GUIDELINES
ON

MAINTENANCE AND OPERATION OF BATTERIES

DECEMBER 2001

IALA / AISM – 20ter rue Schnapper – 78100 Saint Germain en Laye – France
Tel : +33 1 34 51 70 01 – Fax : +33 1 34 51 82 05 – E-mail : **iala-aism@wanadoo.fr**
Internet : **www.iala-aism.org**

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Scope and purpose

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.

Proper maintenance, on the other hand, should prolong the life of the battery and help assure that it is capable of satisfying design requirements. A good battery maintenance program should serve as a valuable aid in determining the need for battery replacement.

These Guidelines provides maintenance directives and operating criteria 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 Guidelines for the safe handling of batteries, 1996* and the *Guidelines on New Light Sources and Associated Power Supplies* developed during the IALABAT/IALALITES Workshop 2001.

1.2 Types of battery power systems

With reference to the AISM / IALA questionnaire on batteries, 1999, the various types of battery power systems in AtoN services currently are:

- Primary batteries

  Air-depolarised and Alkaline batteries are designed to be maintenance-free Their safe use is covered in *The IALA Guidelines for Safe Handling of Batteries, 1996*

- 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

NOTE - These Guidelines currently deal specifically with lead-acid and nickel-cadmium batteries, but may be extended to other battery systems as they become commonly available.

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

A. 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. For example:

- ° to increase reliability of the power systems, so that if the primary source fails, or during maintenance work on it the power supply will not be interrupted (emergency no-fail and standby power supply applications - major fixed stationary AtoN)

or

- ° to ensure a continuous power supply in case the primary source cannot provide a no break supply, for example Photovoltaic (PV) or wind-driven power systems (un-interruptible power supply applications - minor fixed and floating/light buoys AtoN).

B. 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.

2.0 MAINTENANCE DIRECTIVES

2.1 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:

- remote monitoring
- routine checks / inspections
- periodic overhaul
- major overhaul
- disposal.

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

- Size, type and complexity of AtoN
- Accessibility of site
- Local climatic conditions

- Level of training and skills possessed by maintenance crews
- 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:

- Battery maintenance requirements
- 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)
- Requirements of the user / operator

  (Installation site – environment and accessibility, maintenance philosophy, skill and training levels of maintenance staff)

  Only personnel who have been trained to handle the battery installation, charging, and maintenance procedures should be permitted access to the battery area. Relevant safety practices are detailed in the *IALA Guidelines for the Safe Handling of Batteries.*

2.2 Inspections

2.2.1 General

When on 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.

2.2.2 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:

a) Battery terminal voltage and cell voltages

b) Cell electrolyte levels, where accessible

c) Internal temperatures of at least 10% of the cells; for valve-regulated batteries, the temperature of the negative terminal post should be read

d) Ambient temperature

e) Specific gravity reading of each cell corrected to 25 °C, where accessible

f) Charger voltages and current limit

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

2.2.3 Annual measurements and recording

a) Battery terminal voltage, cell / block voltages. If possible, these measurements should be made when the battery is fully charged

b) 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.

c) 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.

d) Cell temperatures whilst on charge should be uniform and the temperature differences between individual units should not exceed 3 °C

e) Insulation resistance

f) Pilot-cell (if used) voltage, specific gravity, and electrolyte temperature (whenever possible)

g) Grounding in the battery room

Note - Use water produced in accordance to the IEC standard.

2.2.4 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.

2.2.5 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.

2.2.6 Annual visual checks

a) 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.

b) Inspect for cracks and splits in battery cases or leakage of electrolyte

c) Look for evidence of corrosion at the connections

Note: - The connections and terminal screws should be corrosion-protected by coating with thin layer of neutral grease or anti-corrosion oil.

d) Check tightness of all bolted connections (torque specified by manufacturer)

Note: - Loose bolts and bad connections can cause failure, high temperatures and even fire.

e) Condition of the ventilation system; verify that the ventilation ducts and filters operate correctly and allow continuous airflow throughout the battery room or cabinet

f) Check for evidence of current leakage to ground

g) Condition of safety equipment e.g. eye wash, rubber gloves, apron, safety glasses

h) Check integrity of battery support structure and enclosure

2.2.7 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.

2.3 Tests

Tests have to 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.

2.4 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.

2.5 Corrective actions

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

a) 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.

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

c) 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.

d) 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.

e) Remove excessive dirt or spilled electrolyte in accordance with good workmanship practices.

f) When the fully charged battery voltage is outside the manufacturer's recommended range, the cause should be determined and corrected.

g) Any other abnormal condition should be corrected as per the manufacturer's recommendations, for example:

   - **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.

- 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.
- 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.
- 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.

- **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
- **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.
- **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).
- **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.

2.6 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:

- Battery terminal voltage
- Charger status (load / charge current)
- Battery temperature

- Electrolyte level

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

3.0 OPERATIONAL CRITERIA FOR PHOTOVOLTAIC POWER SYSTEM

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 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 20 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;

- required daily / seasonal cycle (there may be restrictions on the maximum depth of discharge)
- time required to access the site
- ageing
- temperature impact
- future expansion of the load
- 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;

- maximum charge current: $I_{20} = C_{20} / 20hr$
- average charge current: $I_{50} = C_{50} / 50hr$

Discharge current determined by the load:

- average discharge current: $I_{100} = C_{100}$ / 100hr.

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

3.1.3 Daily cycle

The battery is normally exposed to a daily cycle with:

- charging during daylight hours
- discharging during nighttime 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:

- periods with low solar insolation, for instance during winter causing low energy production
- 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 an equalising or 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.

