

Maintenance-Free Lead Batteries with Immobilized Electrolyte

H. TUPHORN

17.1 INTRODUCTION

Since the maintenance-free sealed nickel/cadmium accumulator became of high importance in the market, in the middle of the 1950s ([Figure 17.1](#)), the German battery company Sonnenschein has invented the first maintenance-free portable lead-acid batteries in small sizes in modules of 2 to 12 V between 1 and about 30 Ah. These batteries have been absolutely maintenance free and because of their immobilized electrolyte they could be used in any position without leakage. Applications for these batteries were electronic flashlights, portable TVs, tape recorders, and electric lawn mowers. Also for emergency power supply and in alarm equipment these batteries in valve-regulated construction are used still today.

Important for the maintenance-free properties of these batteries was the possibility to use antimony-free grid alloys instead of the conventional lead-antimony alloys, which were used only at this time. Because antimony in the grid alloys provides a high cycle life for the battery, it was necessary to develop more sophisticated methods in battery manufacturing in order to achieve the required product properties.



Figure 17.1 Valve-regulated maintenance-free gel batteries from the 1950s.

17.2 FUNDAMENTALS

The basis for charging lead-acid batteries is the redox reaction of lead:

1. $\text{PbSO}_4 + 2\text{H}_2\text{O} = \text{PbO}_2 + \text{H}_2\text{SO}_4 + 2\text{H}^+ + 2\text{e}^-$
2. $\text{PbSO}_4 + 2\text{H}^+ + 2\text{e}^- = \text{Pb} + \text{H}_2\text{SO}_4$

Besides this main reaction, an additional reaction takes place at the electrodes during charging, which generates hydrogen and oxygen:

- 1a. $\text{H}_2\text{O} = 2\text{H}^+ + 1/2 \text{O}_2 + 2\text{e}^-$
- 2a. $2\text{H}^+ + 2\text{e}^- = \text{H}_2$

This water decomposition during charging, which requires the maintenance of topping up of water to the electrolyte, generally takes place in lead-acid batteries if charging is not stopped after full charge of the active masses, because no more lead ions for reactions (1) and (2) are available. This basically takes place during charging with constant current. But the reactions (1a) and (2a) take place generally during the main charging of the masses together with the power saving reactions (1) and (2), because hydrogen is thermodynamically more noble than lead. Because of the thermodynamical law, at the negative electrode basically the more noble element is reduced before the less noble one. The reason that charging of lead-acid batteries basically is possible is the so-called hydrogen overvoltage, which inhibits the reaction (2a), so that PbSO_4 can be reduced to Pb. So the amount of water decomposition during charging is generally influenced by the degree of hydrogen overvoltage.

In order to guarantee an almost maintenance-free operation of lead-acid batteries, which requires low decomposition rates of water, the usage of materials with high values of hydrogen overvoltage is needed. While lead basically fulfills that requirement, antimony, which is used more or less as an alloying component in conventional lead-acid batteries, decreases the overvoltage extremely.

In consequence the potential of the charging reaction of the negative plates is closer at the potential of hydrogen reduction, so that during charging considerable amounts of gas are evolved at the negative plate. The influence of antimony can be demonstrated by [Figure 17.2](#), which indicates the charge characteristic of lead-acid cells containing grids with different alloys.

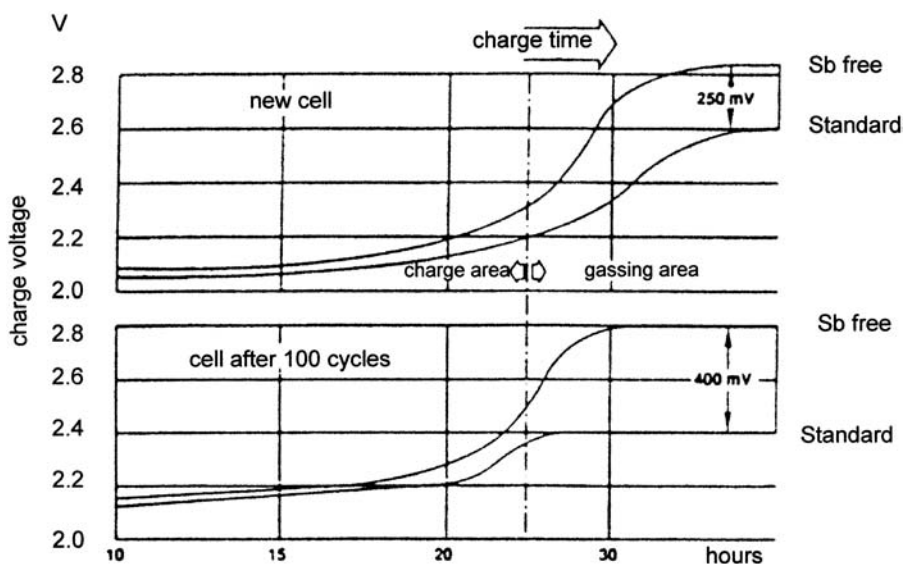
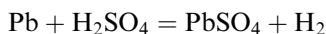


Figure 17.2 Antimony influence in the grid alloy on charge characteristic of vented lead-acid cells.

The upper part of Figure 17.2 indicates the situation on new flooded cells, and the increasing of the charge voltage at the end of charge of the active masses to the voltage of water decomposition is obvious. This voltage range between cells with 4.5% Sb and cells with antimony-free plates is about 250 mV. In the lower part of Figure 3.2 a higher decreasing of the water decomposition voltage is obvious. The reason is, because of anodic corrosion during charging, antimony from the positive plate is soluted and is electroplated at the surface of the negative plates. So the antimony amount at the surface of the negative plates increases extremely, and the battery reacts like a battery with plates of a higher amount of antimony. It is obvious that the voltage range between the new and the cycled batteries increases from 250 mV to 400 mV, and this finally can lead to the consequence that the battery never can be recharged, because the whole current generates hydrogen and oxygen (antimony poisoning).

Figure 17.3 indicates the influence of antimony on the gas extrication of lead-acid batteries during charging with constant voltage (Ford Test).

