The oxygen is passed through a valve into the gas holder, whence it is drawn by compressors, and compressed into cylinders.

Forecoolers generally freeze up after some hours' continuous working, and separators after about a week's working, and both these are in duplicate, so that when one freezes up the other can be put on, and the process thus kept continuous.

The following are features relating to liquid air:—

It is a nearly colourless liquid, consisting mainly of oxygen and nitrogen, boils at —190° C., and as the nitrogen evaporates out of it, it assumes the bluish tint of liquid oxygen.

It occupies 1/800 of its volume as a gas, that is, it will expand eight hundred times if vapourised and restored to normal temperature.

It can only be stored in vacuum vessels, and evaporates from them at the rate of from 5 per cent. to 15 per cent. per twenty-four hours.

The compressors employed to pump the oxygen from the gas-holder into cylinders for distribution are of the following type: —

**Belt-driven, Vertical, Three-stage.**—A cooling tank is fitted to the top of the columns, and the cylinder barrels and pipe coils between the stages of compression are thus kept at normal temperature by means of the circulating water.

As no oil or grease can be used as a lubricant in case of explosion, water is used for this purpose, and is introduced into the first stage suction pipe near the top valve box of the first stage cylinder, and is thus drawn in with the oxygen. Part of the water finds its way out at the glands, and the remainder is trapped in a special separator before the oxygen enters the filling pipes leading to the cylinders. This trap is blown frequently, the water escaping and the oxygen returned to the compressor suction pipe through a special valve.

There is also a circulating water system, consisting of pumps and a spray cooler, situated away from the main building. The pumps employed are belt-driven, geared double-acting, and are arranged over a sump tank inside the main building, and are driven from the line shafting from which the oxygen compressors are driven.

The circulating water, which has passed round the coils and cylinders of the four-stage air compressor, and also the overflow from the $CO_2$ freezing machine, returns to the sump tank (which has a division in it), and part of this cool water is circulated by another pump through the Diesel engine cooling circuit.

The overflow from the Diesel engine, together with the surplus water from the $CO_3$ machine and four-stage compressor, and the overflows from the oxygen compressors, empties into the other compartment of the sump tank, whence the water is pumped through the nozzles of the spray cooler by another pump.

The cooling tank is surrounded by louvres, and is a very efficient cooler. The tank has a capacity of about 2000 gallons, and in hot weather between 4000 and 5000 gallons per hour are circulated, the only losses being evaporation and what little is blown away on windy days.

These losses, however, do not generally exceed 5 or 6 per cent., and a temperature difference of 14 to 16 degrees is obtained under favourable conditions.

There are also two elevated tanks, which automatically deliver water into the main circulating pipe, should the circulating pumps stop pumping from any cause, and thus the various machines are kept cool until the pumps are started again.

**Experiments with Liquid Air to show the intensity of Cold.**

Figure 3 shows the first liquid air plant in England.

