LOW MAINTENANCE NICKEL-CADMIUM BATTERIES

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ABSTRACT

The reduction of maintenance has become a critical issue for battery users and battery manufacturers have proposed various solutions over the years. Most solutions have concentrated on the reduction of battery watering, but there are obviously other factors that have an impact on maintenance.

Over ten years ago, Saft launched a low maintenance product for the standby market which used recombination technology but retained the normal advantages of nickel cadmium in terms of long lifetime and resistance to difficult environmental conditions. This product uses a special recombination assisting separator and a pressure vent, and uses a special cell container to resist the small internal pressure.

Saft have developed this system further, and has now launched a new nickel-cadmium standby product which uses the special separator but without recourse to the pressure vent. This design change allows the use of the standard cell container and simplifies the installation.

This paper describes the low maintenance technology, its advantages in terms of maintenance compared to standard products and experimental data on water consumption at different temperatures and voltages.

INTRODUCTION

In common with suppliers of many products and services to industry, battery manufacturers have been required to provide products with lower maintenance requirements to minimize the cost in service. Thus, a factor which has become important in the market today is the concept of low maintenance which has been linked with the development of the valve regulated lead acid (VRLA) battery and the elimination of the need to top up the battery with water.

However, although the VRLA battery is often acceptable in a benign low risk application it does have limitations in its behavior in difficult conditions.

The nickel cadmium battery has long been established as the most reliable battery system available in the market. Able to be operated in a wide temperature range, it can be stored for long periods of time without deterioration, has little maintenance required other than topping up with water, has a high tolerance to both mechanical and electrical abuse and is not subject to sudden failure. This unique feature enables it to be used in applications and environments untenable for VRLA battery systems.

In order to satisfy the market requirement for a battery that requires no topping up, a recombination pocket plate nickel cadmium product was developed and launched over 10 years ago. This product uses a special recombination assisting separator and a pressure vent, and uses a special cell container to resist the small internal pressure. A variation on this product has now been developed which uses the special separator but without recourse to the pressure vent. This design change still gives significantly improved watering intervals over an open cell but allows the use of standard cell container and simplifies the installation.

LOW MAINTENANCE TECHNOLOGY

The low maintenance battery described uses conventional pocket plate technology. Thus the active materials, nickel hydroxide for the positive and cadmium hydroxide for the negative, are retained in perforated nickel plated steel strips or « pockets » which are welded to a current carrying busbar.

If a cell is not considered to recombine, then Faraday's equation gives that each ampere hour (Ah) of overcharge breaks down 0.335 cc of the water content of the electrolyte into oxygen and hydrogen and, so, pure distilled water has to be added to replace this loss. In a traditional open cell a reserve of electrolyte is provided above the plate stack to give a reasonable interval between the need for topping up.

The level of gas recombination in a cell is linked to the quantity of gas that is retained within the plate stack and the efficiency of the plates in promoting the recombination process. The lower the current, and the lower the gassing, then the higher the level of recombination in percentage terms.

In a standard open pocket plate cell at low floating currents at normal temperatures, the level of recombination can reach as high as 30% to 40%, but is generally lower than this.

In the case of the low maintenance nickel cadmium products described certain factors have been used to enhance the recombination process. The ribbed separator normally used for pocket plate cells is replaced by non-woven polypropylene felt. This has the function of retaining the electrolyzed gas in the plate stack so increasing the recombination level to 80% to 90%.

The rate at which oxygen is produced on overcharge is directly related to the charge current once the positive plate has reached a full state of charge. The charging voltage level set on the charging equipment and the ambient temperature controls the charge current in turn. By controlling the charge voltage level the rate of oxygen generation can be matched to the available rate of oxygen recombination and high efficiencies obtained. In this way the rate of water loss can be reduced to a mere fraction of that from conventional batteries.

Though the efficiency of this oxygen recombination is high it will never achieve 100%, as small quantities of oxygen will escape from the separator before reaching and reacting at the negative plate. Thus a small quantity of hydrogen will ultimately be generated and low rates of water loss occur. The battery is designed to accommodate this by provision of a generous electrolyte reserve both above and around each cell pack within the battery. This ensures a long service life without the need to top up with water.

The original Ultima battery is fitted with a low-pressure vent on each cell. On overcharge the cells have an internal pressure above atmospheric pressure which assists the recombination process at low gassing rates. However, this does require support for the cell walls either in the cell or battery design to resist this small internal pressure from bulging the cell walls.

