

IALA Guideline No. 1044

On

Secondary Batteries for Aids to Navigation

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Document Revisions

Revisions to the IALA Document are to be noted in the table prior to the issue of a revised document.

Date	Page / Section Revised	Requirement for Revision
May 2005	This document incorporates relevant sections of: Maintenance and Operation of Batteries (Guideline 1025 - Dec. 2001) and Guidelines for the Safe Handling of Batteries (Guideline 1002 - 1994 / 1996)	Changes in battery technology has led to the merging and updating of the two existing documents.

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1 INTRODUCTION

1.1 Scope and purpose

These guidelines incorporate Maintenance and Operation of Batteries, December 2001 and Guidelines for the Safe Handling of Batteries, 1994 & 1996, and supersede both.

Marine Aids to Navigation (AtoN) systems are critical systems intended to be available for service at least 99 % of the time throughout their operational life. Batteries, an essential part of the power systems, must be properly designed, installed, operated and maintained if they are to deliver this level of availability.

These Guidelines provide maintenance directives, operating criteria and safe handling guidance for batteries commonly used in Marine Aids to Navigation applications.

While this document gives general recommendations, battery manufacturers may provide specific instructions for battery operation and maintenance.

This directives and criteria are meant to assist battery users to properly select and maintain batteries used in Marine Aids to Navigation systems.

These Guidelines should be used in conjunction with *IALA Guideline 1042 – Power Sources and Energy Storage for Aids to Navigation, Dec. 2004*.

1.2 Types of battery power systems

The various types of battery power systems in AtoN services are Primary Batteries (non-rechargeable) and Secondary (rechargeable) batteries.

Secondary (rechargeable) batteries

Lead-Acid batteries

- a. Sealed (maintenance-free, valve-regulated) batteries
- b. Flooded electrolyte batteries (add-water type)

Nickel-Cadmium batteries

- a. Vented pocket-plate batteries
- b. Vented sintered-plate batteries
- c. Sealed batteries

A number of countries are conducting trials with Nickel-Metal Hydride and Lithium-Ion batteries. These are further defined in section 2.2 G. and 2 H.

The choice of battery types will be made at the design stage. The following listings outline the advantages and disadvantages of the majority of battery types in general use.

1.3 Categories for Application of Secondary Batteries

The applications of the secondary batteries may fall into two main categories:

First Category – those applications in which the secondary battery is used or discharged essentially as a primary battery, but recharged after use rather than being discarded. Secondary batteries are used in this manner for convenience, for cost savings (as they can be recharged rather than replaced), or for applications requiring power drains beyond the capability of primary batteries.

Second Category – those applications in which the secondary battery is used as an energy-storage device, generally being electrically connected to and charged by a prime energy source, and delivering its energy to the load on demand when the prime energy source is not available or is inadequate to handle the load requirement.

2 MAJOR ADVANTAGES AND DISADVANTAGES OF VARIOUS TYPES OF BATTERIES USED IN MARINE ATON

2.1 Existing Battery Types

A. LEAD-ACID BATTERIES (compared with other electrochemical batteries)

Advantages

- Popular low cost secondary battery – capable of manufacture on a local basis, worldwide, from low to high rates of production
- Available in large quantities and in a variety of sizes and designs – manufactured in sizes from smaller than 1 Ah to several thousand ampere hours
- Good high-rate performance
- Electrically efficient – turnaround efficiency of over 70 %, comparing discharge energy out with charge energy in
- High cell voltage – (open-circuit voltage of 2.0 V is the highest of all aqueous electrolyte battery systems)
- Good float charge service
- Easy state-of-charge indication (only wet electrolyte)
- Low cost compared with other secondary batteries.

Disadvantages

- Relatively low cycle life (50 – 500 cycles), up to 2000 cycles with special designs
- Limited energy density – typically 30 – 40 Wh/kg.
- Poor low- and high-temperature performance

- Poor charge retention
- Long-term storage in a discharged condition can lead to irreversible polarization of electrodes
- Hydrogen evolution can result in an explosion hazard
- Thermal runaway in improperly designed batteries or charging equipment*
- Positive post blister corrosion with some designs.
- An intolerance to deep discharging resulting in Sulphation of plates and battery failure.

*The Thermal runaway, a critical condition, whereby a cell on charge or discharge will overheat through internal heat generation caused by high overcharge or over discharging or other abusive condition, may end with self-destruction of the cell.

B. VALVE-REGULATED LEAD-ACID (VRLA) BATTERIES

Advantages

- Maintenance-free
- Long life on float service
- High-rate capacity
- High charge efficiency
- No "memory" effect (compared to nickel-cadmium battery)
- "State of charge" can be determined by measuring voltage
- Low cost
- Available from small single-cell units (2 V) to large 24 V batteries.

Disadvantages

- Cannot be stored in discharged condition
- Relatively low energy density
- Lower cycle life than sealed nickel-cadmium battery
- Hydrogen evolution can result in an explosion hazard
- Thermal runaway in improperly designed batteries or charging equipment
- Poor low- and high-temperature performance
- An intolerance to deep discharging resulting in Sulphation of plates and battery failure.

