1-1-1981

The Design of Oxygen Rebreather Equipment for Use in Foul-Air Speleology

Donald A. McFarlane
Claremont McKenna College; Pitzer College; Scripps College

Trans. British Cave Research Association. Vol. 8, No.3, pp.130-134, September, 1981.

OXYGEN REBREATHER EQUIPMENT FOR USE IN THE EXPLORATION OF FOUL-AIR CAVES

by Donald A. McFarlane

ABSTRACT

The design of a lightweight oxygen rebreather set suitable for short duration explorations in foul-air caves is described, together with a discussion of its performance, limitations, and possible improvement.

Excessive concentrations of carbon dioxide (CO_2) are not a common feature of British caves, and their occurrence is usually limited to a few unusual situations such as sump airbells and constricted passages beneath sewage inputs as at North Hill Swallet, Mendip (Barrington and Stanton, 1972). However, with the recent increase in explorations of tropical caves, British cavers are likely to encounter many more potentially dangerous accumulations of CO_2.

The nature of these caves and their atmospheres has recently been described by James (1977) and need not be reiterated here. It will be sufficient to emphasise that the needs of the speleologist differ markedly from those of the high altitude mountaineer. The latter requires breathing apparatus purely to compensate for the small volume of oxygen inhaled at high altitude - the foul-air speleologist however, is concerned with removing or diluting an essentially toxic addition to his breathing mixture. Indeed, James (1977) has demonstrated that due to the different diffusion rates of the two gases even dangerously high CO_2 atmospheres may contain sufficient oxygen concentrations to sustain life.

The speleologist has, in theory at least, a choice of three alternative life support systems: a non self-contained system based on the dilution of the toxic element to a safe level, or one of two self-contained systems. An examination of the data however, reveals that the former system is impracticable for the speleologist. If we accept a CO_2 concentration of 10% as normal for a foul-air cave of the type that would necessitate breathing apparatus, then allowing a 50% safety factor for upwards fluctuations leads us to consider the problem of diluting an atmosphere of 15% CO_2 to an acceptable level of perhaps 1.0% in the inspired mixture. Since the only advantage of a dilution system is to reduce the volume of oxygen carried by supplementing it with a proportion of the surrounding atmosphere, the 15:1 dilution factor makes such a system redundant.

In the past, foul-air cave exploration has relied on an 'open circuit' system employing standard SCUBA diving equipment (Fincham, 1977). The system has the advantage that the equipment is readily available, well tried, and by and large very safe, but suffers from the not inconsiderable disadvantage of the weight and bulk of the compressed air cylinders. It therefore seems reasonable to suggest that the best solution is to employ a completely closed system - in other words, an oxygen rebreather - in which the expired air is passed via a CO_2 absorbant and then returned to the lungs.

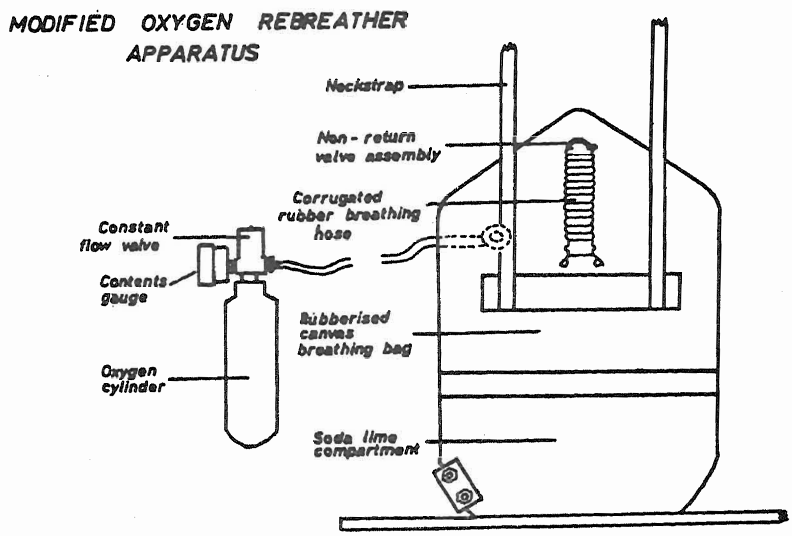
The principle relies on the fact that the human body only uses a small proportion of the oxygen it inhales with some 95-97% of the inhaled air being exhaled again so that in the SCUBA system the biggest proportion of the available oxygen (20.9% in normal air) is exhaled to the atmosphere and lost. Because the oxygen rebreather is so much more efficient, the volume of gas (and hence the size and weight of the cylinders) required for a given length of time is relatively very small.