The self-discharge, too, is influenced by antimony, because this is a reaction of the negative mass with the sulfuric acid of the electrolyte under hydrogen evolution:



If the evolution of hydrogen is inhibited because of an increased hydrogen overvoltage, then the speed of the self-discharge reaction is reduced significantly, as indicated in Figure 17.4

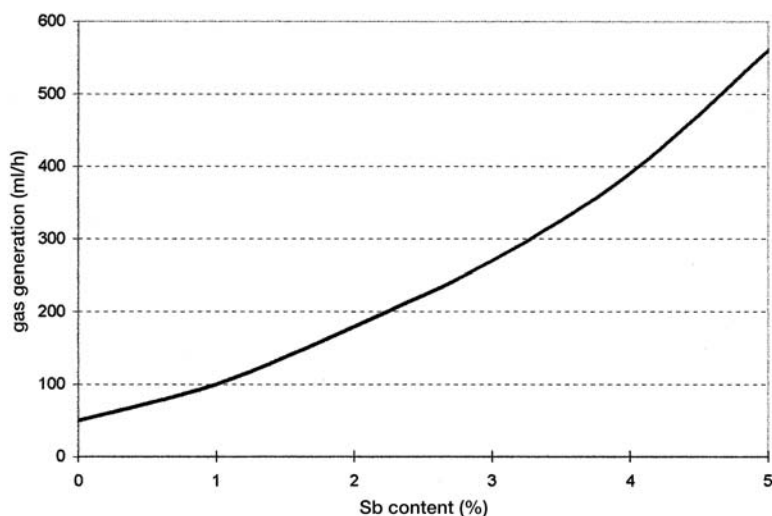


Figure 17.3 Antimony influence in the grid alloy on gas extrication in starter batteries during charging with $U=4.2$ V/cell.

17.2.1 OXYGEN RECOMBINATION

Besides the usage of clean materials and antimony-free lead alloys for the construction of batteries, the so-called oxygen recombination is the basis for the function of valve-regulated maintenance-free lead-acid batteries. Because of the thermodynamic locations of hydrogen and lead, a complete prevention of decomposition of small amounts of water generally is not possible. But the oxygen

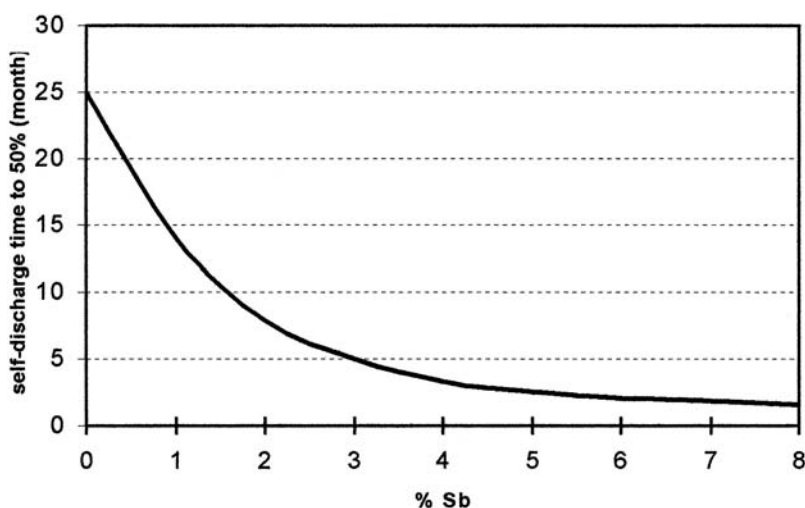


Figure 17.4 Antimony influence on self-discharge of lead-acid batteries.

recombination, which takes place in valve-regulated lead-acid batteries, prevents the extrication of small amounts of hydrogen-oxygen mixture during charging. The recombination is a cathodic reduction of oxygen gas, which still is formed by water decomposition during charging, with hydrogen ions at the negative electrodes to water. In this way a circulation of water-hydrogen-water happens. In order to achieve this, the oxygen which is formed at the positive plates must have the possibility to migrate to the surface of the negative plates, where it will be reduced. This process is demonstrated in Figure 17.5.

Basically required for the function of oxygen recombination are free channels between the positive and the negative plates to allow the oxygen to migrate from the positive plates, where it is formed to the negative plates, where it will be reduced. This is achieved by solidification of the electrolyte either by gelling (Dryfit technology) or by adsorption of the electrolyte in nonwoven glass fiber material, (AGM technology). The AGM method requires that the fiber separator is not fully saturated with electrolyte, so that the oxygen gas can find enough channels for migration to the cathode.

As soon as free oxygen reaches the surface of the cathode, it becomes depolarized, which means its voltage decreases, because the reduction of oxygen to water requires less energy than the reduction of hydrogen ions to hydrogen gas. Therefore at the negative plates oxygen is reduced:

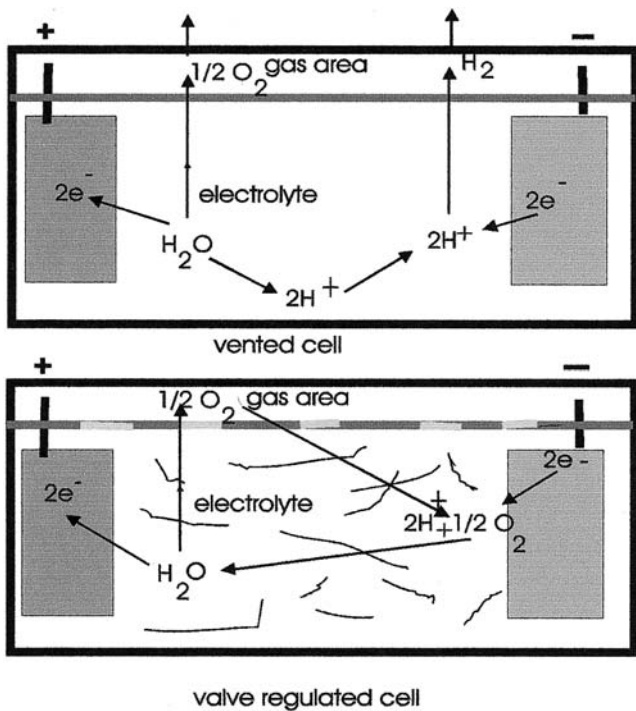
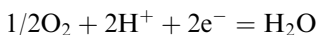
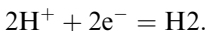


Figure 17.5 Oxygen recombination in lead-acid batteries.



instead hydrogen evolution:



17.3 CONSTRUCTION

As already pointed out, a significant feature of valve-regulated maintenance-free lead-acid batteries is the usage of lead-calcium instead of lead-antimony grid alloys. Because of the high requirements on the hydrogen overvoltage, high purity of all used materials, especially the electrolyte, is required, because small impurities may increase the self-discharging of the battery because of decreasing the hydrogen overvoltage.