C. ABSORBED MATT GLASS BATTERIES (AGM)

Advantages

- Non-spill (absorbed electrolyte)
- High rate charging

Disadvantages

- As per lead-acid batteries
- Higher cost

D. VENTED (INDUSTRIAL) NICKEL-CADMIUM BATTERIES (POCKET PLATE)

Advantages

- Excellent reliability
- Long cycle life (more than 2,000 cycles, the total lifetime may vary between 8 and 25 years or more, depending on the application and the operating conditions)
- Rugged, can withstand electrical (such as reversal or overcharging) and physical abuse and rough handling in general
- Good charge retention
- Can tolerate deep discharge which enables the use of total battery capacity
- Good high and low temperature performance
- Excellent long-term storage (in any state of charge)
- Low maintenance
- Absence of corrosive attack of the electrolyte on the electrodes and other components in the cell

Disadvantages

- Hydrogen evolution can result in an explosion hazard
- Thermal runaway in improperly designed batteries or charging equipment
- Low energy density
- Higher initial cost than lead-acid batteries.
- Contains cadmium, which may increase cost of disposal depending on recycling facilities available.

E. VENTED-SINTERED-PLATE NICKEL-CADMIUM BATTERIES

Advantages

- Flat discharge profile
- Higher energy density (50 % greater than pocket plate)
- Superior high-rate and low-temperature performance
- Rugged, reliable, little maintenance required
- Excellent long-term storage in any state of charge and over a very broad temperature range (-60 °C to +60 °C)
- Good capacity retention; capacity can be restored by recharge

Disadvantages

- Hydrogen evolution can result in an explosion hazard
- Thermal runaway in improperly designed batteries or charging equipment
- Contains cadmium, which may increase cost of disposal depending on recycling facilities available.
- Higher initial cost
- Memory effect (voltage depression) if not periodically deep cycled.
- Temperature controlled charging system required to enhance life

F. SEALED NICKEL-CADMIUM BATTERIES

Advantages

- Cells are sealed
- Maintenance-free operation
- Long cycle life
- Good low-temperature and high-rate performance capability
- Long shelf life in any state of charge
- Rapid recharge capability.

Disadvantages

- Hydrogen evolution can result in an explosion hazard
- Thermal runaway in improperly designed batteries or charging equipment
- Voltage depression in certain applications
- Contains cadmium, which may increase cost of disposal depending on recycling facilities available.
- Higher cost than sealed lead-acid battery.

- Difficult to recycle
- Higher initial cost

Note – The above is not an exhaustive list of Battery types but covers the main types currently used in AtoN applications.

2.2 New Battery Types

A number of countries are making trials of Nickel-Metal Hydride and Lithium-Ion batteries. At present, these battery types are being manufactured mainly for use in electric vehicles. Their main disadvantage in AtoN applications is their significantly higher cost than either Lead-Acid or Nickel-Cadmium batteries, however as they find wider use in the electric vehicle sector it is considered that their cost per kW-hr of capacity will reduce significantly. It should be noted that in AtoN applications the secondary battery cost may be a small percentage of the total AtoN cost, but battery size and weight (especially in buoy applications) per kW-hr of capacity may be a significant design issue. The more expensive secondary batteries may be a better solution than changes to the AtoN structure to obtain the required battery capacity.

Pending the availability of more information from IALA members on their operational experience with Nickel-Metal Hydride and Lithium-Ion batteries, basic advantages/disadvantages are provided below but sections 3, 4 and 5 of this document do not specifically deal with these battery types. Relevant equivalent information should be requested from the battery manufacturer if Nickel-Metal Hydride or Lithium-Ion batteries are to be installed in AtoN installations.

G. NICKEL-METAL HYDRIDE BATTERIES

Advantages

- Maintenance free
- Long life
- High capacity relative to volume
- High capacity relative to weight
- No gas venting in normal operation
- High cycle life (About 1,200 cycles is typical, but depends on the depth of discharge)
- Fully recyclable at end of life
- Wide operational temperature range (A range of -20°C to +60°C is typical)

Disadvantages

- Cost
- Charge regulation essential
- Limited experience of use in AtoN applications

H. LITHIUM-ION BATTERIES

Advantages

- Maintenance free
- Long life
- Very high capacity relative to volume
- Very high capacity relative to weight
- No gas venting in normal operation
- High cycle life (About 1,000 cycles is typical, but depends on the depth of discharge)
- Reasonable operational temperature range (A range of -10°C to +45°C is typical)

Disadvantages

- Cost
- Complexity of battery integrated electronic management system
- Limited experience of use in AtoN applications
- Thermal runaway in improperly designed batteries or charging equipment
- Contains lithium, which may increase cost of disposal depending on recycling facilities available.

Lithium-polymer batteries are available, and have similar characteristics to lithium-ion batteries but are more stable.

3 OPERATIONAL CRITERIA FOR SECONDARY BATTERIES FOR PHOTOVOLTAIC APPLICATIONS

This section specifies the operation criteria for secondary batteries for photovoltaic applications.

