SEALED LEAD/ACID BATTERIES FOR PORTABLE UNDERGROUND LIGHTING

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Introduction

The present-day cap lamp and battery system has been a highly reliable and indispensable aid to miners for many years, and has undergone few changes since its general acceptance in the 1930s. Recent developments in battery technology, however, have made several improvements possible. The most notable change has been the development and commercialisation of valve-regulated (or 'sealed') lead/acid batteries. These are now available in capacities up to 3000 A h and are used extensively in Europe for telecommunications and UPS systems. Since their introduction in 1981, they have established an impressive record of reliability. In the last eight years, Chloride has installed over 600 000 batteries and in that period only 175 cells have failed. Frequent examination of batteries in the field indicates a life expectancy in standby duties of greater than 10 years.

The essential features of these batteries, such as the elimination of watering and regular maintenance, the substantial reduction in gas evolution, and improved volumetric energy density are of considerable value in many applications. In particular, the elimination of leaks and spillages, and the absence of hazardous gases are of particular benefit when used to power portable underground lighting.

In 1982, a new design of cap lamp battery based on this technology was produced and over 500 000 are in use today. This paper describes the design and operating characteristics of this battery.

Design principles

Gas-recombination concepts

Valve-regulated batteries function effectively without maintenance and without the evolution of substantial amounts of hydrogen and oxygen, because oxygen produced by electrolysis during overcharge is converted back to water. The effectiveness of this recombination reaction depends upon the rate of evolution of oxygen and hydrogen from the positive and negative electrodes, respectively, and the sequence in which they occur. Oxygen is

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always evolved on the positive plate at an early stage during the charge period and hydrogen is only produced when the negative plate approaches the fully charged condition [1]. Under suitable conditions, oxygen is converted to water according to:

$$Pb + 1/2O_2 \longrightarrow PbO \quad (1)$$

$$PbO + H_2SO_4 \longrightarrow PbSO_4 + H_2O \quad (2)$$

$$PbSO_4 + 2H^+ + 2e^- \longrightarrow Pb + H_2SO_4 \quad (3)$$

The overall recombination rate is controlled by eqn. (1), *i.e.*, by the rate of diffusion of oxygen to the negative plate. With appropriate materials and with careful design, high rates of recombination can be achieved. When this occurs, the potential of the negative plate is depressed and the evolution of hydrogen is greatly reduced.

The recombination efficiency can be monitored by measuring the weight loss from the battery over a period of time or, more effectively, by measuring the amount of hydrogen evolved. In the latter case, the recombination efficiency (R) based on the current equivalent of the evolved hydrogen is calculated as a percentage according to:

$$R = \frac{(I - I_H)}{I} \times 100\% \quad (4)$$

where I is the average charge current passing through the batteries for the test period, and I_H is the average current equivalent to the hydrogen evolved over the same period.

As an example, sealed lead/acid batteries of the standby design were overcharged continuously for 3 months at two set voltages. The results in Table 1 show that even at a float voltage of 2.27 V/cell, a small amount of hydrogen is evolved. Conversion to an equivalent current gives a gas recombination efficiency of greater than 99%. At the higher voltage (2.4 V/cell), 10.5 cm^3 of hydrogen per cell A h were evolved over the 12-week test period, giving a recombination efficiency of 99.5%.

Battery design

The sealed miners' cap lamp battery is nominally 4 V/16 A h, when discharged at 1 A to 3.7 V. It is illustrated in Figs. 1 and 2 and consists of 2 cells, each containing 4 positive and 3 negative plates. Each plate is

TABLE 1

Gas evolution over 3 months from sealed lead/acid batteries

Charge voltage (V/cell)	Volume of hydrogen (cm^3/cell A h)	Recombination efficiency (%)
2.27	1.0	99.0
2.40	10.5	99.5

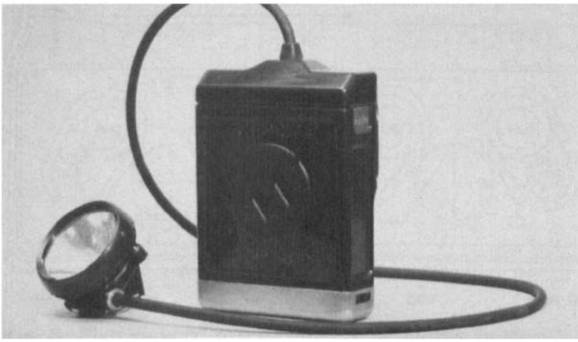

Fig. 1. Miners' cap lamp unit with sealed battery.

Fig. 2. Rear view of miners' cap lamp battery (lid removed).

wrapped in one layer of glass microfibre separator and the assembly is compressed to a defined level before insertion in the container. Both grids are cast in an alloy of lead, calcium and tin. The plates are connected with a top bar and post of lead–tin alloy that is burnt to the insert in the battery cover. More details of the design are given in Figs. 3 - 5.

In one option, the cells are connected externally via a detachable fuse. In a second option, the cells are connected with a lead bar and protected from an external short by using a 'polyswitch'. This is a sealed switch that opens if the current passing through the terminals exceeds 5 A and then closes automatically when the current decreases.