In contrast to conventional lead-acid batteries, valve-regulated batteries do not require free space underneath the plates for mud collecting, because loosened mass particles are fixed between the plates and cannot fall to the bottom of the cell, forming short circuits. In valve-regulated batteries, this space can be used for increasing the plate length in order to increase the capacity.

In gel batteries high-porous plastic separators with very low resistance are used, while in AGM types nonwoven glass fiber mats are used to soak the liquid electrolyte. Simultaneously these glass mats have the function of separators.

An important feature of construction of valve-regulated batteries is the valve, which replaces the vent plug of conventional lead-acid batteries. The vent is necessary to allow the escape of small amounts of gas, which is generated in new batteries during charging. On the other side the vent has to be absolutely tight from outside to inside, in order to prevent the migration of oxygen from the air into the cells, where it would oxidize the negative mass because of the free channels:



Therefore even marginal leakage would increase the self-discharge of that cell. Those cells in series of batteries would be deep discharged during the subsequent discharge operation of the battery with the consequence of premature depletion.

Valve-regulated batteries are constructed with flat plates. Also batteries with tubular plates for stationary and traction applications are produced in gel technology.

17.4 SYSTEMS AND PROPERTIES

17.4.1 Gel System

The electrolyte in gel batteries is gelled by addition of highly dispersed silica dioxide. In this way a thixotropic liquid is obtained, which solidifies after a short standing time after filling. Thus a gelled electrolyte with a high amount of fine capillaries is formed, which allows the oxygen to migrate from the anode to the cathode. Comparing the gas generation of a valve-regulated gel battery during overcharging for 90 hours with constant voltage of $U = 2.35 \text{ V/cell}$ with a conventional battery of

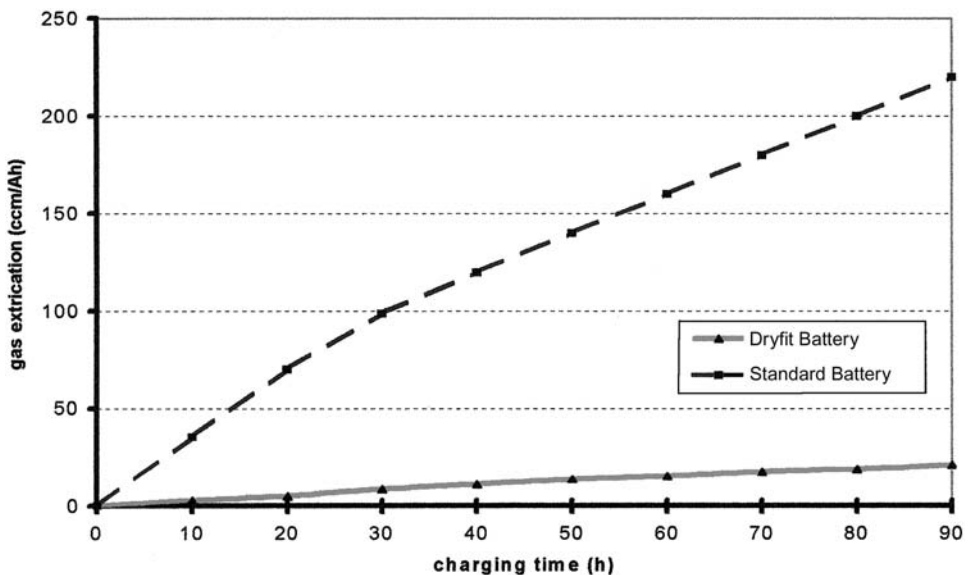


Figure 17.6 Comparison of gas extrication between gel batteries and conventional batteries during charging with $U = 2.35$ V/cell.

the same size indicates that the valve-regulated battery produces only 10% of gas compared with the conventional one (Figure 17.6).

This is valid for valve-regulated batteries in new condition. During longer operation the gas extrication decreases because of aging of the gel. Because of the initial decomposition of small amounts of water, new capillaries become formed, which increase the recombination rate by increasing the oxygen migration. Figure 17.7 illustrates an exponential decrease of the initial gassing during operation

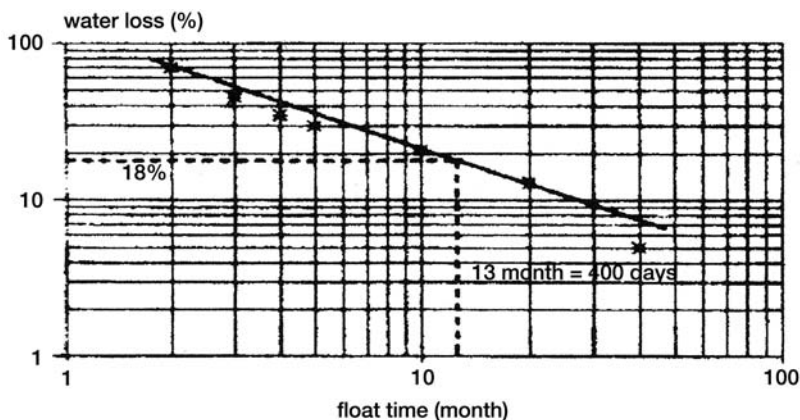


Figure 17.7 Decreasing of gas extrication of gel batteries during charging with $U=2.3$ V/cell.

time to a negligible rest. This process is the reason that valve-regulated gel batteries are never destroyed by drying out if they are operated under regular conditions.

Because of the solid structure of the electrolyte, gel batteries in new condition have a reduced capacity in comparison to flooded batteries. This is valid for similar constructions. Regarding the situation that gel batteries do not require free space underneath the plates, this capacity lack can be compensated partially by increasing the length of the plates. During cycling, gel batteries show a distinct capacity development, which increases over 100% of the nominal capacity in its maximum. During cycling with the 5-hour rate the maximum of the capacity is near 50 cycles, while at the end of life 80% of the nominal capacity is achieved with 250–300 cycles (Figure 17.8).

17.4.2 AGM System

Besides the gel system, during recent years the AGM system (adsorbed glass mat) was developed for the production of valve-regulated lead-acid batteries. This system is used by several battery companies. In this system the leakage of acid is prevented by adsorption of the liquid electrolyte in fiber separators.

In order to achieve the described oxygen recombination also in this system, during filling it has to be respected that an excess of electrolyte is avoided. In order to achieve free pores for the oxygen migration to the negative plates, the separator must not be saturated with liquid. With this technology, too, the initial capacity is significant below the capacity of vented batteries. Without additional measures, the initial capacity is 80–85%, like gel batteries. Figure 17.9 shows the influence of electrolyte saturation of AGM batteries on the recombination and capacity.