The following conditions of use are those associated with stand alone photovoltaic systems. These battery systems can supply constant, variable or intermittent energy to the connected equipment (load). These systems may include hybrid and other renewable energy sources.

3.1 General operating conditions

Batteries in a typical Photovoltaic (PV) system operating under average site weather conditions may be subjected to the following conditions.

3.1.1 Autonomy time

The battery is designed to supply energy under specified conditions for periods of time from 3 days to 30 days without or with minimum solar insolation. Some systems can have significantly more or less than this time in areas of extreme climatic conditions.

When calculating the required battery capacity, the following items should be considered;

1. required daily / seasonal cycle (there may be restrictions on the maximum depth of discharge)
2. time required to access the site
3. ageing
4. temperature impact
5. future expansion of the load
6. local weather conditions

Refer to the IALA Guidelines on a Standard Method for Defining and Calculating the Load Profile of Aids to Navigation, December 1999

3.1.2 Typical charge and discharge currents

Charge currents generated by the PV generator typically are;

1. Maximum charge current: $I_{20} = C_{20} / 20\text{hr}$
2. Average charge current: $I_{50} = C_{50} / 50\text{hr}$
3. Discharge current is determined by the load. Average discharge current:
 $I_{100} = C_{100} / 100\text{hr}$

Depending on the system design, e.g. for hybrid systems, the charge and the discharge current may vary in a wider range.

C_{20} is the rated capacity of a battery, in ampere hours, when discharged over 20 hrs.

3.1.3 Daily cycle

The battery is normally exposed to a daily cycle with:

1. charging during daylight hours
2. discharging during night time hours.

3.1.4 Seasonal cycle

The battery may be exposed to a seasonal charge cycle due to annual variation in solar insolation as follows:

1. periods with low solar insolation, for instance during winter causing low energy production
2. periods with high insolation, e.g. in summer, which will bring the battery up to fully charged conditions. The battery can be overcharged.

The seasonal discharge should not cause the battery to exceed the maximum Depth of Discharge (DOD) specified by the manufacturer for the given environmental temperature conditions. Batteries can be protected by a load cut-off device that operates when the design maximum DOD is exceeded.

3.1.5 Period of high state of charge

During summer for example, the battery will be operated at a high state of charge (SOC), typically between 80 % and 100 % of rated capacity.

A voltage regulator system normally limits the maximum battery voltage during the recharge period.

In a “self-regulated” PV system, the battery voltage is not limited by a charge controller but by the characteristics of the PV generator. The system designer normally chooses the maximum battery voltage with regard to the conflicting requirements of “recover to a maximum state of charge (SOC)” as early as possible in the charging season but without substantially overcharging the battery. The overcharge increases the gas production resulting in water consumption in wet lead acid batteries. In valve-regulated lead-acid batteries (VRLA), the overcharge will cause increased gas emission and heat generation.

Typically the maximum cell voltage is limited to 2.4 V per cell for lead-acid and 1.55 V per cell for nickel-cadmium batteries. Some regulators allow the battery voltage to exceed these values for a short period as a boost charge. Temperature compensation should be used if the operating temperature deviates significantly from 20°C. The battery manufacturer should provide specific values.

The expected lifetime of a battery in a PV system even at regular high state of charge may be considerably less than the published life of the battery used under continuous float charge.

3.1.6 Period of sustained low state of charge

During periods of low insolation, the energy produced by the solar modules may not be sufficient to recharge the battery. Therefore the state of charge of the battery through the year will decrease to a minimum during the winter months and return to full charge during the summer. A daily charge / discharge cycle will be superimposed on the annual charge / discharge cycle curve.

3.1.7 Electrolyte stratification

Electrolyte stratification may occur in lead-acid batteries. In vented lead-acid batteries, electrolyte stratification can be avoided by electrolyte agitation or periodic boost charging whilst in service and in VRLA batteries by operating them according to the manufacturer’s instructions.

3.1.8 Transportation

Batteries are often operated in inaccessible sites, mountaintops and desert locations being two obvious examples and there may be no proper road access to the site.

Batteries may therefore be subjected to a degree of rough handling on their journey and thus suitable packing to protect the batteries must be used during transportation.

Transportation to the aid site can be accomplished in the original shipping container to afford protection. Care must be exercised to avoid extensive vibration, which may cause damage to the cells. Manhandling over difficult terrain may lead to damage, especially to wet cells with plastic cases. Transportation by helicopter as underslung loads is a viable alternative as long as the descent is controlled to prevent swinging into an immovable

object, with the subsequent destruction of the cell and pollution of the eventual landing place with electrolyte. Primary batteries should be transported dry, with addition of water at the aid site, if possible. Secondary batteries may also be transported dry and filled with electrolyte and charged in accordance with the manufacturer's recommendations on site.