In the case of the new, SPL, product a standard open vent is used. This allows the use of standard containers and simple assembly concepts and, as it now becomes effectively an open cell, leads to a more robust battery under difficult conditions. However, it is thought that the lack of a pressure vent will mean that the water consumption will be higher than the standard Ultima product, even though it will be significantly lower than an open cell. The purpose of this testing is to verify this concept.

The low maintenance concept of the battery is not based upon a starved electrolyte technology, as the purpose is to retain the expected robustness of the nickel cadmium industrial product. These cells are flooded cells with sufficient reserve of electrolyte to achieve the maintenance interval required. They can, if necessary, be refilled with water if the application requires it.

WATER CONSUMPTION BASICS

As mentioned in section 2, the products described are flooded products with a reserve of electrolyte above the active plate area. The purpose of the reserve is to allow water to be electrolyzed into hydrogen and oxygen during the battery charging and, the portion that is not recombined, is exhausted from the cell via a venting system. The amount of electrolyte reserve that is available and the rate at which water is electrolyzed and lost from the battery as gases, obviously determines the frequency at which the replenishment of this reserve by distilled water has to be made.

Typically, the reserve of electrolyte in open nickel cadmium cells is in the region of 3 to 6 cm3/Ah (0.2 to 0.4 cu.in./Ah). In other words, a cell of 100Ah, would have an electrolyte reserve of 300 to 600 cm3 (18 to 36 Cu.in.).

The testing described in this paper has been carried on different cell types with different electrolyte reserves. So, in describing the interval between water replenishment in terms of time, this has been based on an electrolyte reserve of 4cm3/Ah (0.24 Cu.in./Ah), to ensure that equivalent comparisons are made.

EXPERIMENTAL RESULTS: WATER CONSUMPTION EXPERIMENTS

Standard Open Cells

Standard low rate open cells of 102 Ah were subjected to continuous floating for six months at 1.40 volts per cell at laboratory temperature (20/25°C or 68/77°F) and an elevated temperature (40°C/104°F), and at 1.45 volts per cell at laboratory temperature. The loss on weight in grams and hence the consumption of water in cm3 was measured over this period.

The results are presented in Table 1 below. The first line of the table shows the actual weight loss over the six month period, the second line shows the equivalent weight loss over a full year and the third line shows the weight loss in grams over a one year period per Ah of capacity (simply line 2 divided by the cell capacity which is 102 Ah).

The fourth line gives the electrolyte reserve of the cell which, as mentioned in section 3, has been standardized at 4 cm3/Ah for the purpose of this exercise. The final line gives the time, in years, which the cell reserve will support before water replenishment is necessary.

These results are consistent with the published data for this product type.

It can be seen that increasing the temperature from 20/25°C (68/77°F) to 40°C (104°F) has a significant effect on the water consumption. This is due to two reasons. The first is that, increasing the temperature, while at the same time maintaining the same voltage, increases the current. As this overcharge current is responsible for the electrolysis of the water, then this will increase and so the water consumption will increase. The second is that increasing the temperature increases the water evaporation. Thus there will be an increase in the water loss due to this phenomena.

It is possible to reduce the electrolysis losses by using temperature compensation of the voltage. This technique is to reduce the charge voltage as the temperature increases to try to maintain the current at the same level as that at normal temperatures. This is not entirely successful as there is still water loss due to evaporation and lowering the voltage increases the charging time of the battery at high temperatures.

Applying temperature compensation to 1.45 vpc at 20/25°C (68/77°F) will give about 1.40 vpc at 40°C (104°F) depending on the actual value of the temperature compensation used. However, the result at 40°C (104°F) is 25% higher than the equivalent 20/25°C (68/77°F) value. This is almost certainly due to higher evaporation rates at the higher temperature.

Table 1: Water consumption for standard open cell at different float voltages and temperatures

	1.40 vpc 20/25°C	1.45 vpc 20/25°C	1.40 vpc 40°C
Weight loss in 6 months (gram)	49	147	188
g/1year	98	294	376
g/1year/Ah	0.9608	2.8824	3.6863
Reserve(cm3)/Ah	4.00	4.00	4.00
Years between water replenishment	4.16	1.39	1.09

As mentioned in 2. Low Maintenance Technology; each ampere-hour (Ah) of overcharge breaks down 0.335 cm3 of the water content of the electrolyte into oxygen and hydrogen. During the test the average current at 1.45 volts per cell was 146mA or 1.43 mA/Ah. Thus over a 1 year period, the amount of water loss would be expected to be 0.335*1.43*365*24/1000 = 4.2 cm3. In the experiment it was found to be 2.88 grams (or 2.88 cm3).