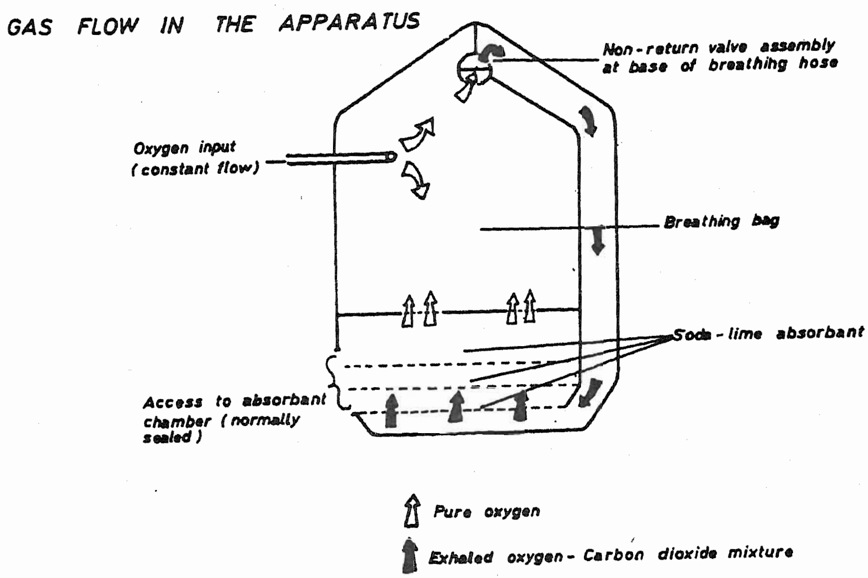
EQUIPMENT AND TRIALS

Recently, Life Support Engineering Ltd., a firm specialising in providing military underwater oxygen rebreathers, have designed and produced a small set intended primarily for emergency mine rescue work. The apparatus was loaned to members of the British Speleological Expedition to Jamaica in 1977 with the intention of testing its speleological potential in the further exploration of Riverhead Cave, where progress has been hindered by serious concentrations of CO_2 in the further reaches. Although high water conditions prevented its use in Riverhead Cave, the apparatus was experimented with by the author and others both above and below ground.

The design of the Life Support Engineering prototype is as follows (Fig. 1). A rubberised canvas "counterlung" of 6.0 dm^3 capacity is fed from a diminutive 63.0 dm^3 (0.3 dm^3/210 Bar) oxygen cylinder. The cylinder, which weighs 1.7 kgs, is fitted with a contents gauge and a fool-proof constant flow valve pre-set, in our case, at 1.5 dm^3/minute. Pure oxygen is breathed directly from the counterlung and separated from the exhaled oxygen/CO_2 mixture by a simple non-return valve arrangement behind the mouthpiece. The exhaled mixture travels down an integral sleeve at the side of the counterlung and feeds into the base of the lower compartment. This compartment contains 0.5 kg of soda lime granules in two layers which 'scrub' the exhaled gas clean of CO_2. The purified oxygen then passes back into the counterlung to begin the cycle again, with a small loss due to metabolism. The equipment is provided with a safety valve to relieve excess pressure in the counterlung, but to all intents and purposes this is superfluous since excess oxygen can be easily and comfortably vented from the mouth. The equipment, as described, provides a self-contained life support system of approximately 30 minutes duration.

Fig. 1.





Prototype oxygen re-breather apparatus in use in Bridge Cave, South Wales.

As a result of practical trials underground, several disadvantages of this prototype equipment were revealed. The first of these is particularly apparent in crawls. The construction of the sets is such that the oxygen cylinder is attached directly onto the counterlung (strapped to the caver's chest) so that the effect is reminiscent of a horse's bridle in that it prevents the wearer from seeing where he is going.