3.1.9 Storage

Manufacturers may provide recommendations for storage. Recommended storage conditions of batteries for solar applications are shown in table as follows:

Battery type	Temperature range	Humidity	Storage period with electrolyte filled	Storage period without electrolyte
Lead-Acid	-20 °C to +40 °C	< 95 %	up to 0.5 year	1- 2 years (dry charged)
Nickel – Cadmium	-40 °C to +50 °C	< 95 %	up to 0.5 year	1 - 5 years (drained)

Filled and charged batteries require periodic recharging. The battery manufacturer should provide instructions concerning intervals and methods of recharge.

A loss of capacity may result from exposure of a battery to high temperature and humidity during storage. The temperature of a battery stored in a container in direct sunlight, can rise to 60 °C or more in daytime.

3.1.10 Operating temperature

The temperature range during operation experienced by the battery will significantly affect battery life and is an important factor for the battery selection. The limiting values for operation conditions of batteries for solar applications are shown in the table as follows:

Battery type	Temperature range	Humidity
Lead – Acid	-20 °C to +40 °C	< 95 %
Nickel – Cadmium	-40 °C to +50 °C	< 95 %

The manufacturer should provide instruction for temperatures outside this range. As experience shows, typically the life expectancy for lead-acid battery will halve for every 10 °C rise in temperature above the manufacturer's recommended maximum operating temperature. Temperature will also have some effect on nickel-cadmium batteries. Low temperature will reduce the charge and discharge performance and the capacity of the batteries. The manufacturer should provide detailed information.

3.1.11 Physical protection

Physical protection needs to be provided against consequences of adverse site conditions and handling, for example, against effects of

1. temperature gradient and extremes of temperature,
2. exposure to direct sun light (UV radiation),
3. airborne dust or sand
4. explosive atmospheres
5. high humidity and flood water
6. earthquakes
7. shock, spin, acceleration and vibration (particularly during transport, and light buoy applications)
8. severe mechanical abuse and rough handling

NOTE: An insulating cover should be provided to all terminal connections

3.2 Capacity

The storage capacity is expressed in ampere-hours (Ah) and varies with the conditions of use (electrolyte temperature, discharge current and final voltage). Normally the rated capacity for 10 h and 5 hours discharge, respectively, is published. The knowledge of the capacity for a 100 hours (C_{100}) discharge time is also required as these times are commonly used in PV applications.

3.3 Cycle Life

The cycle life (endurance) is the ability of the battery to withstand repeated charging and discharging.

The cycle life is normally given for cycles with a fixed depth of discharge (DOD) and with the battery fully charged in each cycle. Batteries are normally characterized by the number of cycles that can be achieved before the capacity has declined to the value specified in the relevant standards (e.g. 80 % of the rated capacity).

In photovoltaic applications the battery will be exposed to a large number of shallow cycles but at a varying state of charge. The batteries should therefore comply with the requirements of the test described in IEC 61427, which is a simulation of the PV system operation. The manufacturer should specify the number of cycles the batteries can achieve before the capacity has declined to 80 % of the rated capacity.

3.4 Charge control

To maintain optimum performance of a battery it is essential that its charge is properly controlled. Ideally the charge current should be limited at the start of the charge cycle to ensure that gassing does not occur due to excessive applied cell voltage; while the recharge capacity is being restored the charge current should be limited to maintain the cell voltage to that, or just below that required for gassing; once the full discharge current has been restored a finish charge at constant current should be applied for a fixed time

period. Whilst these conditions may not be practically achieved in PV energy systems, there are certain conditions that need to be addressed in order to minimise maintenance and maintain battery life. The parameters of the regulator should take into account the effects of the PV generator design, the load, the temperature and the recommended limiting values for the battery. Wet lead-acid or nickel-cadmium batteries should have sufficient electrolyte to cover at least the period between planned service visits.

Excessive overcharge does not increase the energy stored in the battery. Instead, overcharge affects the service interval due to water consumption in wet lead acid batteries as a result of gassing. To minimise this effect the charge / regulation voltage should be compensated for changes in battery temperature since this has a direct affect on the gassing voltage threshold. Contrary to this, stratification can occur in wet lead acid batteries, particularly in PV systems where insolation is often insufficient to provide regular gassing during normal operation. Stratification is where the electrolyte settles with the denser electrolyte layers near the bottom of the plates, which results in reduced battery capacity. This can be overcome by the mixing that occurs during gassing of the battery. Consequently, the charge / regulation process should be designed to purposefully promote gassing at regular intervals. This can be achieved by raising the charge control voltage for a period, resetting it once the voltage has been attained and gassing has occurred. This is commonly called the boost period. Boost charging valve regulated lead acid batteries may result in the electrolyte drying out resulting in the loss of capacity or overheating and therefore if attempted should be carefully controlled to achieve optimum lifetime.

3.5 Charge retention

Charge retention is the ability of a battery to retain capacity during periods of no charge, i.e. when not connected to a system, during transportation or storage. A battery for PV application should show a high capability of charge retention. The charge retention should be stated by the manufacturer and should meet the requirements of the relevant battery standard,

NOTE: Charge retention may affect the permitted storage and autonomy time.