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

- temperature gradient and extremes of temperature,
- exposure to direct sun light (UV radiation),
- airborne dust or sand
- explosive atmospheres
- high humidity and flood water
- earthquakes
- shock, spin, acceleration and vibration (particularly during transport, and light buoy applications)
- 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 discharge time is also required as these times are commonly used in PV applications.

3.3 Endurance in cycles

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

Normally the cycle endurance 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 shall therefore comply with the requirements of the test described in IEC 61427, which is a simulation of the PV system operation. The manufacturer shall specify the number of cycles the batteries can achieve before the capacity has declined to 80 % of the rated capacity.

3.4 Charge control

Excessive overcharge does not increase the energy stored in the battery. Instead, overcharge affects the water consumption in wet lead acid batteries and consequently the service interval. In addition, valve-regulated lead-acid batteries may dry out resulting in a loss of capacity or overheating.

Overcharge can be controlled by use of dedicated charge controllers. The parameters of the regulator shall 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 shall have sufficient electrolyte to cover at least the period between planned service visits. Boost charging valve regulated lead acid batteries shall 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 shall show a high capability of charge retention. The charge retention shall be stated by the manufacturer and shall 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 shall 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 shall 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 shall 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 Safety

The instructions for procedures to be observed during transport and storage, installation, putting into service, operation and maintenance, taking out of service, and disposal need to be provided by the manufacturer, but also need to meet national regulations.

A procedure must be established describing how to safely enter battery compartments, how to open battery boxes and the use of insulated and spark free tools.

3.9 Disposal

Both lead acid and nickel cadmium batteries should be disposed of via a safe and environmentally acceptable disposal route. See *IALA Guidelines for the Safe Handling of Batteries, 1994, revised 1996*.

REFERENCES

Author	Title	Printer	Year	ISBN/Ref
Linden, David	Handbook of Batteries, Second Edition	Mc Graw-Hill Inc	1995	0-07-037921-1
Vincent, C.A.; Scrosati, B.:	Modern Batteries - An Introduction to Electrochemical Power Sources, Second Edition	Arnold	1997	0-340-66278-6
IALA, Engineering Committee	REPORT IALABATT 87, IALA Workshop on Batteries, Drujba, Bulgaria, April 1987	IALA	1987	
IALA, Engineering Committee	Report IALABATT 2, IALA Workshop on Batteries, September 1993	IALA	1993	
IALA, Engineering Committee	IALABATT3, Session Reports, April 1997	IALA	1997	
IALA, Engineering Committee	AISM / IALA Questionnaire on batteries, 1999	IALA	1999	
IALA, Engineering Committee	IALA Guidelines for the safe handling of batteries	IALA	1994, revised 1996	
	International Electro technical Vocabulary, Chapter 486: Secondary cells and batteries		1991	IEC 50 (486),
	IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) Systems		15 June 2000	IEEE Std 937-2000
	Secondary cells and batteries for solar photovoltaic energy systems - General requirements and methods of test.		1999-11	IEC 61427
	Stationary lead-acid batteries - General requirements and methods of test Part 1: Vented types Amendment No 1 (1988-01) Amendment No 2 (1990-12)		1987-01	IEC 60896-1
	Stationary lead-acid batteries: General requirements and test methods		1995-11	IEC 60896-2

Author	Title	Printer	Year	ISBN/Ref
	Part 2: Valve regulated types			
	Portable lead-acid cells and batteries (Valve regulated types) Part 1: General requirements, functional characteristics - Methods of test		1991-05	IEC 61056-1
	Sealed nickel-cadmium prismatic rechargeable single cells		1988-11	IEC 60622
	Vented nickel-cadmium prismatic rechargeable single cells		1990-03	IEC 60623
	Accumulators, electrolyte and refilling water, general			DIN 43530-1
	Electrolyte for vented nickel-cadmium cells			IEC 60993
	Accumulators; electrolyte and refilling water; electrolyte for lead acid batteries			DIN 43530-2

ANNEX

MAJOR ADVANTAGES AND DISADVANTAGES OF

VARIOUS TYPES OF BATTERIES USED IN MARINE ATON

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 – sulphation
- 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.
- Sulphation of plates reduces capacity

*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
- Sulphation of plates can reduce capacity.

C. 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
- 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.
- Costs of disposal have to be recognised

D. 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
- Costs of disposal have to be recognised
- Higher initial cost
- Memory effect (voltage depression)
- Temperature controlled charging system required to enhance life

E. SEALED NICKEL-CADMIUM BATTERIES

Advantages

- Cell 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
- Costs of disposal have to be recognised
- Higher cost than sealed lead-acid battery.
- Difficult to recycle

F. AIR-DEPOLARISED BATTERIES

Advantages

- High energy density
- No active cathode material is needed
- Long shelf life (sealed)
- Wide range of operating temperature (- 20 C° to + 50 °C)
- Low cost (on service energy basis)
- Capacity independent of load and temperature when within operating range
- robustly designed
- maintenance-free

- easy to install, use and replace.

Disadvantages

- Not independent of environmental conditions
- “Drying out” limits shelf life once opened to air
- “Flooding” limits power output
- Limited power output
- Short activated life.
- Reduced performance at low temperature
- May contain hazardous elements.

G. Alkaline-Manganese Dioxide Cells, compared to zinc-carbon cells

Advantages

- High energy density
- Better service performance: Continuous and intermittent operation- Low and high discharge rate, low temperature
- Low internal resistance
- Long shelf life
- Great resistance to leakage
- Better dimensional stability

Disadvantages

- Higher initial cost

Note-This is not an exhaustive list of battery types