Liquid Oxygen and its Uses.

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AN article or product regarded as a scientific curiosity by one generation not infrequently becomes a commonplace of the next. The vacuum flask used by Dewar to preserve very cold liquids at normal pressure has become a household necessity for retaining the temperature of warm liquids, and, under modern mass-production methods, the glass flask is now obtainable at a remarkably low price. The metal vacuum vessel, with charcoal in connexion with the vacuous envelope, is less widely known. It is not suitable for the retention of hot liquids; but by reason of its relative robustness and of the large sizes in which it can be made, it is preferable to the glass form for the storage and transport of liquid oxygen or liquid air. Without question, the introduction of the metal vessel has rendered possible such expansion in the commercial and scientific uses of liquid oxygen as is now slowly proceeding. That the importance of the metal vacuum bottle is fully realised, becomes clear upon a perusal of the recently published Report of the Oxygen Research Committee.[1] Quite 90 per cent. of the Report is devoted to the manner of construction of these vessels, to the mode of testing them, to the evacuation of the envelopes, and to certain ancillary but vital problems, particularly those concerned with the behaviour of gas-adsorbents (activated charcoals, colloidal silica, etc.) at liquid-air temperature. Though the general reader may regret the absence from the Report of information respecting both the manufacture of oxygen and the specific uses to which the liquid is put, the Committee has decided wisely in limiting its survey to the aspect of its subject which its members have experimentally studied.

The starting-point of the Committee's labours was a series of memoirs prepared in 1918 by the late Dr. J. A. Harker and his assistants in the Munitions Inventions Department. Harker's nomination to the Committee was most fortunate; armed with a knowledge of physical literature that was probably unequalled in our day, he addressed himself, shortly after the formation of the Committee, to the task of collating the available data concerning the chief low-temperature liquids, and of attempting the quantitative expression of the various sources of heat-ingress to liquid oxygen contained in a metal vacuum vessel. As was to be expected, a few of his tentative conclusions had to be left by the wayside as the research developed; the fact nevertheless remains that Harker erected the scaffolding, dug the foundations, and laid not a few of the lower courses of an edifice which, tragically enough, he was not destined to see in its completed state.

The most important type of metal vacuum bottle is the so-called "container"—a vessel holding about 50 lb. of liquid oxygen, and used for both the storage and transport of the liquid. The manufacture of these containers was a German monopoly before the War, and when, in 1918, they came to be required for the Air and Medical Services, considerable difficulty was encountered in getting satisfactory vessels built in Great Britain. Thanks principally to the persistent labours of the research officers of the Air Ministry, this difficulty has largely been removed, and the British-made container has become equal to the German vessel. At the same time, there is still scope for improvement in these storage flasks, and certain possible lines yet remain to be investigated by the Oxygen Research Committee. There has been a tendency to follow too uncritically the German practice; the Committee has not ascertained, for example, whether the 50-lb. size is the best. When the method of emptying the liquid from the bottle was that of pouring it through the neck, there was much to be said in favour of a vessel that could be lifted and handled by one man; but the introduction of the pressure syphon (and with the advantages of that device the present writer fully concurs) has altered the case, and it would seem not unlikely that a larger vessel is to be preferred. The introduction of bigger containers would decrease the evaporative loss per pound of liquid stored, would reduce the number of vessels required to hold a given supply, and probably would also reduce the ratio of dead-weight to that of the liquid.

