaphragm and the spiral spring is able to re-assert itself, so that the diaphragm and floating valve components are returned to their original position, thus uncovering the main jet again and allowing the flow of high-pressure oxygen to recommence.

It may appear from this description of the action of the reducing valve that the diaphragm and attached components vibrate continually while the oxygen flow is maintained, but this is not the case. What actually happens is that the floating valve adopts a position (usually from 0.025 to 0.05 mm above the inlet jet) related to the pressure of oxygen delivered from the cylinder. Initially, when the pressure is high (132 atmospheres) the floating valve is very near the inlet jet, but as the pressure of oxygen diminishes, the floating valve moves progressively farther away from the inlet jet until, when the cylinder pressure is approximately zero, it has returned to the starting position with the spiral spring fully extended.

c. Circulation of oxygen

When the cylinder valve is opened, oxygen flows from the cylinder through the main union and filter screw into the valve group. The pressure gauge valve being open, oxygen makes its way into the pressure gauge tube and on to the low-cylinder-pressure warning whistle and the pressure gauge. The whistle sounds momentarily as the pressure builds up to 30 atmospheres and ceases immediately this pressure is exceeded. The oxygen pressure in the central column is indicated by the pressure gauge.

In passing through the reducing valve, the high-pressure oxygen is reduced to a lower breathable pressure and the flow is regulated to 2.5 litres per minute. From the reducing valve outlet, the low-pressure oxygen enters the oxygen supply tube and passes into the rear compartment of the breathing bag via the small diffuser.

When the wearer inhales, oxygen from the rear compartment of the breathing bag is drawn into the cooling canister and after circulating round the inner container passes through the inhaling non-return valve into the inhaling tube and mouthpiece to the wearer's lungs. The exhaled impure breath enters the front compartment of the bag via the exhaling tube and non-return valve. Here it halts momentarily until the next inhalation, when it is drawn from the front compartment to the rear through the space below the rubber curtain (or diaphragm) between the two compartments of the bag. Whilst passing through the Protosorb absorbent charge, the carbon dioxide is removed and the gas diffuses into the rear compartment. Replenished with oxygen delivered by the cylinder through the reducing valve, the purified exhaled breath in the rear compartment is then re-inhaled.

d. Putting on the apparatus

It is important that the correct sequence of operations is followed when putting on and starting up the set, and the drill as laid down in the Fire Service Drill Book should be carefully followed. When the set has been put on and adjusted properly, it should fit as shown in Fig. 6.

Fig. 6 Proto BA worn correctly
SFB Photograph courtesy of K.L. Mettam

e. Operation of the set

If an oxygen breathing apparatus of the type described above has been correctly assembled and put on it will call for little further attention, and the wearer can safely leave it to its own business. The only items which need to be remembered are:

(1) The pressure gauge should be consulted from time to time to see how much oxygen remains in the cylinder, and therefore how long the wearer can remain in a poisonous atmosphere. The scale is calibrated in atmospheres and sometimes also in minutes. The lower end of the scale is usually marked in red to indicate when the wearer should withdraw to fresh air. In any event withdrawal should always be made as soon as the low-cylinder-pressure warning whistle sounds. The gauge will show a reading throughout the period when the set is in operation and if consulted at regular intervals will keep the wearer informed of the amount of oxygen left in the cylinder. As explained above, the pressure gauge valve is provided solely to prevent leakage of oxygen should the gauge or its flexible tube become damaged. It should never otherwise be closed.

(2) When a set other than the Mark V, which is fitted with an automatic relief valve, has been in use for some time, particularly if no strenuous work has been undertaken, the bag will be found to become unduly inflated and some of the excess contents should be released by means of the relief valve.

The fact that the bag inflates so much as to become obtrusive is in itself a sufficient reminder that the relief valve should be used. Breathing will also be found to become slightly uncomfortable if the bag is too full as the wearer will be exhaling against pressure; this should be regarded as a warning to use the relief valve.

(3) If the wearer is working under exceptionally arduous conditions, or indulging in short periods of violent effort, the regulated supply of 2.5 litres per minute may temporarily be insufficient for his needs, and a feeling of restriction may be experienced. When this occurs the by-pass valve should be opened momentarily to give an increased supply. It will also be found beneficial after working in a heated atmosphere for some time to discharge the accumulated gases in the breathing bag by using the relief valve, and to flush out the hag with a fresh supply of oxygen from the by-pass valve.

