

OXYGEN CANDLES

RECENT DEVELOPMENTS

BY

LIEUTENANT-COMMANDER R. A. BRUTY, M.Sc., C.Eng., M.I.Mar.E., R.N.
(Sea Systems Controllerate)

Introduction

The standard oxygen candle currently used in H.M. submarines was developed by the Dockyard Laboratory in Portsmouth in the late 1950s. Manufacture was then transferred to Bardyke Chemicals, Ltd., a small company in Glasgow specializing in producing copper-based chemicals for the industrial paints industry. The company became the sole supplier of candles for the next twenty years when, in August 1984, the Health and Safety Executive (HSE) banned the use of asbestos fibre in the candle manufacture. The prohibition order posed a potential threat to the operation of Britain's submarine fleet; particularly in terms of provision of oxygen during escape and rescue. Attention was then hurriedly focused on the rapid development of an asbestos-free oxygen candle. This article briefly describes these recent developments.

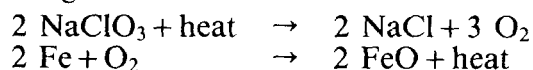
Candle Pyrotechnics

Oxygen is produced from sodium and potassium chlorate candles by the process of controlled thermal decomposition. The candles are burnt in units called oxygen generators provided with pyrotechnic ignition. The basic candle is 380 mm (15 inches) high and 115 mm (4.5 inches) in diameter, and weighs approximately 7 kg (15 lb). The candle is composed of three stages with compositions as shown in TABLE I.

TABLE I—Composition of Oxygen Candles

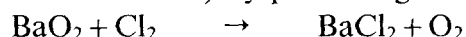
	<i>First Stage (14 gm) 25 mm diam igniter disc</i>	<i>Second Stage (250 gm)</i>	<i>Main Body (7 kg) 115 mm diam × 380 mm high</i>
Sodium chlorate	—	—	87%
Potassium chlorate	49.4%	73.5%	—
Asbestos fibre	—	12.1%	5.0%
Barium peroxide	16.9%	2.0%	2.1%
Copper powder	—	0.8%	0.8%
Nickel carbonate	—	0.1%	0.1%
Iron powder	29.6%	11.5%	5.0%
Charcoal	4.1%	—	—

In order to initiate the thermal decomposition, an ignition cartridge inserted into the oxygen generator is fired, igniting the first stage. Released oxygen combines with the iron powder to produce ferrous oxide plus heat which in turn assists the decomposition of the sodium chlorate in accordance with the following reaction:



The reaction is progressively transposed to the second stage and then to the main body where heat given off is sufficient to sustain the reaction. In order to avoid molten sodium and potassium chlorates from forming a blanket over the undecomposed part of the candle, asbestos fibre is added and this also serves to impart physical strength to the candle.

The copper powder and nickel carbonate function as catalysts and the barium oxide helps to absorb any released chlorine (a secondary reaction from the chlorates) by producing barium chloride according to the reaction:



Replacing the Asbestos Fibre

Attempts to find a replacement for asbestos started in 1977 when the Dockyard Laboratory in Portsmouth¹ produced some experimental candles with various binding agents. Chopped glass fibre, high modulus graphite, and fine iron wool were selected and the merits of each were evaluated. The fine wire wool showed good binding properties whereas candles with glass fibre or graphite were difficult to press and were prone to radial cracking. In all cases the candles were difficult to ignite and often produced much higher levels of carbon monoxide and carbon dioxide in the oxygen product.

Later in 1977, the manufacturer was invited to produce some experimental candles incorporating two types of alumino silicate, namely chopped Fibrefrax* and Capoflex**. The results were a marked improvement over the previous three binding agents tried. The candles were well formed, relatively crack-free, smooth, and closely resembled the overall quality of the asbestos candle. The thermal reactions were stable throughout the burn and gave a marginally improved output of oxygen. Drawbacks were limited to candle burning being too fast for the oxygen generator filters to accommodate, and higher concentrations of carbon monoxide and carbon dioxide being released.

At this stage the candle development looked promising. A suitable binding agent had been found which was compatible with oxygen candle production. The Capoflex fibre gave the most suitable burn time but yielded high concentrations of carbon monoxide; whereas the Fibrefrax performed in the opposite manner. It was thought that the burn time was the easier to control (by varying the concentration of iron powder) and hence Fibrefrax was chosen as the most suitable agent. Furthermore, it was evident that during manufacture of the experimental candles, a higher hydraulic pressure could be applied to the Fibrefrax mixture to press out the candle. Since oxygen output is directly related to the weight of chlorate, an increased bulk density gave an added bonus to the overall candle performance.