Thus a simple calculation, ignoring the very slight self-discharge losses, shows us that the recombination level at this voltage and temperature was (4.2-2.88)/4.2 = 32%.

At 1.40 volts per cell the current was 51mA or 0.5 mA/Ah and, as above, this should result in a water loss of 0.335*0.5*365*24/1000 = 1.47 cm3. In the experiment it was found to be 0.96 grams (or 0.96 cm3). Thus the recombination level at 1.40 volts per cell was (1.47-0.96)/1.47 = 35%.

Thus, these two low floating voltages at normal temperature both gave recombination levels of about 35%, the lower floating voltage giving a slightly higher value.

However, as the current at the 1.45 vpc floating voltage is three times higher than that at 1.40 vpc, then, despite a similar recombination level, the water consumption is three times higher. Thus the recombination level is not a factor to be considered alone but in conjunction with other parameters.

The effects of a pressure vent using the Ultima SLM cell.

The Ultima SLM product uses both a felted separator and a pressure vent to improve the recombination efficiency. To look at the effect of the pressure vent, a comparative experiment was carried out at an elevated temperature with the standard SLM product and one with the pressure vent replaced with an open vent.

The results of this are shown in Table 2. At the lowest float voltage, and therefore the lowest float current, the pressure vents improve the water consumption two-fold. However, as the voltage is increased, the effect becomes less marked, the pressure vents only giving 20% to 30% improvement over the open vent.

However, it must be remembered that, to accelerate the effect, this experiment was carried out at 40°C (104°F) and so the water loss was much higher than would be experienced at normal application temperatures and the effect of the pressure vent may be to reduce evaporation. This is a phenomena which is less important at lower temperatures.

Table 2: Water consumption for Ultima SLM cells at 40°C(104°F) with both open and pressure vents at different float voltages

Temperature 40°C (104°F)	Open vents			Pressure vents		
	1.42 vpc	1.45 vpc	1.47 vpc	1.42 vpc	1.45 vpc	1.47 vpc
Weight loss over 4 *3mths (gram)	50	100	150	21	84	114
Weight loss per month (gram)	4.17	8.33	12.50	1.75	7.00	9.50
g/1year/Ah	0.77	1.54	2.31	0.32	1.29	1.75
Reserve(cm3)/Ah**	4.00	4.00	4.00	4.00	4.00	4.00
Years between water replenishment	5.20	2.60	1.73	12.5	3.10	2.30

** The same 4cm^3/Ah reserve is used in Table 2, for consistency. It is worth noting, however, that the wicking action of the felted separator actually allows the electrolyte level to drop below the minimum line, without affecting operation of the cell.

Experiments with the SPL range

Following the experiments with the Ultima product with and without pressure vents, a series of tests were carried out with 130Ah cells from the new SPL range. This range was designed to give the low maintenance advantages of the Ultima range but with the simplicity of the standard flooded ranges in terms of cell case design and battery arrangement.

Water consumption tests were carried out at various voltages and temperatures and the results are given in Table 3. These results are also shown graphically in Figures 1 and 2.

Referring to Figures 1 and 2, it can be seen that there is a very similar trend between voltages regardless of the temperature, with the higher temperature giving a much higher overall consumption. Referring to the more detailed data in Table 3. The first line gives the average weight loss over the 5-month period of the test to date, the second line gives this value per month and the third line calculates the weight loss in grams (cm3 of water) per year per Ah of capacity. This is then used to calculate the years between water replenishment based on a reserve of electrolyte of 4 cm3/Ah.

This experiment demonstrates two major factors that effect the water consumption, the float voltage and the temperature.

The results from the float voltage show the same pattern at both temperatures. Not surprisingly, the lowest water consumption is at the lowest float voltage. This is because the lowest float voltage has the lowest current and hence the lowest level of electrolysis. Increasing the float voltage from 1.42 volts per cell to 1.45 volts per cell increases the water consumption about 3 times, and further increasing this to 1.47 volts per cell further doubles the water consumption.

The effect of temperature is very large. Running the battery continuously at 50°C (122°F), which admittedly is generally outside the range of a normal application, increases the water consumption by about 20 times.