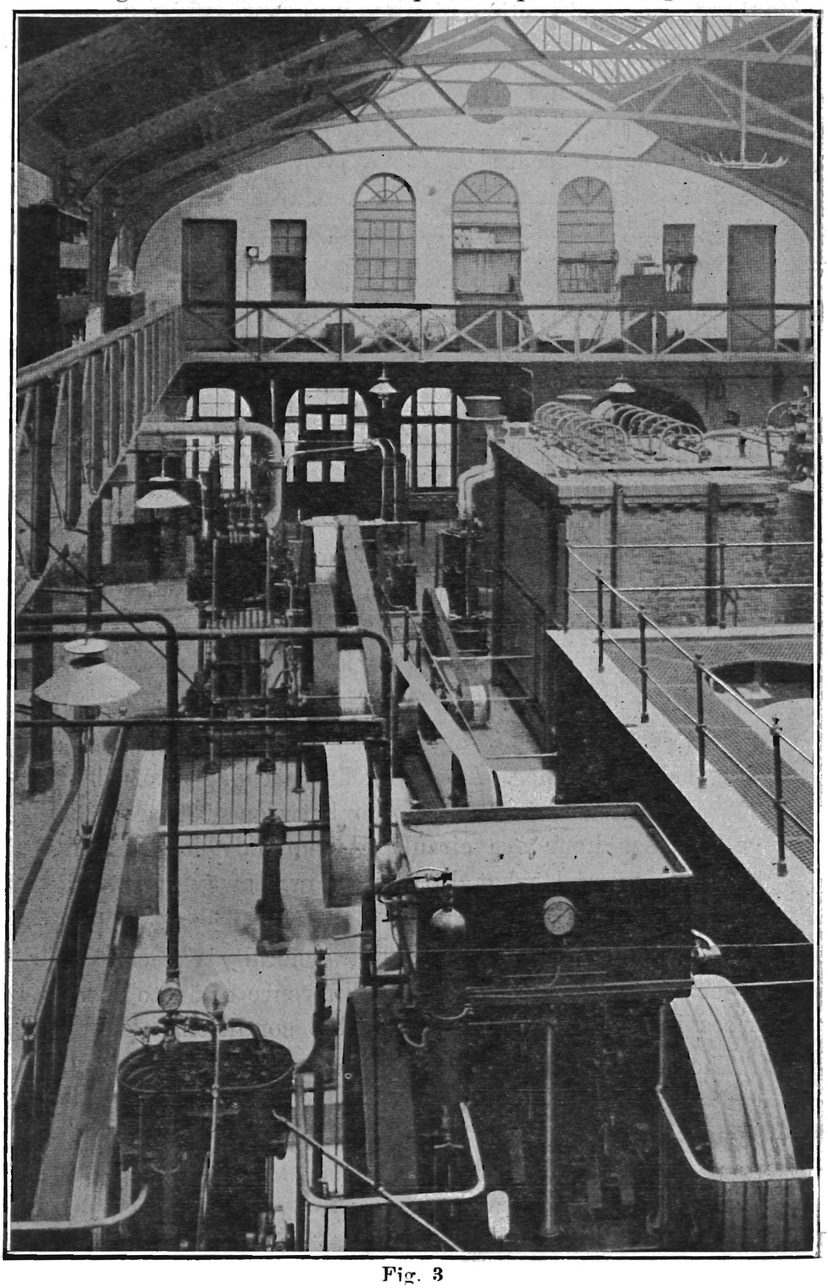

Fig. 3

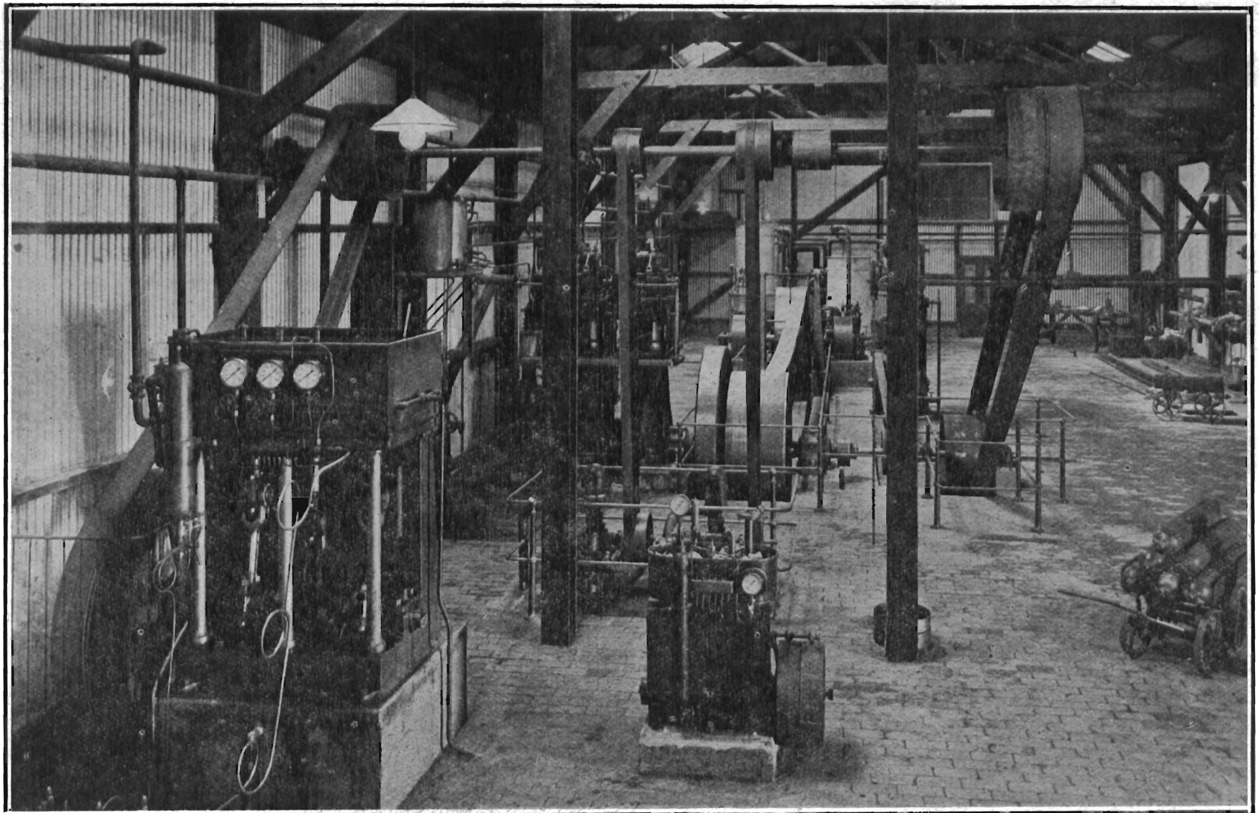

Figure 4 shows liquid air plant at Alexandria, N.S.W.

Fig. 4

Figure 5 shows liquid air plants in Westminster Works, London.

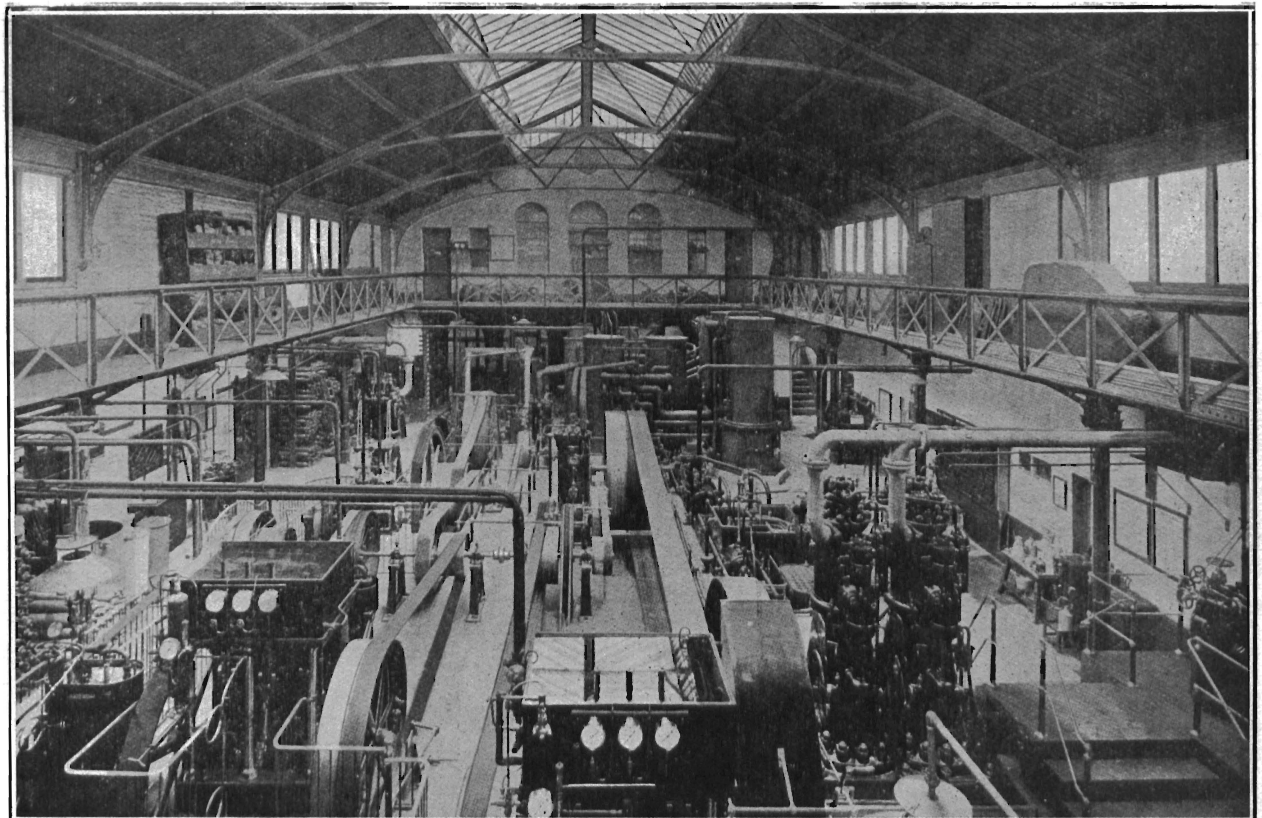

Fig. 5

Having now given a brief description of how oxygen is produced, there is another very important question to consider, and one which is really of greater importance to the gas-user than the means by which the oxygen is produced, viz., the precautions taken to ensure the soundness and reliability of the cylinders or tubes into which the oxygen is compressed for distribution.