In 1979 the development continued by experimenting with candles containing varying ratios of chopped Fibrefrax and iron powder. At this stage it became clear that the conditions of manufacture had to be carefully controlled. It was discovered that the moisture content of the chemical constituents had a critical effect on the thermal reaction; too little would cause cracking during the drying process and too much would cause ignition failure. It was also critical that the iron powder and Fibrefrax were mixed homogeneously in order to produce a stable and even burn throughout the total length of the candle.

Despite these factors it was still difficult to obtain consistency in burning characteristics. Burn times varied from 46 to 80 minutes and in some instances the oxygen flow rate ranged from 1 to 40 litres/minute; not the kind of characteristic which submariners in an escape scenario would wish to observe.

*Fibrefrax: Trade name of The Carborundum Company

**Capoflex: Trade name of Cape Insulation Ltd.

Over the following three years development was extremely slow, mainly because the production rate of the asbestos candle outstripped the company's ability to maintain a full R and D programme simultaneously.

August 1984 was the turning point in the search of a replacement asbestos-free candle. The MOD(PE) had to ensure continuity of supply of oxygen candles into DGST(N)'s stores. After several discussions with Bardyke Chemicals it was agreed that a concerted effort must be made to find a satisfactory replacement candle. Several batches were made followed by rigorous testing, and finally 200 candles were sent to five submarines in December 1984 for final evaluation. The test was a failure in that several candles burned erratically, some cracked, others failed to sustain ignition, and the majority failed to burn in the specified time of 70 ± 10 minutes. It became abundantly clear that the chemistry of candles was far more complex than originally thought and that the failure of the trial was not through lack of effort by the company.

It was fortuitous that independent negotiations had also taken place with Mine Safety Appliances (MSA) at Glasgow. Their parent company in Pittsburgh annually manufactures several thousand asbestos-free candles for the U.S. Navy. Performance was considered to be most satisfactory. It was naturally assumed that the company could produce a candle to burn in the British oxygen generator by making adjustments to the chemical composition. Five prototypes were evaluated and in general were found to be satisfactory. Faced with the prospect of dwindling candle reserves, a production contract for 12 500 candles was placed with MSA in January 1985 on the strength of the small candle evaluation. Some of the candles are being made at Pittsburgh whilst the remainder will be manufactured at Glasgow using a new production facility.

Meanwhile, Bardykes persevered unrelentingly. Several batches were made and tested using a single oxygen generator (a low stock situation at SPDC Eaglescliffe precluded further generators being made available for testing purposes). Gradually they reaped the fruits of their labours. Candle consistency and overall quality improved, and burning characteristics became more stable. With renewed enthusiasm, a further 80 candles were delivered and tested in two more submarines in June 1985. The trial was a marked improvement on the previous submarine trial. In general the ships' staff were satisfied by the performance, the only reservation being that the candles still burnt a little too fast. It appeared at last that the correct ratio of chopped fibrefrax, iron powder, chlorate, and catalysts had nearly been established.

Two weeks later, MSA commenced evaluating the first of their production candles. Salt carry-over in the evolved oxygen was found to be excessive and rapidly choked the filters. The company are now making further adjustments which help to reduce the overall thermal reaction temperature and hence the degree of evolved salt contaminants. As for the future, the candles will be supplied by whichever manufacturer can meet the specification and stringent quality standards, and conform to the demands of competitive tender. Since neither manufacturer has yet proved its ability to sustain quality, it remains to be seen who wins the race.

Conclusion

The chemistry of a pyrotechnic candle appeared to be a simple matter to adjust in order to conform to the customer's requirements. The replacement of the asbestos fibre in the oxygen candle clearly disproved that assumption and even now both companies admit that there is still a lot more to learn. Had this not been the case, a replacement asbestos-free candle would have

been found long before now. However, to date both MSA and Bardykes have independently found a suitable replacement for asbestos but the burn characteristics do not conform to the MOD's requirements. It is envisaged that only after experience of producing several thousand candles will the expertise be available to undertake controlled fine tuning of the candle composition.

Reference

1. Gisborne, J. T., Jarrett, D. and Meyer, P.R.: Oxygen candle manufacture: alternative fibres to asbestos, parts 2-5; *Admiralty Marine Technology Reports* TM78627, TM79524, TM81535, and 83555. 1978-1983.
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