3.6 Over discharge protection

Lead-acid batteries should be protected against over discharge to avoid capacity loss due to irreversible sulphating. This can be achieved by low voltage disconnect that operates when the design maximum depth of discharge is exceeded.

NOTE - Nickel-cadmium batteries do not normally require this type of protection.

3.7 Mechanical endurance

Batteries for PV application should be designed to withstand mechanical stresses during normal transportation and rough handling. Additional packing or protection may be required for off road conditions.

Batteries for PV application on light buoys should be chosen to withstand shock, vibration and acceleration as the light buoy can be subject to violent movement. The battery design should prevent any electrolyte leakage and an adequate venting arrangement provided to enable any gas generated to escape but to prevent water

accumulating in the battery compartment.

3.8 Recycling and Disposal

Laws and regulations governing the recycling and disposal of batteries are getting stricter every year. In many countries, batteries are considered hazardous waste. The heavy metals used in these batteries, when improperly disposed of, will damage the environment; the corrosive nature of battery electrolytes can also cause damage if released. While lithium batteries pose little pollution risk they must still be disposed of as hazardous waste because of their history of explosive venting in various circumstances. Lead-acid and nickel-cadmium batteries are recyclable in most countries, although restrictions on nickel-cadmium recycling appear to be increasing, along with the associated costs. Every effort should be made to handle these batteries correctly when it comes time to dispose of them, in most countries, strict laws govern the handling of hazardous waste. In addition detailed records must be maintained to account for the whereabouts of batteries during all phases of disposal. Reputable transporters are used to ensure that the material ends up at the destination and not by the wayside. The first point of contact for establishing disposal arrangements should be the battery vendor.

4 SAFE HANDLING OF BATTERIES

Batteries are an integral part of any solar, wind or hybrid power system used in aids to navigation, yet little has been written on their safety, installation, maintenance, recycling and disposal.

4.1 Battery Safety Issues

Large battery systems are a source of extremely high short circuit currents. Care must be exercised when installing and servicing any of the components in the power system to prevent shorting.

Secondary batteries generate hydrogen gas during the charging process. Significant amounts of hydrogen gas are generated when the battery reaches full charge. Hydrogen gas ignites easily and produces an especially violent explosion.

Accordingly, the following safety precautions should be observed at all times.

1. Do not smoke, use an open flame or create arcs or sparks in the vicinity of the battery.
2. Sense the interior of a battery enclosure with a suitable gas detector before entering. The compartment should have a removable, non-sparking pipe fitting for insertion of a sensor probe.
3. Ventilate the enclosure (leave doors open) for at least 5 minutes before servicing the batteries.
4. Discharge static electricity from the body before touching the cells by touching a grounded surface such as a conduit.
5. Hydrometers for nickel-cadmium and lead-acid batteries must be kept separate and not interchanged.

6. Primary batteries of the wet air depolarised type and nickel-cadmium secondary batteries typically contain a strong caustic electrolyte. Secondary lead-acid batteries contain a strong acidic solution. When installing and servicing these types of batteries, workers should wear goggles, rubber apron, rubber gloves and have eye wash facilities available.

4.2 Installation

Unless shipped dry, batteries should be installed as soon as possible after receipt. Otherwise, batteries should be stored indoors in a cool, dry area. Secondary batteries should received a freshening charge immediately after installation or if stored, at periods specified by the manufacturer. Freshening charges typically require a substantial charging system.

Large secondary battery systems are quite heavy, 100 kg or more per cell is not uncommon. Lifting and transporting of batteries should be done in accordance with established safe working practices. Batteries should not be lifted by their terminal posts or by friction type battery carriers unless provided for or authorised by the manufacturer. Lift batteries using manufacturer supplied lifting eyes or insulated lifting belts. Insulating material should be placed over the posts to prevent shorting due to overhead chains and hooks.

Installation should preferably be in a clean, dry area and out of direct sunlight (to prevent individual cell heating). Exterior battery boxes should be constructed of an insulating material, light coloured to prevent heating by the sun, and provide containment in the event of a cracked cell (wet batteries only). Interior battery racks, if used, should employ insulated trays or linings to isolate the cells from ground, and should be properly rated and well secured to prevent tipping. Batteries installed on platforms in the water should be secured so that they can be retrieved in the event of the aid being destroyed by a storm or passing vessel.

Absorbent sponges or material capable of neutralizing spilled electrolyte may be installed in a containment system below the battery, and should be capable of holding at least two cells' quantity of electrolyte.

Install cell interconnections as per manufacturer's instructions. Coat cell posts and interconnections with anti-oxidizing grease or petroleum jelly to prevent corrosion. Insulated interconnection covers are recommended to prevent accidental shorting, but in order to be effective they should be designed so as not to impede routine servicing tasks.

No ignition sources, including electric switching devices or lighting fixtures, should be installed in the battery room unless specifically approved for use in a hydrogen atmosphere. For larger systems the electrical distribution system will need over current protection, circuit breakers are most often preferred to fuses because the breaker can be reset, while fuses must be replaced with the right physical and capacity replacement in a remote location.