Up to the year 1895 there were no regulations in the United Kingdom regarding the cylinders used for compressed gases, and, as several fatal explosions had taken place, a committee of experts was formed to thoroughly investigate the causes of these explosions, and to decide what precautions were necessary to safeguard the public.

This step was welcomed by the compressed gas makers, and the result was that Government recommendations were framed, and a standard to which cylinders had to be made was decided upon. This, besides protecting the gas compressor, also protected the public in general against the danger of unscrupulous cylinder makers, who were inclined to sacrifice strength for lightness, thereby effecting a slight saving in freight and cost of distribution.

These Government recommendations became practically an unwritten law, strictly adhered to by all parties, and the immunity from accident in the United Kingdom since their adoption is the best proof of the wisdom of such a step.

I may say that the British Oxygen Company, Limited, of London, alone handles over 50,000 gas cylinders per week. The standard type of cylinders employed is the solid drawn seamless steel cylinder, of which an actual section of a one-hundred cubic feet cylinder is on view.

These cylinders are made of the following capacities:—200, 100, 40, 20, and 10 cubic feet, at a pressure of 120 atmospheres.

The cylinders owned by the Commonwealth Oxygen Co., Ltd., are of this type, and to the British standard, and as there may be some members present who are not acquainted with these regulations, they are as follows:—

**Summary of Recommendations of the Committee appointed by the British Government to inquire into the Causes of the Explosion and the Precautions Required to Ensure the Safety of Cylinders of Compressed Gas. 1903.**

**1. Cylinders of Compressed Gas (Oxygen, Hydrogen, or Coal Gas).**

(a) **Lap-welded Wrought Iron.**—Greatest working pressure, 120 atmospheres, or 1800lbs. per square inch.

Stress due to working pressure not to exceed 6½ tons per square inch.

Proof pressure in hydraulic test, after annealing, 224 atmospheres, or 3360lbs. per square inch.

Permanent stretch in hydraulic test not to exceed 10 per cent. of the elastic stretch.

One cylinder in 50 to be subjected to a statical bending test, and to stand crushing nearly flat between two rounded knife edges without cracking.

(b) **Lap-welded or Seamless Steel.**—Greatest working pressure, 120 atmospheres, of 1800lbs. per square inch.

Stress due to working pressure not to exceed 7½ tons per square inch in lap-welded, or 8 tons per square inch in seamless cylinders.

Carbon in steel not to exceed 0.25 per cent., or iron to be less than 99 per cent.

Tenacity of steel not to be less than 26, or more than 33, tons per square inch.

Ultimate elongation not less than 1.2 inches in 8 inches. Test bar to be cut from finished annealed cylinder.

Proof pressure in hydraulic test, after annealing, 224 atmospheres, or 3360lbs. per square inch.

Permanent stretch shown by water jacket not to exceed 10 per cent. of elastic stretch.

One cylinder in 50 to be subjected to a statical bending test, and to stand crushing nearly flat between round knife edges without cracking.

### Regulations Applicable to All Cylinders.

Cylinders to be marked with a rotation number, a manufacturer's or owner's mark, an annealing mark with date, a test mark with date. The marks to be permanent, and easily visible.

Testing to be repeated at least every two years, and annealing at least every four years.

A record to be kept of all tests.

Cylinders which fail in testing to be destroyed or rendered useless.

Hydrogen and coal gas cylinders to have left-handed threads, for attaching connections, and to be painted red.

The compressing apparatus to have two pressure gauges, and an automatic arrangement for preventing overcharging. The compressing apparatus for oxygen to be wholly distinct, and unconnected with the compressing apparatus for hydrogen and coal gas.

Cylinders not to be refilled until they have been emptied.

If cylinders are sent out unpacked, the valve fittings should be protected by a steel cap.

A minimum weight to be fixed for each size of cylinder, in accordance with its required thickness. Cylinders of less weight to be rejected.