17.4.3 System Comparison

Comparing both valve-regulated battery systems, it is obvious that AGM batteries are full in oxygen recombination already in new condition if the electrolyte

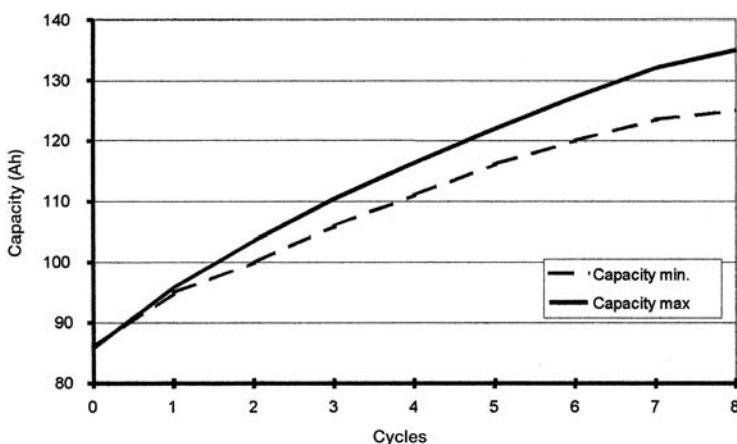


Figure 17.8 Capacity development of VR 110Ah gel batteries during cycling with I_5 .

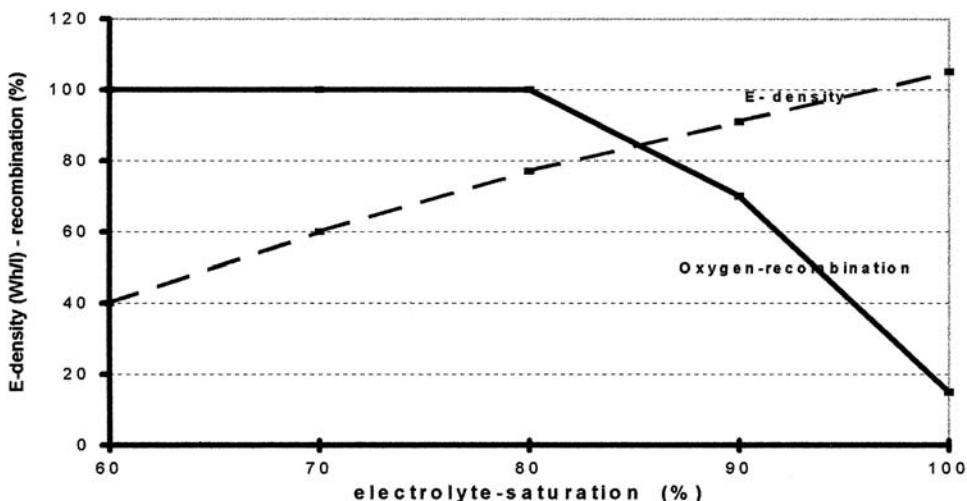


Figure 17.9 Influence of electrolyte saturation on energy density and oxygen recombination of AGM batteries.

saturation of the glass mat is significant below 100%. In contrast, gel batteries in new condition have still a very low gas extrication in the beginning of life. This water decomposition together with aging of the gel leads to the forming of more new capillaries, with the consequence of increasing oxygen recombination up to values which prevent any gassing. So in both systems drying out because of water decomposition will never be a reason of early end of life, as soon as the batteries are charged in correct condition. Because of the larger pores in AGM batteries, in comparison to the gel capillaries, the recombination rate of AGM batteries is about 20 times higher than that of gel batteries. The oxygen recombination is defined by the equation

$$R = 100 - \frac{V \times 100}{n \times i \times t \times 0.62} (\%)$$

where R = recombination rate (%), V = gas developed (L), i = average charging rate (A), t = charging time (h), n = number of cells. Because of the influence of the charge voltage on the charge current, the recombination rate R decreases with increasing charge current.

On principle the full function of the oxygen recombination, which is necessary for valve-regulated maintenance-free batteries, can be achieved with both technologies (Figure 17.10).

In one attribute both systems are substantially different, that is the charge condition. The reason is the big difference in the recombination rates of the two systems, caused by the different structures of the pores in the systems which are needed for the migration of the oxygen from the positive to the negative plates of the cells. While the glass fiber mat of AGM batteries has pore diameters of up to 100 microns, the capillaries of gel batteries are formed by shrinking of the gel because of aging. In this way capillaries are formed which are in maximum one-tenth of the

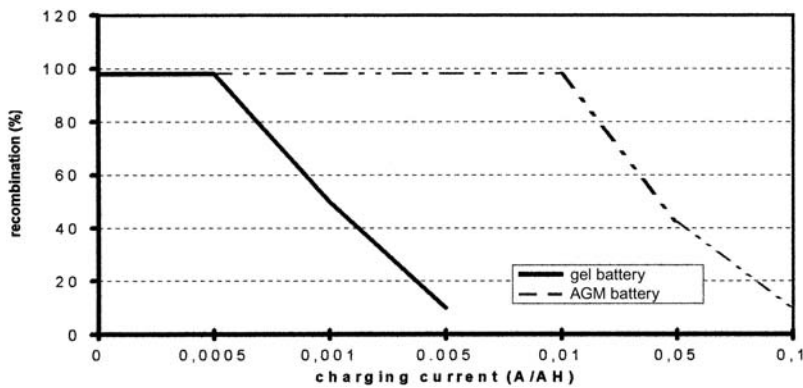


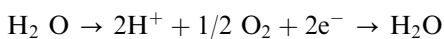
Figure 17.10 Oxygen recombination of valve-regulated battery systems. (From NTT.)

pores of the AGM material. This is the reason for the substantial difference of recombination of the two systems.

The recombination rate for gel batteries with 100% up to a charge current of 0.5 mA/Ah is fully sufficient for maintenance-free operation, because the EOC currents of gel batteries never exceed this value. In contrast, the consequence of a too high oxygen recombination depolarizes the negative plate extremely, so that the anodic potential increases are very high. Because this grade of polarization increases the oxygen development, the exothermic oxygen reduction to water, which takes place at the same time at the negative electrode, increases the temperature of AGM batteries more than gel batteries.

The current voltage curve (Figure 17.11) indicates the situation of the influence of the recombination rate on the charge current of valve-regulated lead-acid batteries. During charging with 2.3 V/cell the voltage divides up to 1.87 V at the positive plate and -0.43 V at the negative plate. The corresponding charge current is 50 mA/100 Ah. For gel batteries the oxygen which reaches the negative electrode causes a depolarization from -0.43 to -0.40 V, which polarizes the positive plate to 1.89 V. The corresponding recombination current I_{gel} increases after that to 80 mA/100 Ah.