The inner cover is ultrasonically welded to the container. Both cells are leak tested prior to filling with a metered amount of acid and sealed by means of one-way valves that allow gas to escape at higher internal pressures. The outer cover, through which the cable is clamped, is connected via a

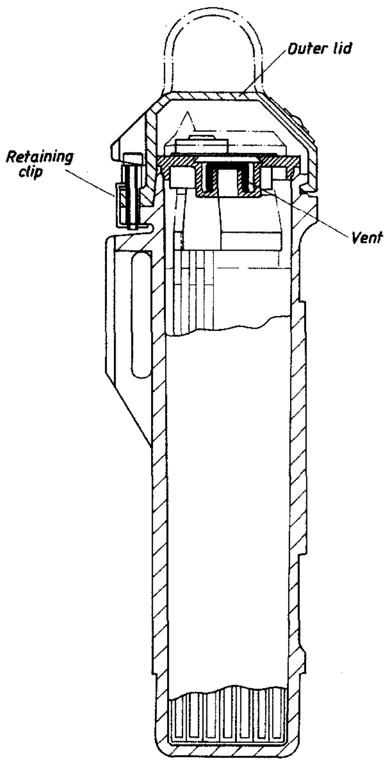

Fig. 3. Side view of miners' cap lamp battery assembly.

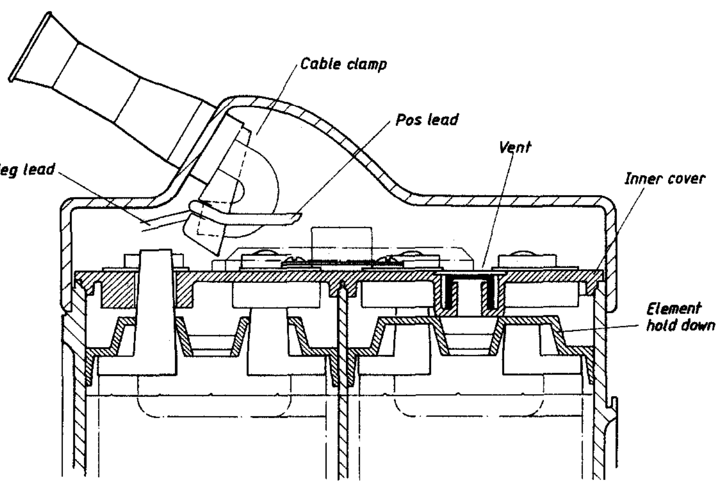

Fig. 4. Sideview of top assembly of miners' cap lamp battery.

retaining clip to the main body of the container. A special unlocking tool is required to remove the outer cover to prevent access to the electrical connections whilst in use.

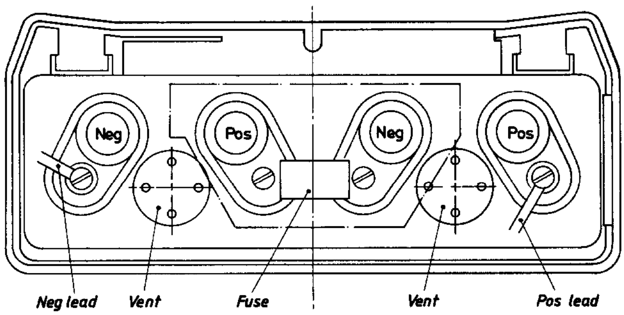

Fig. 5. Plan view of top of miners' cap lamp battery.

Operating characteristics

In the U.K., the miners' cap lamp battery must conform to the British Standard BS4945: 1973 [2]. It must supply power to a 0.9 A bulb for a minimum of 9 h and maintain a voltage greater than 3.70 V. On occasions where an extended shift is worked, the battery may be required to operate for 12 h. To provide this facility and also allow for extended duty underground in an emergency, the battery is designed with nominal capacity of 16 A h on a 1 A discharge. A typical voltage profile on a complete discharge is shown in Fig. 6. During discharge, the battery can be used in any position without spillage or leaks. The recommended recharge conditions are at a constant voltage of 4.90 ± 0.05 V for 15 h by charging from a rack through the lamp bracket.

Approximately 600 cycles (or 2 years service) is achievable on normal shift operation (*i.e.*, 9 h at 0.9 A). Figure 7 shows test results with these batteries when cycled at this rate with full capacity checks every 50 cycles. Throughout this test, the water loss was monitored. The weight loss figures, which are a further indication of recombination efficiency, are also given in Fig. 7.

Details of the operating characteristics of the battery are given in Table 2 and are compared with the previously used designs.

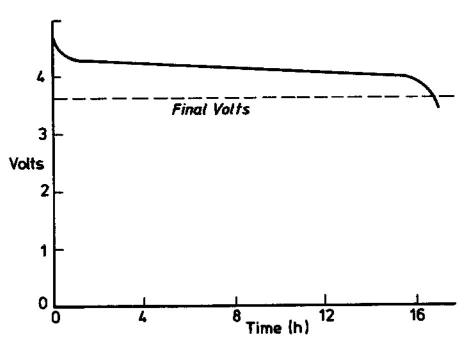

Fig. 6. Discharge profile of miners' cap lamp battery at 1.0 A.