## Cylinder Fittings.

No oil or similar lubricant to be used for cylinder valves, pressure gauges, regulators, or other fittings.

Pressure gauges to have a check to prevent a sudden inrush of gas.

Pressure gauges for hydrogen and coal gas to have left-handed screws, and to be painted red.

You will realise from these regulations that great care must be exercised in the manufacture of these cylinders, and a brief description of how seamless cylinders are made may be of interest.

A flat steel slab is raised to a red heat, and subjected to three hot drawing-through processes. It is then annealed, and pickled in acid to remove the scale, after which it is subjected to about six cold drawings to produce the right shape, length and thickness.

The bottom of the cylinder is hemispherical, and the open end is swaged down after the end of the tube has been upset, to form the neck of the cylinder, which is screwed to receive the valve.

The precision with which these operations are done is beautifully illustrated by the samples on view.

After manufacture the cylinders are annealed by the makers, and re-annealed, valved and tested by the compressing firm. One in every fifty made is tested to destruction, and pieces of the metal analysed.

After being repeatedly pumped to such a high pressure, the metal of the cylinders has a tendency to become crystalline, and to counteract this effect, and to relieve the strains set up in the metal, the cylinders are annealed in a special furnace once in every three or four years, and are hydraulically tested every second year.

The year in which a cylinder is put into commission is stamped on the neck, and stamps are put on every time the cylinder is tested or annealed, and thus the whole history of a cylinder can be traced in its life-time. The working pressure of the cylinders is 1800lbs. per square inch, and they are tested to one and three-quarter times this pressure, or 1½ tons per square inch. The method employed for testing cylinders by the British and other Governments is as follows:—

**Figure 6.**—The apparatus consists of a cast iron chamber B, in which the cylinder A to be tested is suspended. D is an hydraulic pump, employed for testing the cylin-

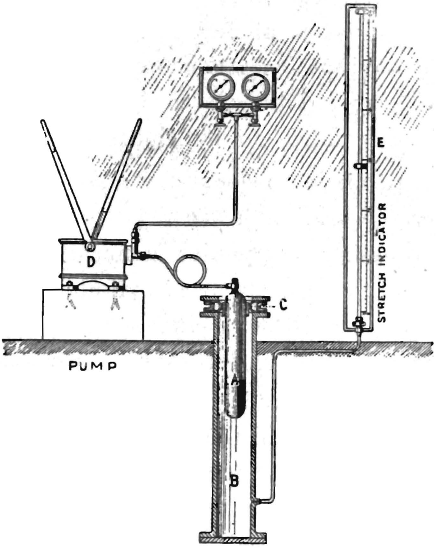


Fig. 6

der A, E a gauge glass communicating with the bottom of chamber B, and C an india-rubber joint ring, which closes and forms a perfect joint round the shoulder of the cylinder.

Both chamber B and cylinder A are filled with water to the exclusion of all air, and a perfect joint made by inflating the india-rubber ring C, which is done instantaneously by water pressure off the ordinary main. When the cylinder is gradually subjected to the test pressure by the pump D, its expansion is measured by the displacement of water from the chamber B, and this displacement is indicated by the rise of the water level in the gauge glass, which continues until the maximum test pressure is obtained. The pressure is then released, and if no permanent stretch has been given to the metal, the water will return to its original level in the indicator.

If, however, any permanent stretch has taken place, this will not be the case, and the cylinder would, therefore, be rejected as unfit for use. The value of this apparatus is obvious, as it ensures that a cylinder is never strained beyond the elastic limit of its metal, and without this safeguard no hydraulic test is reliable.

Cylinders are made to certain weight limits, and any falling below the minimum are rejected.

Gas compressing companies generally reserve the right to decline to fill customers' cylinders, and in every case of a strange cylinder being sent to be filled with oxygen, it is annealed and tested before such is done.

The French and German Governments have also cylinder regulations, but only in recent years, and their cylinders are almost without exception made of a high carbon steel, of great strength, which gives a cylinder considerably lighter in weight than those made to the English standard. The small section of cylinder on view is one of German make, and of almost equal capacity, at 120 atmospheres pressure, to the English cylinder, being slightly longer in diameter, and the stress on the metal is much greater when fully charged.

There are in India very stringent regulations relating to compressed gas cylinders, and this was brought about by the fact that until a few years ago India had no cylinder regulations at all, and, unfortunately, like Australia (where at present there are no regulations), became the dumping ground where unscrupulous makers could send those cylinders which failed to come up to standard.