Because of the high oxygen concentration, at AGM batteries the negative plate is depolarized up to 0.34 V, which effects a polarization of the positive plate to 1.96 V. This causes an increasing of the recombination current I_{AGM} up to 800 mA/100 Ah. The recombination current is effected by the redox reaction



which causes a strong heat development. This higher oxygen cycle in AGM batteries in contrast to gel batteries is responsible for the risk of thermal runaway if no removal of the reaction energy is possible. The thermal runaway, which causes a spontaneous end of life of batteries because of overheating, is often discussed in technical publications as a problem of valve-regulated lead-acid batteries. It is not observed in gel batteries, which is a consequence of the low recombination rate of this system.

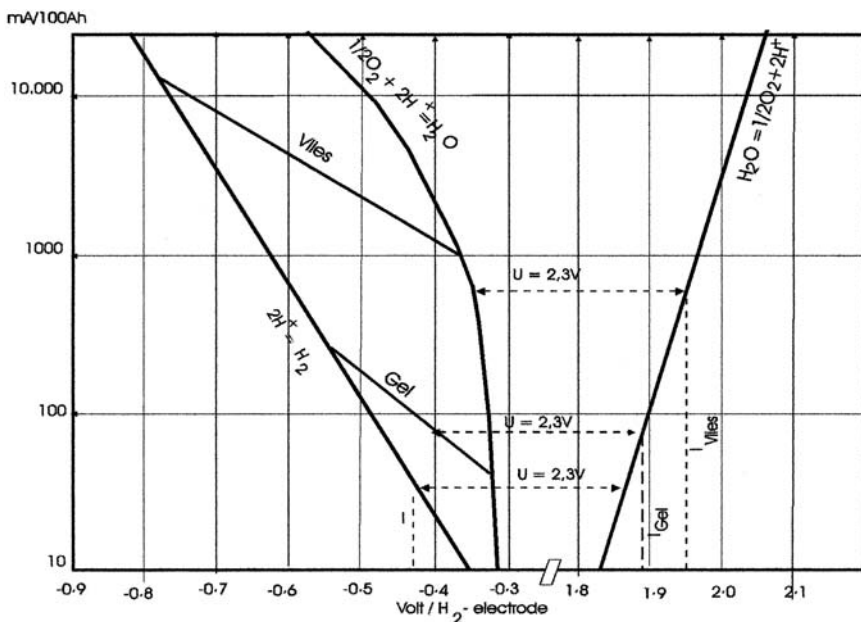


Figure 17.11 Influence of the oxygen recombination on the charge current of VRLA batteries of different systems.

A further distinction of both systems is the acid stratification. This often causes early end of life in flooded lead acid batteries. The acid stratification is caused by the dilution of the sulfuric acid electrolyte, which reacts with the active masses during discharging of the battery. During charging this sulfuric acid is formed in high concentration, which deposits to the bottom of the cell because of its higher concentration if no stirring of gas development occurs. So in flooded batteries which are charged maintenance free, which means without gas development, a stratification of the electrolyte takes place which forms low acid concentration in the upper regions and a high acid concentration in the bottom areas of the cells (Figure 17.12). This affects an acid limitation, which reduces the capacity of the cell spontaneously during cycling. But it is more dangerous; the high acid concentration at the bottom area of the cells causes corrosion of the positive grids in the low plate areas, which destroys the battery.

That those dangerous stratification effects never are observed in conventional batteries is a consequence of the water decomposition especially at the end of charge because of the charge method and the low hydrogen overvoltage of the lead-antimony grids. So during charging the formed oxygen and hydrogen gasses agitate the electrolyte, so that the different concentrations become mixed again. The maintenance-free starter batteries, as they are used in the automotive industry today, are vibrated during their operation in the car, so that here the electrolyte is agitated, too.

Figure 17.12 indicates this situation at 350 Ah for traction cells. In all cases the electrolyte had a gravity of 1.23 g/cm^3 . It is obvious that in the flooded cell even after

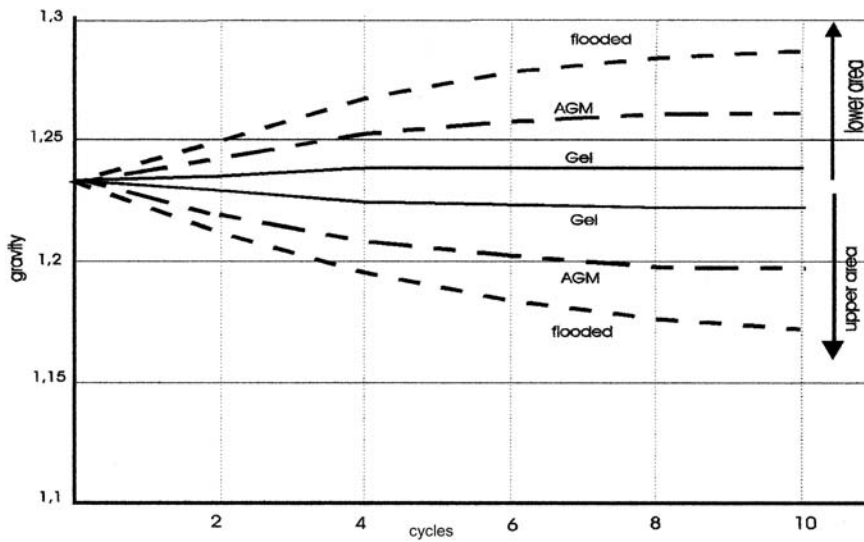


Figure 17.12 Acid stratification during cycling of maintenance free lead-acid batteries of different technologies.

10 cycles we find a difference of gravity between the upper and the lower parts of the cell between $d = 1.16$ and $d = 1.29$. Because of the lower mobility in AGM batteries here the stratification is almost halved but still relevant. Because of the immobilization of the electrolyte a vibration of the cell will not equalize the stratified electrolyte layers. By the structure of the gel electrolyte in gel batteries the sedimentation of the higher concentrated acid, which is formed during charging at the plate surface, is inhibited so extremely that the diffusion of the higher concentrated electrolyte prevents practically total stratification. Early failures because of acid stratification are never observed in gel batteries.