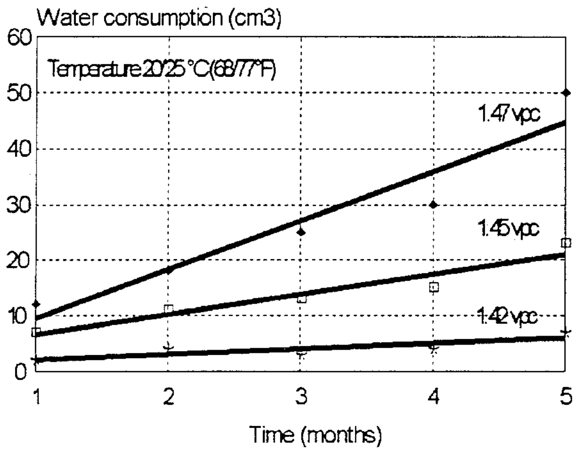

Figure 1 : Water consumption at 20/25°C (68/77°F)

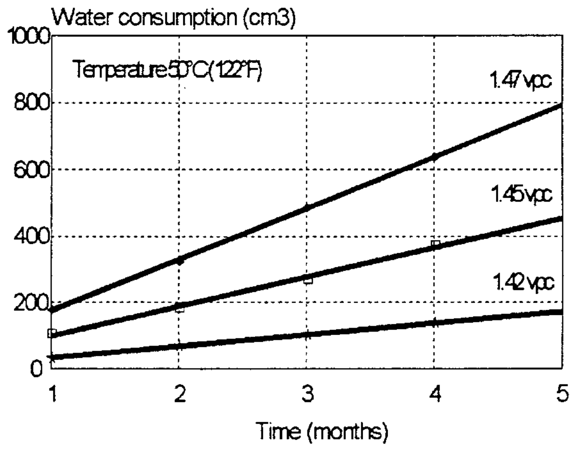

Figure 2 : Water consumption at 50°C (122°F)

Table 3: Water consumption for SPL cells at different temperatures and voltages

	20/25°C(68/77°F)			50°C (122°F)		
	1.42 vpc	1.45 vpc	1.47 vpc	1.42 vpc	1.45 vpc	1.47 vpc
Weight loss over 5mths (gram)	7	23	45	180	450	800
Weight loss per month (gram)	1.4	4.6	9.0	36	90	160
g/1year/Ah	0.129	0.425	0.831	3.32	8.31	14.77
Reserve(cm3)/Ah	4.00	4.00	4.00	4.00	4.00	4.00
Years between water replenishment	31	9.4	4.8	1.2	0.5	0.3

The effect of using temperature compensation to reduce the water consumption is demonstrated by comparing 1.47 vpc at 20/25°C with 1.42 vpc at 50°C. This is a typical change in voltage which would be expected if temperature compensation of the voltage was used. Comparing the two figures, it can be seen that at 50°C the water consumption is 'only' 4 times higher than at 20/25°C. This is significantly better than comparing 1.47 vpc at the two temperatures, a comparison which gives 16 times the consumption. Table 4 gives a comparison between the recombination levels for the different voltages and temperatures.

At the lowest voltage levels the recombination level is about 95% at 20/25°C. As the voltage increase the recombination level decreases. This shows that the change in water consumption is not only due to the current in the cell but also the level of recombination. Clearly, as the current increases the volume of gas produced increases and the separator is less able to trap the gas to improve the recombination.

As the temperature increases, again the chemical activity and the current increases and so, the volume of gas given off increases. This results in a reduction in the recombination possible. However, temperature also has an effect on evaporation, so, in fact, the recombination at higher temperatures may be higher than the calculation indicates.

Table 1 and Table 3 allows a direct comparison to be made between a standard open cell and an SPL cell to be made at 1.45 volts per cell and 20/25°C. With our theoretical reserve of 4 cm3/Ah, the standard cell gives a watering interval of 1.39

Table 4: Calculation of recombination efficiency for SPL cells at different temperatures and voltages

	20/25°C			50°C		
Floating voltage	1.42 vpc	1.45 vpc	1.47 vpc	1.42 vpc	1.45 vpc	1.47 vpc
g/year/Ah	0.129	0.425	0.831	3.32	8.31	14.77
average current (mA)	119	187	286	479	817	1044
mA/Ah	0.92	1.44	2.20	3.68	6.28	8.03
g/year/Ah calculated	2.69	4.22	6.46	10.81	18.44	23.57
recombination (%)	95.2	89.9	87.1	69.3	54.9	37.3

years and the SPL cell gives 9.4 years. Thus the SPL cell is nearly 7 times better. This is consistent with the SPL documentation where an improvement of 5 times is claimed.