It is a drawback of large Committees that they seldom possess the courage of their convictions; though the present Report provides a sufficiency of the necessary data, definite recommendations upon which makers may act are very few. The reader will look in vain for a specification of the 50-lb. container setting forth in plain terms the findings of the Committee as to this vessel, which has received five years of its attention. But it is in the section on the evacuation of metal vessels that the widest breach yawns between the conclusions of the experimental side of the inquiry and the nature of the evacuation plant so completely described and illustrated. The fact is that the latter plant, erected at Kidbrooke by the Air Ministry, was designed a few years ago at a period when data did not exist as to the extent of the reduction of pressure brought about by the activated charcoal connected with the envelope of a Dewar flask, when the charcoal is cooled to liquid oxygen temperature. At the time it was thought to be necessary (and the present writer shared in that belief) to evacuate the envelope to a high degree of tenuity by pumping, and plant consisting of such as the Trimount pump or the Langmuir mercury vapour pump, backed in each case by a rougher pump, generally the Fleuss, was advised. A few plants, like this at Kidbrooke, go even further, and have, sealed to the evacuating system, a bulb containing charcoal. After reducing the pressure by pumping to, say, one-hundredth of a millimetre, the pumps are closed-off, the charcoal bulb immersed in liquid air, and the pressure drawn down to an excessively small amount. Now all this is correct enough practice in evacuating thermionic valves or high-class glass or porcelain vacuum vessels; but the Dewar metal flask possesses its own charcoal, and is thus provided, so to speak, with an internal automatic pump of great potency. The Report makes it abundantly clear (pp. 49-55) how

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[1] Department of Scientific and Industrial Research. Report of the Oxygen Research Committee. Pp. vii+177. (London: H.M. Stationery Office, 1923.) 8*s*. 6*d*. net.

supremely effectual is the charcoal of the Dewar bottle in reducing the envelope pressure; it shows, for example, that if that pressure were as high as 1 mm., the cooling-down of the charcoal by pouring liquid air into the container would bring about a drop in the pressure to *circa* 0·00002 mm. Hence, for such vessels, "the important conclusion to be drawn is that a really high vacuum pump is not absolutely necessary. A single oil pump, if in good condition, is sufficient."

The Report would have been improved, and a grave inconsistency removed, if the Committee, taking its courage in both hands, had affirmed that the Kidbrooke plant, in spite of certain advantages, represents a stage of development of evacuating apparatus which has now been outgrown. During war a plant of this kind might be required to run continuously, and to depend on a single Fleuss pump would then be a mistake; but if a stand-by pump were required, a second Fleuss pump connected "in parallel" with the first would be preferable to the present arrangement of a Fleuss and a Trimount connected "in series."

It is a relief to turn from this, the weakest section of the Report, to the portion devoted to the operations of testing metal vacuum vessels (p. 91). The writer has experienced the difficulty of "spotting" the very minute leaks which spell the ruin of these flasks, and can appreciate the practical value of the methods which have been evolved by the Air Ministry Oxygen Laboratory.

Perhaps the first attempt to make an industrial use of liquid air was a short-lived trial by Dewar to employ it in driving self-propulsive vehicles. Another early application was that of Linde, who, so long ago as 1897, experimented with the liquid as an agent in blasting. Though Linde's trial was unsuccessful, the idea of preparing an explosive charge by dipping an absorbent cartridge of carbonaceous material into liquid oxygen was taken up by others, and the method was rapidly improved, notably by Claude in France and Kowatsch in Germany. It was found that to be effective the liquid should contain at least 95 per cent. of oxygen. Owing to the shortage of nitrates, Germany, during the War, made great use of liquid oxygen explosives for mines and quarries. The system was introduced at that time into several Lorraine iron mines, and it is significant of its success that the French, after taking over the mines, have not only retained the system but also in some instances are actually amplifying it. Liquid oxygen explosives have certain striking advantages; they obviate, for example, the need for a magazine of explosives near the mine, while in the case of a miss-fire the charge soon becomes innocuous through the evaporation of the liquid. At present, however, there is no known method of rendering them flameless, and their use in the majority of coal-mines is therefore inadmissible. If this drawback could be removed and certain other difficulties relieved, there is a reasonable probability of their use extending.