17.5 ELECTRICAL PROPERTIES

17.5.1 Methods of Charging

The charging voltage of lead-acid batteries depends on their open circuit voltage, which can be calculated according to the gravity of the electrolyte by the formula

$$OCV = d + 0.84(V)$$

In order not to exceed the voltage to the amount of the electrolyte decomposition, valve-regulated lead-acid batteries basically have to be charged with controlled voltage, which has to be above the OCV voltage but below the voltage for reduction of H^+ ions. At room temperature a charge voltage between 2.3 and 2.35 V/cell has to be used. Therefore for charging of valve-regulated lead-acid batteries IU chargers are to be used with a recommended current limitation of $I = 1$ to $2 \times I_5$.

During charging without current limitation the initial current increases up to 0.5 A/Ah. Then the increasing cell voltage decreases the current exponential to an EOC current of about 1 mA/Ah (Figure 17.13). By use of current-limited chargers the maximum current of the charger will remain as long as the current reaches the dotted line in Figure 17.13. After that it follows this current curve. For complete charging, a full discharged battery needs 15 hours to achieve 100% charge condition.

Because valve-regulated gel batteries are not damaged by partial charging, which is forbidden for conventional lead-acid batteries. Partial charge operations are allowed if after every five cycles the battery is fully charged again.

Figure 17.13 indicates that, for instance, a charging time of only 1 hour with $U = 2.35 \text{ V/cell}$ without current limitation brings the state of charge up to 50%. (This is valid for room temperature.) The temperature influence on the charge voltage is indicated in Figure 17.14. It has to be marked that the charge voltage for cycle operation has to be 50-100 mV/cell above the charge voltage for float application. The temperature influence on the charge voltage is due to the influence of the temperature on the charge reactions of the positive and negative masses as well as on the reaction of the water decomposition.

Charge units regulated by constant current or by constant resistance generally should not be used for charging of valve-regulated batteries unless highly experienced staff can control the whole charging operation with interruption of the current as soon as the end of charge voltage is achieved.

Besides the IU charging, an IUI charging is recommended for valve-regulated traction batteries which are switched together to high voltages. In this way the charge current has to be kept constant for 4 hours for equalization of the charge condition of the single cells, as soon as it has achieved a value of 20 mA/Ah.

An equalized charge condition on single cells before discharging a battery is important in order to avoid deep discharging or reverse charging.

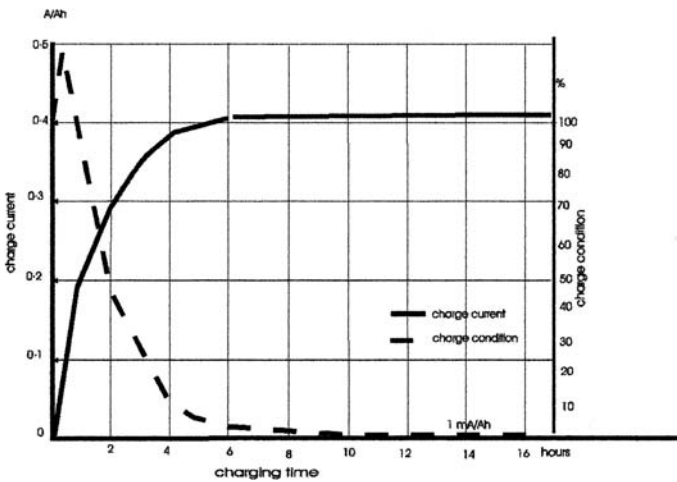


Figure 17.13 Charge characteristic of valve-regulated gel batteries with $U=1.35 \text{ V/cell}$.

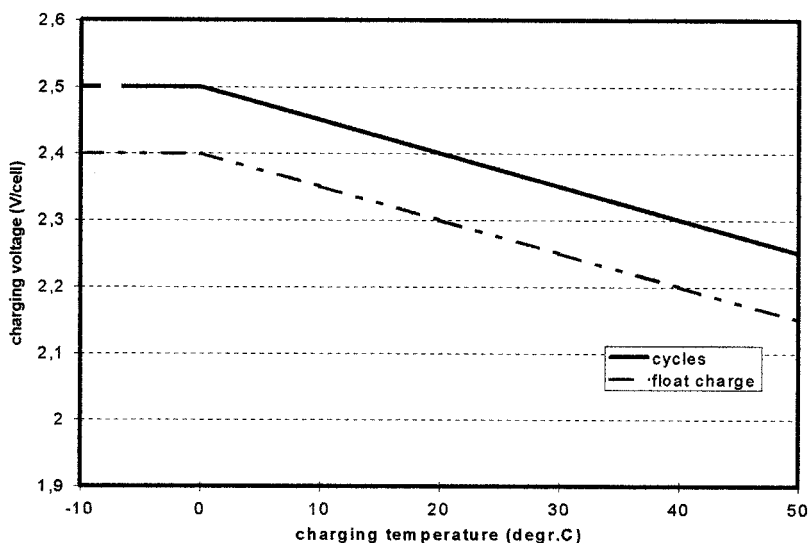


Figure 17.14 Temperature influence on charge voltage of valve-regulated gel batteries.

17.5.2 Discharge Conditions

The nominal capacity of valve-regulated batteries is defined between I_5 and I_{20} according to the application and the technology of the battery. For definition the rated capacity following discharge rates is valid at $T = 20^\circ\text{C}$:

- Cells with flat plates (nonmilitary types): I_{20}
- Military batteries: I_5
- Stationary batteries (tubular plates): I_{10}
- Traction batteries (tubular plates): I_5

In a similar way as indicated by conventional battery systems, the capacity of valve-regulated batteries depends on the discharge current and on the temperature of the battery. With increasing of the discharge rate and decreasing of the temperature, the capacity decreases as indicated in [Figure 17.15](#).

Although in valve-regulated batteries the electrolyte which takes part in the discharge reaction is immobilized and its diffusion is limited, valve-regulated batteries have a very good high rate performance at low temperatures, which is superior than conventional batteries. [Figure 17.16](#) indicates on a 12-V 100-Ah battery, as used in military tanks, the discharge performance for discharging with $I = 25 \times I_5 = 500\text{ A}$ at 0° and -30°C and the performance of valve-regulated batteries is distinctly superior compared with flooded batteries. This can be explained because at high temperatures only a small part of the electrolyte takes place on the discharge reaction in combination with the oxygen recombination.