As an example of the rough handling which oxygen cylinders receive at the hands of some firms' employees, Figure 7 is a valuable illustration.

It is taken from a photograph of two of our Company's standard type oxygen cylinders of 100 feet capacity, at 120 atmospheres pressure. These cylinders, when in the works of a customer, were crushed into the shapes shown by a heavy joist falling on them.

The cylinders were returned to our Greenwich works several days after the occurrence, along with several uninjured ones. On testing the two damaged cylinders, one was found to be **fully** charged with oxygen, and the other **partially** so. No **leakage** could be detected in either.

This shows, in a very practical manner, the amount of rough treatment which gas cylinders made in accordance with the British regulations will stand.

Oxygen, hydrogen and coal gas, being permanent gases when they are compressed into cylinders, no safety device is necessary on the cylinder valve, such as is fitted to the valves of cylinders containing ammonia or carbon di-oxide. These latter being in a liquid state in the cylinder, excessive pressure arises if the cylinder containing them is subjected to undue heat.

The pressure in a full oxygen cylinder, on the other hand, does not increase very much, even though exposed to heat, but nevertheless, care should be taken always, and full cylinders should not be exposed more than is absolutely necessary to the direct rays of the sun, or any other source of heat.

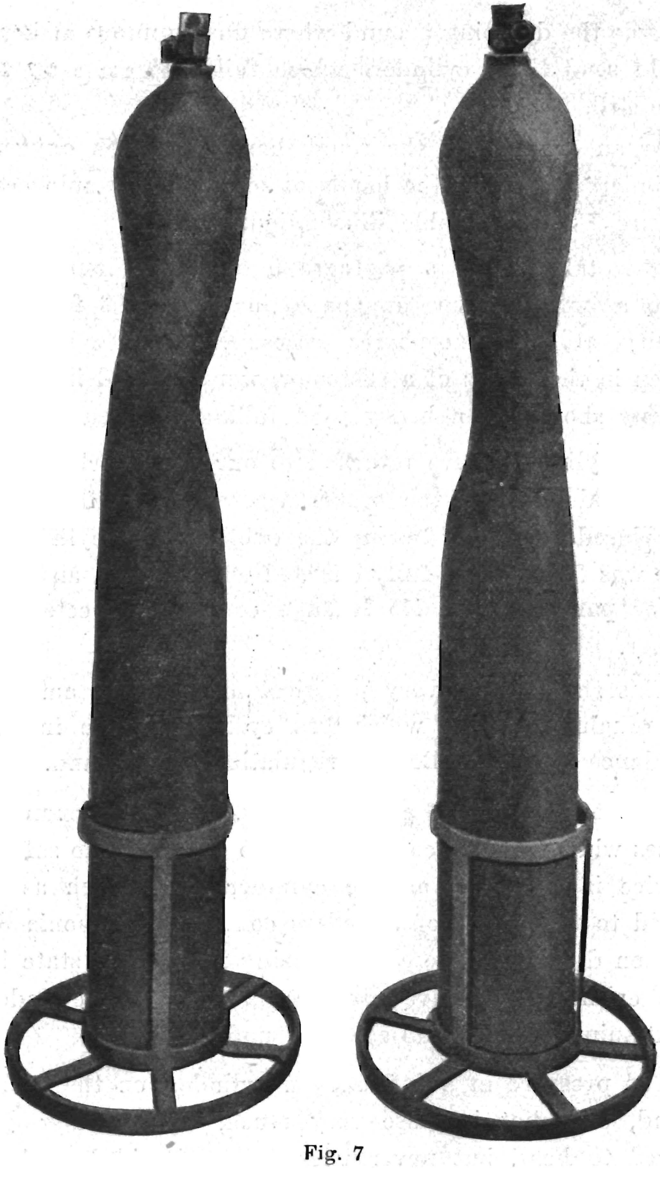

Fig. 7

In conclusion, it may not be out of place to mention that enormous quantities of oxygen are being used at the present time in munition work, shipbuilding, etc.,