The by-pass valve serves also as a secondary means of supplying oxygen to the bag in the event of failure of the reducing valve; this, however, is unlikely if the apparatus is properly maintained.

(4) The carbon dioxide absorbent which fills the communicating compartment between the two halves of the breathing bag is so placed that air passing through the bag has to flow through the absorbent. The bag should not be violently shaken during use as this creates dust, but from time to time it should be gently kneaded with the hand or may be lightly shaken. This movement of the granules exposes fresh surfaces to absorb carbon dioxide from the exhaled breath ; it also prevents channelling, which is the term used to describe the formation of passages through which the exhaled breath can flow freely without passing over sufficient granules for the carbon dioxide to be absorbed.

(5) To prevent misting during use, the eyepieces of the goggles, or the visor of a face mask, should be treated with anti-dim compound of the type recommended by the makers of the apparatus. This should be done after each time of use, and it will be found advantageous to treat the external surfaces as well as the internal ones to minimise fogging on the outer surfaces due to heat and smoke.

"Salvus" Closed Circuit Oxygen Breathing Apparatus

Whilst the above text deals with the "Proto" oxygen breathing apparatus sets which were carried on the Division Street Emergency Tender, two "Salvus" sets were carried on each pumping appliance. Whilst the operation of the "Salvus" sets intrinsically the same as the "Proto" sets, they had a shorter working duration and were lighter to don and use. (Fig. 7)

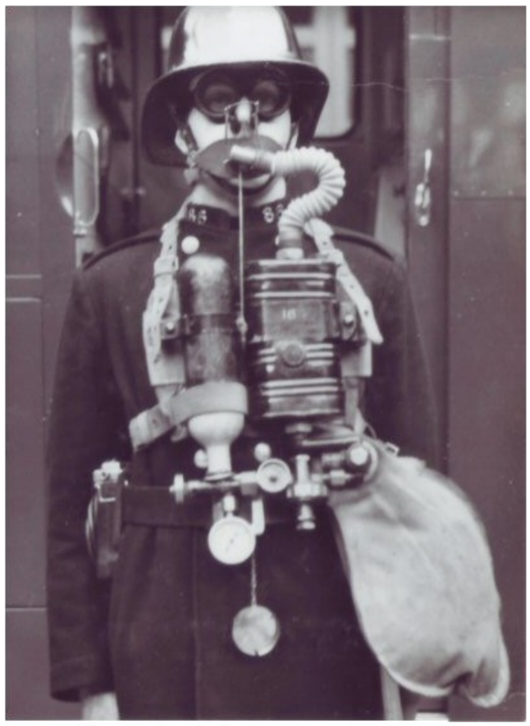
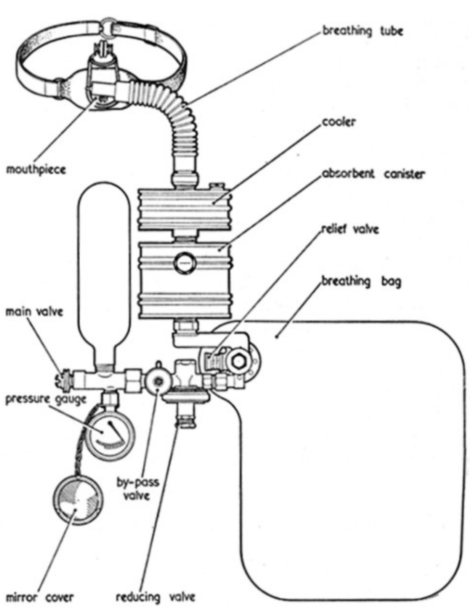


Fig. 7 Salvus BA worn correctly
SFB Photograph courtesy of K.L. Mettam



The 'Salvus' breathing apparatus is of closed circuit regenerative type employing oxygen. It consists of a cylinder containing 3.5 cubic feet of oxygen at 1,800 lbs per sq ft. In pressure, a valve group, breathing bag, carbon dioxide absorbent and cooler. The reducing valve is, however, adjusted to give a flow of two litres per minute.

The valve group is connected directly onto the breathing bag, which is of similar construction, and respiration is carried out through one breathing tube only; both the cooler and the absorbent container are inserted between the tube and the breathing bag.