By the oxygen recombination the negative electrode becomes depolarized and so its voltage decreases to more positive values, with the result of increasing the voltage of the positive electrode, because the charge voltage is fixed ([Figure 17.17](#)). Because of the more positive voltage of the positive plate, this plate is shifted into a

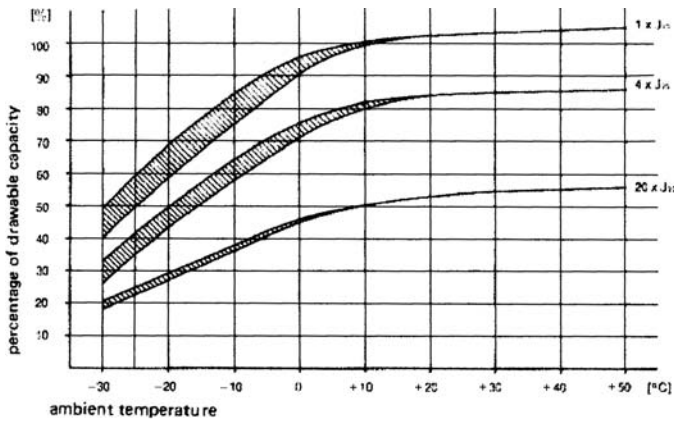


Figure 17.15 Influence of temperature and discharge rate on capacity of gel batteries.

higher state of charge. This superiority of valve-regulated batteries is clearer with decreasing temperature and decreasing discharge rate.

17.5.3 Life and Self-Discharge

During cycling operation between I_{10} and I_{20} at 20°C gel batteries with flat plates achieve a cycle life of about 250-300 cycles up to a residual capacity of 80% of the initial capacity. In order to achieve this life with antimony-free valve-regulated batteries an especially highly controlled production technology of the positive plates, which normally limit the cycle life of antimony-free batteries, is required.

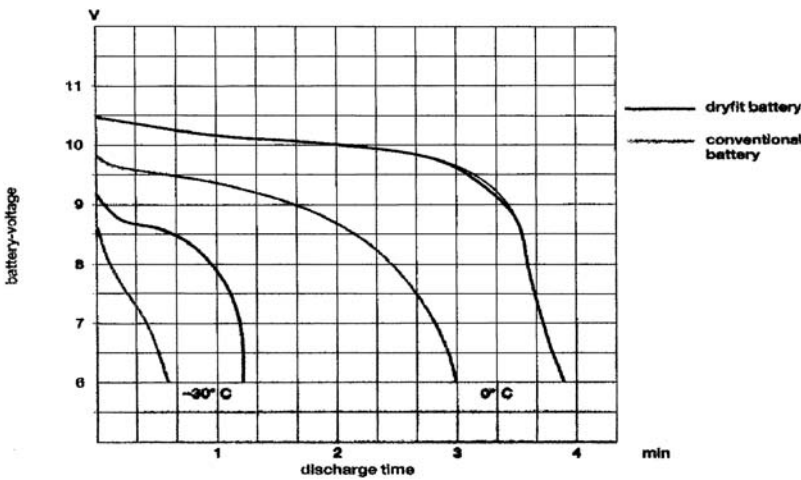


Figure 17.16 Discharge characteristic of different battery technologies at 0 and -30;°C with $I = 25 \times I_5$.

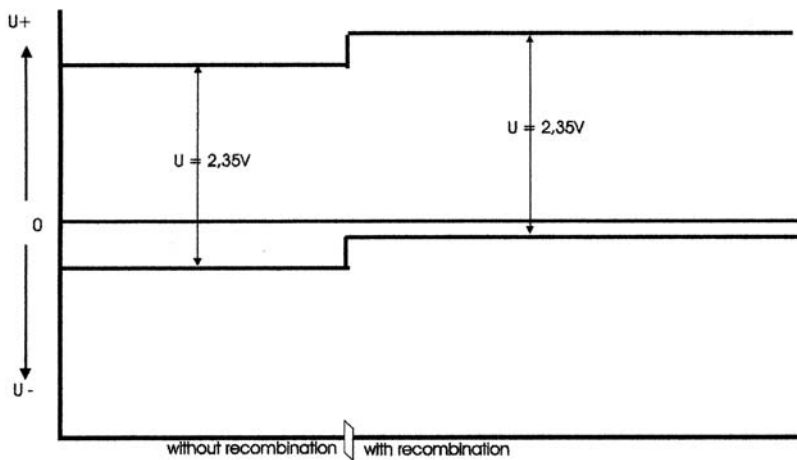


Figure 17.17 Influence of oxygen recombination on the single voltages of the electrodes of valve-regulated batteries.

Obviously the float life depends on the battery temperature, too. Figure 17.18 indicates the life results of an accelerated test. In the solid line the values achieved between 50° and 70°C are plotted. The charge voltages were adapted according the values in Figure 17.14. The results follow very well the Arrhenius equation since a temperature increasing of 10°C decreases the float life always to 50%. The extrapolation indicates an average float life at room temperature of 10-12 years, which is identical with practice.

According to the usage of antimony-free grid alloys, the self-discharge of valve-regulated batteries is extremely low. Figure 17.19 indicates values of a long-term test, and it is obvious that the self-discharge decreases with increasing time. Even after a

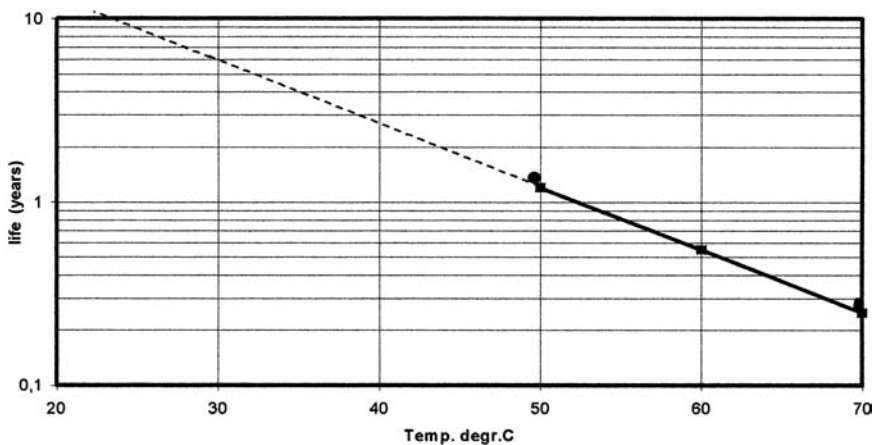


Figure 17.18 Influence of temperature on float life of valve-regulated gel batteries.