A comparison of the calculated recombination level at the same voltage and temperature gives 32% for the open cell and 90% for the SPL cell. The currents found for both experiments were similar indicating a good consistency between experiments.

BATTERY LIFETIME

One of the major advantages of nickel-cadmium batteries is the long lifetime. However, the introduction of maintenance free, or rather products which do not require topping up with water, has made this factor of major importance to users. The purpose of the SPL range is to give both options, long life and minimum maintenance.

The lifetime of the nickel-cadmium battery and valve regulated lead acid (VRLA) battery at high temperatures is described by the Arrhenius equation and the relative lifetimes have been well reported[1,2]. In essence, the lifetime of a lead acid battery falls by 50% for every 10°C above 20/25°C and the nickel cadmium battery by 20%. This is related to the inherent technology and will not be repeated here.

Table 5 gives a comparison between the lifetime at the two temperatures tested for the SPL and the VRLA battery types. The lifetime of the nickel-cadmium battery under floating conditions at normal temperature is at least 20 years[1,2] and a high quality VRLA battery, if premature failures are ignored, is generally about 7 years[1,3] under the same conditions.

The first three lines of Table 5 give the lifetime of the nickel-cadmium battery, the water replenishment interval as found in the test and the number of times the battery has to be refilled during its lifetime.

It can be seen that at normal temperatures and a low floating voltage then the electrolyte reserve will last the full 20-year life of the product. At higher voltages there becomes a need to replenish the cell with water up to 4 to 5 times during its lifetime. At 50°C, due to the high water consumption, water would have to be replenished yearly or bi-yearly depending on the voltage.

The lifetime of the VRLA battery is about one third that of the nickel cadmium battery at normal temperature but, due to its much greater problems with high temperatures, this falls to only one tenth of the nickel-cadmium lifetime at 50°C.

If the SPL battery is compared with the VRLA battery, then, at normal temperatures and voltages, the SPL battery would not have to be replenished with water during the lifetime of the VRLA battery. At high temperatures, if temperature compensation is used, and so 1.42 vpc would be the voltage, then this would also be true.

Table 5: Water consumption and lifetime comparison between SPL and VRLA batteries

	20/25°C(68/77°F)			50°C (122°F)		
	1.42 vpc	1.45 vpc	1.47 vpc	1.42 vpc	1.45 vpc	1.47 vpc
Nickel-cadmium (SPL) lifetime in years	20	20	20	14	14	14
Topping up interval in years from Table 3	31	9.4	4.8	1.2	0.5	0.3
Topping up / lifetime for SPL	0	2	4-5	10	30	50
VRLA lifetime in years	7	7	7	1.2	1.2	1.2
Lifetime SPL versus VRLA	3 times	3 times	3 times	10 times	10 times	10 times
Topping up interval SPL v lifetime VRLA	0	0	0-1	0	approx 2	approx 4

Thus, the aim to produce a product with the reliability and lifetime of nickel-cadmium and the convenience of VRLA in terms of water replenishment has been achieved.

CONCLUSIONS

The purpose of the SPL cell has been to give the advantages of the low water consumption of the Ultima product without the need for special cell containers required by the low-pressure vent used in the Ultima range.

The experiments have shown that the use of the Ultima separator in an open cell (the SPL range) gives a marked improvement over a standard open cell in terms of water consumption. An improvement of 5 times has been claimed and has been demonstrated.

Experiments with the Ultima range has shown that the low-pressure vent gives some additional advantage in terms of water consumption and justifies its use in specific applications.

In general terms, when compared to a VRLA product, the interval between the requirement to replenish the SPL battery with water is, at least, the lifetime of the VRLA battery. Thus the choice for the user becomes that of replacing the VRLA battery or adding water to the SPL battery. This then becomes a question of life cycle costing, an issue which has been addressed in an earlier paper[4].

FURTHER WORK

The work carried out has provided a useful insight into the behavior of low maintenance and open nickel-cadmium cells at high temperatures. The experimental results have shown increases in the water consumption that cannot be explained simply by the increase in the current in the battery and the resulting increase in electrolysis of the water.

Evaporation would seem to have an important bearing in this increase and the difference found in the Ultima cells with and without pressure vents would tend to confirm this. The pressure vent would have a significant part to play in reducing evaporation. Further tests will therefore be carried out with different venting systems, in particular the gas manifold system, to investigate how maintenance at high temperatures can be further reduced beyond the existing SPL product.

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