4.3 Ventilation

Lead-acid and nickel-cadmium batteries produce hydrogen and oxygen gas when charging. Secondary batteries that employ recombination features will only gas when the gassing rate exceeds the recombination rate. This generally occurs during overcharge.

Batteries without recombination features will gas when they are fully charged and continue to receive a charge (float condition). The amount of hydrogen and oxygen evolved is not dependent on the type and size of battery (lead-acid or nickel-cadmium), but rather on the charging rate, number of cells and the length of time charge is applied. Hydrogen and oxygen are produced as a result of electrolysis of the water in the electrolyte. Hydrogen concentrations of up to 3% (by volume) are non-flammable, at 4-8% hydrogen will burn if exposed to an open flame or spark, and above 8% hydrogen will ignite explosively. Hydrogen can also be produced in battery pockets by reaction between residual water and dissimilar metals or corrosion of metals by spilled electrolyte.

The maximum hydrogen concentration for an enclosed space set by the Occupational and Safety Health Act (OSHA) in the USA is 1%. Check with your department which regulates worker safety or fire protection for acceptable limits in your country. Some countries have substantially lower limits.

Some batteries also release small quantities of toxic gases. However, calculating the ventilation requirements based on the predominant gas, hydrogen, will maintain these gases below their toxic limits.

Hydrogen production for lead-acid and nickel-cadmium standards should be complied with:

$$H = 0.459 \times N \times I$$

Where:

H is the amount of hydrogen produced in I/hr (litres/hour);

0.459 I/hr is the maximum hydrogen production per cell per ampere charge current at standard temperature and pressure;

N is the number of cells;

I is the estimated charge current.

The charge current for the battery must be determined. Battery manufacturers can provide information on gassing rates for their batteries. Be aware that some batteries, especially lead-antimony, will gas at a higher rate as they age, and as the battery temperature rises above nominal (usually 25 degrees C). Short of this, a general rule of thumb is that the float current will not exceed one percent (0.01) of the rated capacity in ampere-hours. This rule of thumb does not account for charger failure, which could charge the battery at a rate higher than one percent of the rated capacity. While this type of failure is rare, it is wise to see if the factor of safety between the maximum concentration level (see below) and the lower flammable limit (4 percent) can accommodate the excess hydrogen production. Hydrogen detectors or overvoltage alarms tied to telemetry systems can provide advance warning of dangerous levels of gas. Installation of such warning systems in enclosed compartments in aids to navigation should be considered.

Knowing the amount of hydrogen produced, the amount of new air required to prevent the concentration from exceeding the predetermined level can be calculate:

$$A = H/C$$

Where:

A is the amount of new air required in I/hr;

H is the amount of hydrogen production in I/hr;

C is the maximum concentration level as a decimal.

Next, the size of the battery enclosure or room must be calculated. For larger systems ashore, manufacturers of “Modular” rooms may be able to provide information on natural air change rate. On converted dwellings, a “tight” battery room will have an air exchange in about 4 hours. Therefore, as an example, if we require 8000 I/hr of new air, then the battery room must have a volume of at least 32000 litres if no vent system is installed. If additional venting is required, then the preferred type is a low mounted louvered vent in the door or wall and a ridge vent (to expel hydrogen trapped near the ceiling) at the highest point in the shelter. Warning signs should be posted on each door to a battery space similar to the following example:

<p style="text-align: center;">WARNING! HYDROGEN GAS. EXTINGUISH SMOKING MATERIALS. ALLOW SPACE TO VENTILATE FOR 5 MINUTES BEFORE ENTERING</p>

If natural ventilation is unable to produce the necessary air changes, then mechanical exhaust ventilation should be employed, arranged with the exhaust at the top of the space, and adequate inlet air openings at or near floor level. Exhaust fans must be of a type designed for use in a battery compartment. The associated fan motor and ducting should be arranged so the motor is completely external to the ducting and battery space being ventilated.

Recombination caps are available for various battery types. These will reduce the amount of hydrogen vented by the battery but battery compartment ventilation will still be required. Details of volumes of gas produced will be available from the battery manufacturer.

4.3.1 Buoy Installation

Buoy pockets housing batteries should be vented where necessary to prevent hydrogen build up or for the correct operation of air-depolarised batteries. One method is to provide a vent line for each battery pocket of at least 19mm diameter. The vent line should enter the top of each pocket with crossover tubes at the bottom. If the vent lines terminate at opposite sides of a radar reflector or other solid structure, then air flow is created as prevailing winds set up a pressure differential between the two vents. The crossover tube ensures that the entire pocket is purged. Two vents are used in the case of a single battery pocket design; one enters the pocket at the top, the other at the bottom to ensure complete evacuation. Vent lines may have vent valves installed to restrict intrusion of water. This method of venting has proved suitable for providing oxygen for up to 6000 ampere-hours of primary air depolarized batteries

Battery boxes in the buoy superstructure can be easily ventilated and drained thus avoiding the gas and flooding hazards associated with pockets in the buoy body.