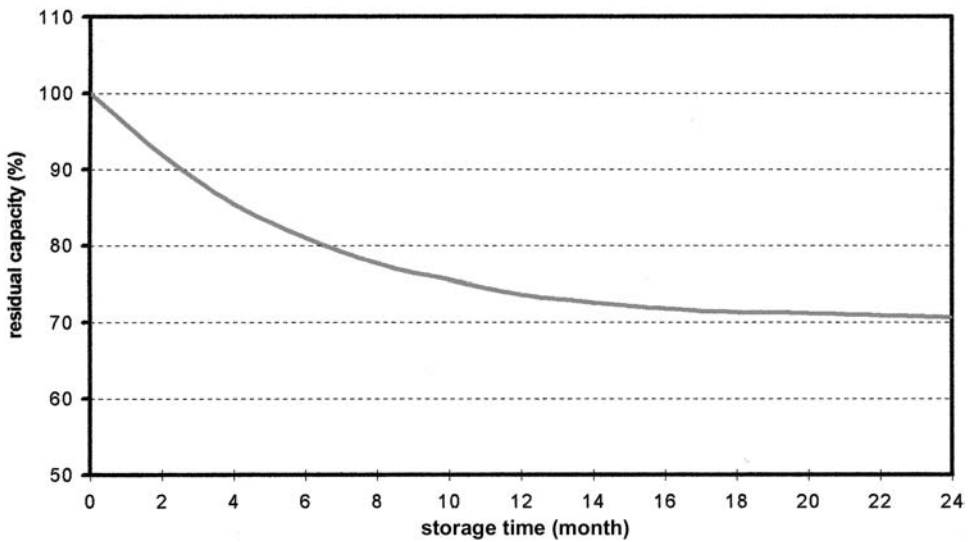


Figure 17.19 Self-discharge of 12-V 100-Ah gel batteries at room temperature.

storage time of 2 years, the residual capacity of gel batteries is still 70%, so that these batteries can be used without recharging even after 2 years storage.

17.5.4 Deep Discharge Ability

Conventional lead-acid batteries are sensitive against deep discharging and should never become fully discharged. After a complete discharging and the subsequent recharging of flooded batteries, often short circuits from lead dendrites growing from the negative to the positive plates are the result. The reason is that by reaction of the sulfuric acid with the active masses during discharging, the electrolyte dilutes up to neutrality. Because in neutral water the solubility of lead ions is 100 times higher than in sulfuric acid, lead ions are soluted in the electrolyte. During recharging of such a battery lead is precipitated in dendrite shape at the negative plates and grows through the separators to the positive plates.

In valve-regulated batteries the sulfuric electrolyte is reacting with the electrodes, too, so that here also the same dilution of the electrolyte takes place. But in contrast to flooded batteries, because of the solidified electrolyte, the lead ions are hindered from diffusion into the cell. Thus the concentration of lead ions near the plate surface increases extremely, so that because of the solution equilibrium a further solution of lead is prevented. Therefore the electrolyte cannot become saturated with lead ions and no precipitation of lead dendrites takes place.

This deep discharge ability was one of the reasons for introducing gel batteries in several military applications, because the early end of life of batteries because of deep discharging is a very frequent failure.

During recharging, deep discharged batteries have a different behavior than normal discharged batteries. Because of the very high resistance of the diluted electrolyte the initial current during recharging starts extremely low until enough acid

is formed by charging. Then because of the higher conductivity of the electrolyte the charging current increases very steeply. The time for current increasing at charging of deep discharged valve-regulated batteries can last up to 1 or 2 hours.

17.6 BATTERY TYPES AND APPLICATIONS

Valve-regulated lead-acid batteries are used today in almost all applications which are applicable for conventional lead acid batteries. Since these batteries' generation was basically for portable batteries, this is still a market today, for instance in the medical area. Larger types, which were developed about 20 years ago, have a wide field in military applications. Since the 1980s modern tanks and military shelters have been equipped with the 123-V 100-Ah NATO type. Its advantage besides the high deep discharge ability is the maintenance-free behavior, especially due to the limited space conditions in modern tanks.

Figure 17.20 shows modern gel batteries in tubular plate construction as single cells for float application. Those batteries are used today in emergency equipment as well as for many uninterruptible power supply (UPS) applications.



Figure 17.20 Valve-regulated OPzS batteries: Dryfit A600 in gel technology.

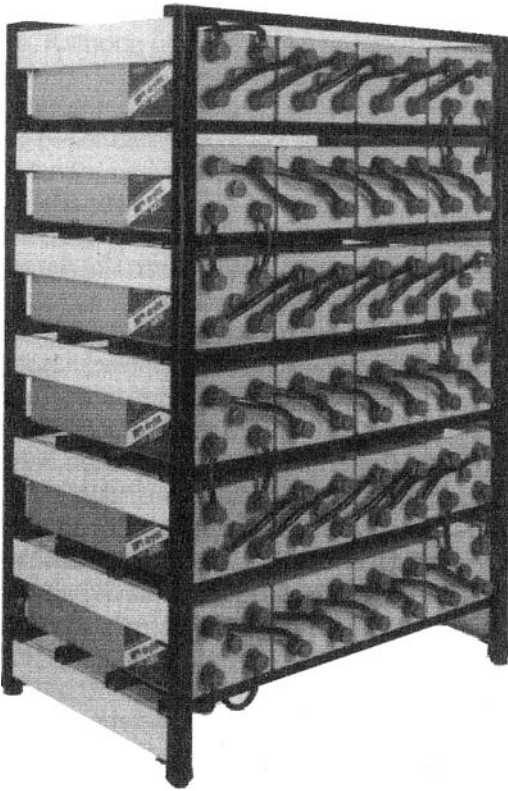


Figure 17.21 48-V battery for emergency power: Dryfit A600;–Horizontal.

Another advantage of valve-regulated batteries is the possibility for horizontal installation. Together with the low requirement for ventilation for valve-regulated batteries, this is a possibility for saving expensive space in the battery rooms (see Figure 17.21).

17.7 STANDARDS

Today the following international and European standards for valve-regulated lead-acid batteries are valid:

- IEC 61056-1: Portable lead-acid cells and batteries (valve-regulated types).
- EN 61056-1 Part 1: General requirements and methods of test.
- IEC 61056-2: Portable lead-acid cells and batteries (valve-regulated types).
- EN 61056-2 Part 2: Dimensions, terminals, and marking.
- IEC 61056-3: Portable lead-acid cells and batteries (valve-regulated types) and Part 3: Safety requirements.
- VG 96924: Portable lead-acid cells and batteries for military applications.

These standards describe the essential properties of valve-regulated batteries together with construction details and the test methods and technical demands for batteries of this technology.

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