The earliest self-contained mine rescue apparatus depending for its supply of oxygen upon the evaporation of liquid air carried in the apparatus was that of Suess, an Austrian engineer, whose British patent is dated 1906. It was not successful; nor did that of Claude (1909) meet with a better fate. It was reserved for Col. W. C. Blackett, the well-known English mining engineer and a member of the Oxygen Research Committee, to bring out (1910–11) the first safe liquid air rescue apparatus, the "aerophor." Since then the apparatus has been much improved, and recently three variants of the aerophor have received official approval for use in Great Britain; they have been adopted at nine mine-rescue stations. The charge for the aerophor for at least two hours' effective service is 5½ lb. or more of liquid "air" containing more than 45 per cent. of oxygen; the charge is poured into a non-vacuum vessel containing tightly-packed asbestos-wool and insulated with magnesite-asbestos and leather. The evaporation of the liquid, uncontrolled by any mechanical device, provides the wearer with the oxygen he needs. The apparatus, simple and efficient though it is, could be improved further by using liquid oxygen instead of enriched liquid air. A liquid oxygen rescue apparatus, in which the supply was held in a metal vacuum flask, was proposed in 1921 by E. A. Griffiths. The bottom of the exterior vessel consisted of an aneroid diaphragm; when the diaphragm was flexed inwards, by means of a screw, contact was made across the vacuum space, and an inflow of heat to the liquid of greater or lesser intensity was secured. The rate of evaporation of the oxygen could thus be regulated between sufficient limits.

The airman flying to great heights requires to carry oxygen, and to be provided with mechanical control arrangements to enable him to supply himself with the gas at will. In this connexion a gas-cylinder is objectionable because of its weight, and the lighter liquid oxygen "vaporiser" is preferred. In its usual form the vaporiser is a small metal vacuum vessel fitted with an external boiler, in which is evaporated liquid oxygen syphoned over from the vacuum flask. Originally invented in Germany by Heylandt, and used by the Germans on their long-distance bombing raids, the vaporiser has been improved in detail by the research officers of the Air Ministry, and has become an efficient device capable of giving an accurate and rapid adjustment of supply.

The technical and industrial applications of liquid oxygen are, in peace-time, and under existing conditions, neither numerous nor important. Quite otherwise, however, is the position of gaseous oxygen; its industrial use, especially in America and Germany, has of recent years greatly increased. At least 95 per cent. is used for welding and cutting. A point often overlooked is that, weight for weight, gaseous oxygen can be produced more cheaply than liquid oxygen. With the latter substance the cold as well as the oxygen has to be paid for; in the former, however, the liquefaction process can be made entirely regenerative, and thermal losses (and therefore the power consumption) reduced to a low figure. From the Jefferies-Norton process, now operating on a large scale in America, gaseous oxygen and nitrogen are obtained at roughly the same pressure as they are delivered from the air-compressor (20 atmospheres); all the power needed to run the plant is got by superheating the nitrogen yielded and making it do work in an ordinary steam-engine; when the plant is producing at the rate of 4000 cu. ft. of oxygen per minute the gas costs (it is claimed) only 3*d.* a thousand cubic feet, while when giving 1000 cu. ft. per minute the equivalent price is 7½*d.*

The advent of cheap oxygen in bulk is bound to bring about revolutionary changes, particularly in metallurgy and gas-making. The boon to these industries in being able to employ what is virtually a nitrogen-free product is sufficiently apparent. Even before the War the use of enriched air for iron smelting attracted attention, and for several years the late Dr. Peters ran a small blast-furnace at Ougrée, Belgium, with slightly oxygenated air obtained by centrifuging atmospheric air on the principle so capably and patiently developed by the veteran engineer, Prof. Mazza, of Turin. The application of oxygen or enriched air to iron making will involve important changes in the chemical reactions involved and in the character of the furnace.

The advantages of oxygen treatment for pulmonary complaints has long been recognised; during the War, and afterwards, a mixture of oxygen and nitrous oxide has proved invaluable in anæsthesia. To render oxygen cheap and plentiful, and to reduce the still grievous weight of the cylinders in which it is carried, would, from the medical point of view, be a great blessing; moreover, in modern warfare it would be of incalculable service to both the military forces and the civil population.

The Transport of Food Substances in the Plant.