5 MAINTENANCE PRACTICES

5.1 General considerations

In a correctly designed AtoN application, the battery may require a minimum of attention. However, it is good practice with a battery system to carry out an inspection of the battery system either at least once per year, or at the recommended interval to ensure that the charger, the battery, and the ancillary electronics are functioning correctly.

The maintenance of batteries may be divided into a number of levels:

1. remote monitoring
2. routine checks / inspections
3. periodic overhaul
4. major overhaul
5. disposal.

Procedures should be established for individual Marine Aids to Navigation systems taking into account the specifics of each site; including:

1. Size, type and complexity of AtoN
2. Accessibility of site
3. Local climatic conditions
4. Level of training and skills possessed by maintenance crews
5. Required period of service before replacement

The basic requirements for the maintenance of a battery power system may fall into three groups, which can be considered and optimised for any set of circumstances:

1. Battery maintenance requirements
2. Requirements of the application and environment:
(The type of AtoN, its intended mode of operation, charging method, environment and service and maintenance requirements will greatly influence the type of battery power system to be employed)
3. Requirements of the user / operator:
(Installation site – environment and accessibility, maintenance philosophy, skill and training levels of maintenance staff)
4. Only personnel who have been trained to handle the battery installation, charging, and maintenance procedures should be permitted access to the battery area.
Inspections

5.2 Inspections

When an inspection is carried out, it is recommended that specific procedures should be adopted to ensure that the battery is maintained in a good state. The results of all inspections should be recorded. It is good practice to keep a logbook in which the measured values can be recorded as well as events such as mains power cuts, discharge tests, capacity tests, storage times and condition, topping up dates etc.

Adequate battery records (previous maintenance procedures, environmental problems, system failures and any corrective actions taken in the past) are invaluable aids in determining battery condition. The inspection procedures are described in the following paragraphs. The date of the installation should also be noted.

5.2.1 Initial readings

The initial readings are those readings taken at the time the battery is placed in service. The following readings should be taken and recorded on a fully charged battery with no load on the system:

1. Battery terminal voltage and cell voltages
2. Cell electrolyte levels, where accessible
3. Internal temperatures of at least 10% of the cells; for valve-regulated batteries, the temperature of the negative terminal post should be read
4. Ambient temperature
5. Specific gravity reading of each cell corrected to 25 °C, where accessible
6. Charger voltages and current limit

It is important that these initial readings be recorded for future comparison.

5.2.2 Annual measurements and recording

1. Battery terminal voltage, cell / block voltages. If possible, these measurements should be made when the battery is fully charged.
2. Charging voltage (charge voltage settings, charge current limit and charge controlling system verification); in parallel operation, it is of great importance that the recommended charging voltage remains unchanged. High water consumption of the battery is usually caused by improper voltage setting of the charger resulting overcharging and gassing. Poor charging regime is responsible for short battery life more than any other cause.
3. Specific gravity of each cell, corrected to 25° C prior to topping up with water. The specific gravity of the cells should be within 0.015 kg / l of the manufacturer's specified value.
4. Cell temperatures whilst on charge should be uniform and the temperature differences between individual units should not exceed 3 °C

5.2.3 Insulation resistance

1. Pilot-cell (if used) voltage, specific gravity, and electrolyte temperature (whenever possible)
2. Grounding in the battery room
3. Use of distilled water

5.2.4 Electrolyte Level

Never let the level fall below the lower (MIN) mark. Use only approved distilled or de-ionised water to top up according to defined period, which will depend on float voltage, cycles and temperature. Do not overfill the cells. Experience will indicate the time interval between topping up; this time interval may vary from one to several years depending on the type of alloy, cell type, temperature consideration, and battery age. It is therefore recommended that initially electrolyte levels should be monitored regularly to confirm the frequency of topping up required for a particular installation. Water consumption should be recorded.

5.2.5 Electrolyte Consumption

Excessive consumption of water indicates operation at too high a voltage or too high a temperature. Negligible consumption of water, with batteries on continuous low current or float charge, could indicate undercharging. A reasonable consumption of water is the best indication that a battery is being operated under the correct conditions. Any marked change in the rate of water consumption should be investigated immediately.

Sealed maintenance-free batteries do not require water topping up. Pressure valves are used for sealing and cannot be opened without destruction.

5.2.6 Annual Visual Checks

General appearance and cleanliness of the battery and battery area (room, cabinet). Exclude any potential contamination and keep the battery housing, cells, vents, terminals and connectors clean and dry all times, as dust and damp cause current leakage. Any spillage during maintenance should be wiped off with a clean cloth. The battery can be cleaned using pure water; do not use a wire brush or a solvent of any kind. Vent caps can be rinsed in clean water, if necessary.