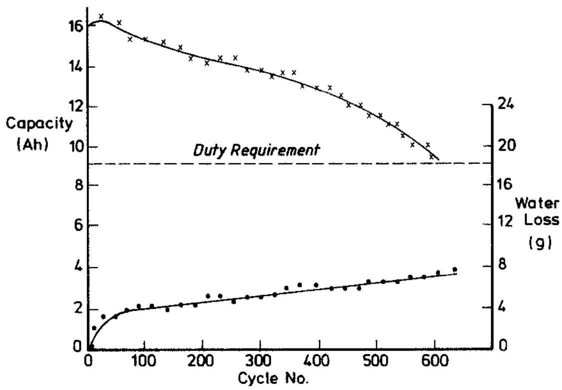

Fig. 7. Cycle-life test schedule for miners' cap lamp battery.

TABLE 2

Technical characteristics of miners' cap lamp battery

	Old design	Valve-regulated battery
Voltage/capacity	4 V/10 A h	4 V/16 A h
Number of plates	3 (2 neg/1 pos)	7 (4 pos/3 neg)
Battery dimensions (mm)	41 × 150 × 187	40 × 125 × 187
Volume (cm^3)	1150	935
Mass-filled, with cover (kg)	2.24	1.96
Cycle life (cycles, 70% DOD)	750	600
Container material	resin rubber	abrasive resistant plastic
Duration (h at 0.9 A)	10	16
Operating voltage range (V)	4.00 to 3.70	4.00 to 3.70

The safety aspects of these batteries have been examined by the British Coal Corporation [3], see Fig. 8. Combinations of hydrogen and oxygen are inflammable over a wide range. The limit of safety for hydrogen in the air is 4% and 74%; for hydrogen in pure oxygen the limits are 4% and 94% [4]. Only mixtures containing less than 4% hydrogen will not burn, while mixtures with less than 5% oxygen and containing 4% - 100% hydrogen are not in themselves flammable but become so on dilution with oxygen or air. Analyses of the head-space gases of the sealed battery with gas recombination were carried out alongside the more conventional flooded/vented design and a low-maintenance sealed battery with no recombination characteristics. All the batteries were cycled according to BS4945 and the head-space gases were analysed after the fourth cycle. In the sealed battery with gas recombination, the oxygen level rises initially on charge but quickly drops to less than 2% as the recombination becomes effective. The gas composition is outside the flammable range for the whole of the discharge phase. In the flooded cell, the hydrogen concentration increases as the cell approaches full charge but quickly decreases after charging due to the venting action. Nevertheless, the

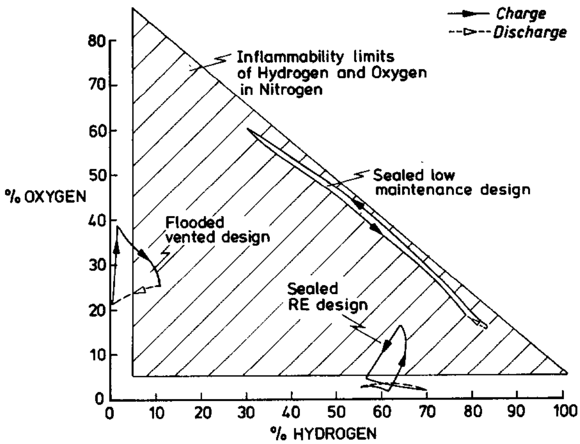

Fig. 8. Cell head-space gas compositions related to flammability limits of hydrogen and oxygen in nitrogen [3].

gas composition remained within the flammable range for about the first 45 min of the discharge. In the sealed battery with no gas recombination, the head-space gases remained in the flammable range at all times.

Discussion

Prior to development of the new miners' cap lamp battery, market research [5] identified a number of disadvantages of the traditional flooded/vented design. These were:

- limited ampere-hour capacity that did not allow for longer shifts
- inadequate light output for the future needs of the mining industry
- dissatisfaction with the regular topping-up procedures that required each filler plug to be removed for inspection
- spill danger inherent in liquid-filled designs
- the mass of battery was considered somewhat high in relation to output.

The development and application of the gas-recombination principle opened the way for all these objectives to be achieved. The seven-plate design described in this paper provides higher utilisation of active material. This feature, together with more efficient use of the cell volume, enables the capacity to be increased by 60%. At the same time, more effective use of the electrolyte (which is totally absorbed within the separator and the plates) provides a small reduction in the overall weight of the batteries.

An operational life of about 600 cycles over 2 years is slightly below that expected for the heavier flooded design, but it is generally accepted that the additional benefits of the valve-regulated design more than make up for the slight shortfall in cycle life.

Analysis of gas in the sealed battery shows, as expected, that the oxygen recombination results in a head space with a 'safe' gas composition. In normal service, the possibility of an internal explosion should a short or bad connection occur is greatly reduced.

Finally, experience during the past 6 years with over 500 000 batteries in service confirms the view that the disadvantages previously expressed in market surveys have been eliminated.

References

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