The other problem, common to all simple oxygen rebreathers, is that of the warming of the breathing mixture. Ordinarily, heat loss from the body via expired air is a significant physiological phenomenon, but in an oxygen rebreather this is obviously to some extent circumvented. The result, which may be entirely desirable in cold-water diving, is an uncomfortable overheating for the caver. Whilst this is not really dangerous, and really little more than an unpleasant hinderance, it is a factor that does need to be borne in mind if hard work is contemplated.

MODIFICATIONS TO THE PROTOTYPE

The equipment proposed by the author for speleological use is based on the described LSE prototype, with the following modifications. In order to allow for a reasonable duration in terms of speleological exploration, the 30 minute limitation of the existing apparatus needs to be extended. This is readily achieved by increasing the size of the CO_2 scrubbing compartment to allow the addition of a third layer of soda-lime, raising the absorbant charge to 0.75 kg, and adding a second cylinder to the input. This allows for one hour duration at a breathing rate of 1.5 dm^3/min, although the author has found that a fit caver undertaking moderate exertion (eg. crawling and scrambling underground) can function comfortably on an input of 1.0 dm^3/min. In the latter case a single cylinder of the size described will suffice.

The cylinder or cylinders can be conveniently side-mounted on the caver's belt, requiring only a short extension of the plastic feed hose running into the counterlung, and thereby removing the problem of the weight of the apparatus being borne on the mouthpiece.

The other proposed modification involves the insertion of a short length of corrugated rubber hose, of the type used on twin hose SCUBA demand valves, between the mouthpiece and the non-return valve of the counterlung. This allows for a much increased freedom of head movement, which is rather important in the context being discussed.

CONCLUSIONS

As a result of practical trials with prototype apparatus, a modified version has been proposed which it is felt fills some of the needs of the foul-air speleologist. The equipment represents a compromise between duration, bulk and weight, and cost. The inherent simplicity of the system is one of its great advantages, not only from a constructional point of view but also from considerations of safety. There is only a single mechanical component, the constant flow valve, which is itself the epitomy of simplicity. It can be stripped down and reassembled with a nail file in less than a minute.

The disadvantages of the equipment can be summarised as follows:

1. After 20 minutes or so of use the breathing mixture becomes sufficiently warm to be mildly uncomfortable, unless of course the apparatus is being used in a very cold environment.
2. Some individuals using pure oxygen may experience light-headedness, which is overcome only by experience.
3. The equipment is not designed for immersion in water. In an emergency the set could be submerged provided that the vent on the constant-flow falve was covered and no water was admitted to the mouthpiece, but such a situation is to be avoided except perhaps for short swims in river passages and pools.
4. Care must be taken to flush all the atmospheric air out of the equipment before use, since nitrogen being neither absorbed on soda lime nor metabolised will dilute the oxygen intake into the lungs. (A more detailed description of the use of rebreathers, relevant to this equipment, is to be found in Cullingford,(1962)).

ACKNOWLEDGEMENTS

I should like to thank the following for their invaluable assistance: Mr. B.J. Richards of Life Support Engineering for the loan of the equipment, constant advice and demonstrations, and extreme patience. Also Mr. M. Roger for help with the field trials, and the Jamaica Caving Club

for posing the original problem.

REFERENCES

Barrington, N and Stanton, W. 1972. *The Complete Caves of Mendip,* Barton, Cheddar, Somerset.

Cullingfordm C.H.D. 1962. *British Caving*. Routledge, Kegan Paul, London, 2nd edn.

Fincham, A. 1977. *Jamaica Underground*. Geol. Society of Jamaica.

James, J. 1977. Carbon dioxide in the Cave Atmosphere. *Trans. Brit. Cave. Res. Assoc.* vol. 4, pp.417-429.

Revised MS received 20th April 1981

D.A.McFarlane, B.Sc.,
c/o School of Environmental Sciences,
Ulster Polytechnic,
Shore Road, Newtownabbey,
Co. Antrim BT37 OQB,
Northern Ireland.