1. Inspect for cracks and splits in battery cases or leakage of electrolyte
2. Look for evidence of corrosion at the connections
3. The connections and terminal screws should be corrosion-protected by coating with thin layer of silicone grease or anti-corrosion oil.
4. Check tightness of all bolted connections (torque specified by manufacturer)
5. Loose bolts and bad connections can cause failure, high temperatures and even fire.
6. Condition of the ventilation system; verify that the ventilation ducts and filters operate correctly and allow continuous airflow throughout the battery room or cabinet

7. Check for evidence of current leakage to ground
8. Condition of safety equipment e.g. eye wash, rubber gloves, apron, safety glasses
9. Check integrity of battery support structure and enclosure

5.2.7 Special Inspections

If the battery has experienced an abnormal condition, such as a severe discharge or adverse temperature excursion, an inspection should be made to determine if the battery has been damaged. This inspection should include the measurement of battery terminal voltage and cell voltages, specific gravity, internal temperature plus a detailed visual inspection of each cell, cables and connections.

5.3 Tests

Tests should be carried out according to relevant national or international standards, for instance established cycle tests are specified in

IEC 60896/1 - for stationary lead-acid batteries: vented types

IEC 60896/2 - for stationary lead-acid batteries: valve-regulated types

IEC 61056/1 - for portable lead-acid batteries: valve-regulated types

IEC 60622 - for sealed nickel-cadmium prismatic batteries

IEC 60623 - for vented nickel-cadmium prismatic batteries

NOTE - Electrical battery testing is not part of normal routine maintenance, as the battery is required to provide the back-up function and cannot be easily taken out of service. However, if a capacity test of the battery is needed, the manufacturer's recommendation should be followed.

5.4 Faults

Immediately correct faults in the battery or the charging unit. The availability of the recorded data will be very helpful to find the cause of failure.

5.5 Corrective Actions - General

The following items are conditions that should be corrected at the time of inspection:

5.5.1 Physical Conditions

For wet cells, correct low electrolyte levels and record the amount of water added. Enough water should be added to bring all cells to the high-level line. To avoid electrolyte overflow, water should be added only when it has been determined that the cells are in a fully charged condition. It is important that water is not added without mixing of the electrolyte in climates where freezing may occur.

Note - the addition of water will alter the specific gravity of the electrolyte, and additional charging will be required for mixing.

1. Clean corroded connections (high-connection resistance) by disassembling, cleaning, and reassembling them; then tighten all bolted connections to the torque specified by the manufacturer.

2. When cell temperatures deviate more than 3 °C from each other during a single inspection, determine the cause and correct, if practical. Temperature difference is normally caused by different internal resistances.
3. If a battery outside the system design limits is noted, determine the cause and correct, if practical. This will normally require cell or battery replacement.
4. Remove excessive dirt or spilled electrolyte in accordance with good workmanship practices.
5. When the fully charged battery voltage is outside the manufacturer's recommended range, the cause should be determined and corrected.
6. Any other abnormal condition should be corrected as per the manufacturer's recommendations, for example:

5.5.2 Equalizing charge

The corrective action of an equalizing charge to bring the cells to uniform voltage and specific gravity levels, performed in accordance with the manufacturer's instructions, is required after exhaustive discharges and inadequate charges, and when ever any of the following conditions are found. These conditions, if allowed to persist for extended periods, can reduce battery life. They do not necessarily indicate a loss of capacity.

1. For wet lead acid cells, the specific gravity, corrected for temperature and electrolyte level, of an individual cell is more than 0.010 kg/l below the average of all cells at the time of inspection.
2. For wet lead acid cells, the average specific gravity, corrected for temperature and electrolyte levels, of all cells drops more than 0.010 kg/l from the average installation value when the battery is fully charged.
3. The fully charged cell voltage is 0.1 V outside of the manufacturer's recommended end-of-charge cell voltage.

Note: The equalizing (high) voltage may present a hazard to other connected equipment.

5.5.3 Changing electrolyte

In most battery operations, the electrolyte will retain its effectiveness for the life of the battery. Thus, normally it is not necessary to change the electrolyte. However, under certain battery operating conditions, involving high temperature and cycling, the electrolyte can become excessively contaminated. Under these circumstances the performance of some battery types can be improved by replacing the electrolyte. Specialist advice must be taken before undertaking such operations

5.5.4 Cell replacement

A faulty cell may be replaced by one in good condition of the same make, type, rating, and approximate age. A new cell should not be installed in series with older cells except as a last resort.

5.5.5 Stratification of the electrolyte

The stratification of the electrolyte in large cells into levels of varying concentration can limit charge acceptance, discharge output, and life unless controlled during the charge

process. Two methods for stratification control are: by deliberate gassing of the plates during overcharge at the finishing rate or by agitation of cell electrolyte by pumps (usually airlift pumps).

5.5.6 Memory Effect

The memory effect, describing a process which results in the temporary reduction of the capacity of a nickel-cadmium sintered cell following repetitive shallow charge / discharge cycles, is completely reversible by a maintenance cycle consisting of a thorough discharge followed by a full and complete charge/overcharge.

5.6 Remote Monitoring

In many instances, accessibility is poor, and frequent routine maintenance visits uneconomic. The parameters, which require monitoring and recording, depend to some extent upon the type of battery power system. However, where appropriate the following parameters should be included:

1. Battery terminal voltage
2. Charger status (load / charge current)
3. Battery temperature
4. Electrolyte level

NOTE: - If the site is to be monitored remotely, climatic protection is necessary.

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