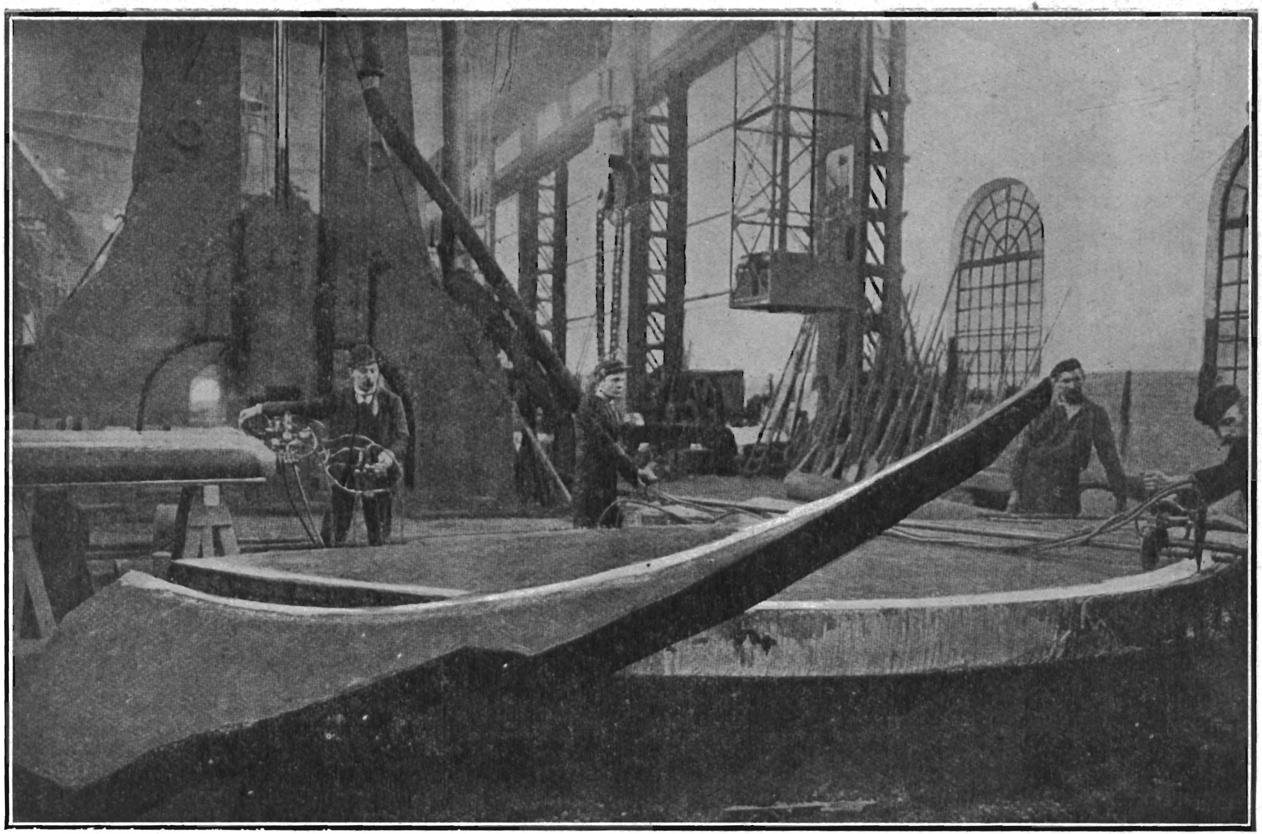

Fig. 8

and Figure 8 shows how accurately the thickest and hardest armour plate can be cut by means of oxygen.

Oxygen is also being extensively used at the fighting front for cutting away wrecked ironwork in bridges, buildings, etc., and for construction and repair of aeroplane parts, and also for saving human lives.

In fact, the Commonwealth Oxygen Co., Ltd., had to send home to England several hundred oxygen cylinders of the sizes used for medical purposes, about the time when we first read of the use of poison gas by the Germans, and I have no doubt that large quantities of oxygen were used in endeavouring to alleviate the sufferings of the victims of the poison gas, as oxygen resuscitating apparatus is always at hand in mines and places where workmen are liable to be overcome by noxious gases or fumes, and when the history of the great war comes to be written, we shall find that in many ways the part played by oxygen was of great importance.

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## DISCUSSION.

Mr. D. F. J. Harricks, in moving a vote of thanks to the author for his excellent paper and demonstrations, said he had no doubt that it at once proved interesting and instructive to all of them. When we consider the progress that has been made in the Commercial Manufacture of Oxygen, it is useful to remember that it is only a matter of comparatively recent years since this has been successfully done, and when one is reminded that the fractional distillation of liquid air appears to be the method now almost univer-