IF the stem of a flowering plant is cut across, examination under the microscope reveals the constant presence of three striking tissue systems with their elements extended in a longitudinal direction through the stem, which lie embedded in ground tissue, the cells of which are much less elongated. The outermost of these tissues is composed of fibres in which the walls nearly fill up the cell cavity, and is regarded as strengthening in nature. Within this are two tissues: first, the phloem with elastic walls usually of cellulose, and innermost, the xylem with rigid lignified walls. To these tissues botanists have been practically unanimous in attributing different functions in relation to transport, the xylem being looked upon as carrying the ascending column of water, the phloem as bearing the downward current of manufactured food substances. When, however, Prof. H. H. Dixon, after a preliminary communication to NATURE of February 23, 1922 (vol. 109, p. 236), challenged these long-established views in his presidential address to Section K (Botany) at the British Association meeting at Hull in 1922, it soon became clear upon what a relatively slender experimental basis they rested. The phloem being situated outside the xylem in the stem, it is possible, by cutting a shallow groove, to sever all communication through the phloem whilst leaving the xylem intact. When such ringing experiments are performed, an accumulation of food takes place above the ring, and on the basis of such experiments, largely developed and extended by F. Czapek, who showed that when the phloem was severed in the petiole, for example, starch fails to disappear from the leaf-blade above, the conclusion has been reached that the phloem must be responsible for the downward movement of food substances. Dixon directs attention to Deleano's earlier criticism of these experiments, and certainly, in view of the wider knowledge now available as to the complicated machinery involved in the disappearance of starch from a leaf-blade, many of these experiments cannot now be regarded as convincing, although the accumulation of food substances above a ring upon a leafy stem remains a very significant, well-known fact.

Dixon's main criticism of the view that the phloem is thus functional recalls the "Statical Essays" of the pioneer plant physiologist, Stephen Hales. Considering the carbohydrate present in a potato tuber, and the length of time in which a tuber forms, measuring the cross-section of the phloem in the underground stem leading to the tuber, he estimates the rate at which that carbohydrate must have moved as sugar along the phloem to the tuber. Assuming a sugar solution of 10 per cent. concentration, he finds that its rate of flow would need to have been 50 cm. per hour. Similar calculations, using available data on photo-synthesis in the leaf and measuring the cross-section of the phloem in the petiole, give velocities of the same order for a 10 per cent. solution, figures being obtained of from 20 cm. to 140 cm. per hour. As Dixon points out, no such rate of flow has ever been contemplated by botanists, and the structure of the sieve tubes, the long elements in the phloem with pitted transverse plates, is by no means suited for the transmission of liquid in mass at this rate. It is true that the slimy contents of the sieve tube may contain a much more concentrated solution, Dixon's figure of 2·5 to 5 per cent. concentration in the xylem vessel scarcely being relevant, but such greater concentration would still leave an unexpectedly high rate of flow, for which the phloem seems utterly unfitted. Dixon's alternative explanation is that the bulk of the transport is carried out along the wider vessels of the xylem, in which a more dilute solution may move readily along a channel of greater cross-section.

Dixon marshals experimental evidence for an occasional downward flow in the xylem, from the early experiments of Stephen Hales, in which a tree was inarched into two adjacent trees, its roots being taken out of the ground and its supplies of water drawn entirely from the neighbouring trees. The possibility of such a downward flow will not be doubted; Dixon's difficulty is to show that such a downward flow is of sufficiently regular occurrence in the normal plant to account for the constant return of assimilates from the leaf to the rest of the plant. In this connexion his reminder is timely that earlier experiments have shown how isolated neighbouring tracts of conducting tissue may be within the same stem, so that currents of sap in opposite directions in the xylem of a same shoot are conceivable; they have still, however, to be demonstrated. As a possible driving force for such occasional return currents of sap he directs attention to Thoday's observations upon the changes in volume of a leaf, which may amount to as much as 7 per cent. of the leaf volume in ten minutes. Obviously, however, there is as yet no evidence from the anatomical structure of the leaf to assume that such volume changes should compress liquid into the xylem vessels, and the only observations showing a return drive of sugar solution along the leaf petiole have been obtained by Pitra, in experiments repeated later by Priestley and Armstead, in which the leaves were immersed in water.