Battery Applications and Technology

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Contents

1.0 Definitions

Active material - Constituents of a cell that participate in the electrochemical charge/discharge reaction.

Battery - Two or more cells electrically connected to form a unit. Under common usage, the term "battery" also applies to a single cell.

Capacity - Number of ampere-hours (Ah) a fully charged cell or battery can deliver under specified conditions of discharge.

Cell - Basic electrochemical unit used to store electrical energy.

Current - Flow of electrons equal to one coulomb of charge per second, usually expressed in amperes (A).

Cutoff voltage - Cell or battery voltage at which the discharge is terminated. The cutoff voltage is specified by the manufacturer and is a function of discharge rate and temperature.

Cycle - The discharge and subsequent charge of a secondary battery such that it is restored to its fully charged state.

Duty cycle - Operating parameters of a cell or battery including factors such as charge and discharge rates, depth of discharge, cycle length, and length of time in the standby mode.

Electrode - Electrical conductor and the associated active materials at which an electrochemical reaction occurs. Also referred to as the positive and negative plates in a secondary cell.

Electrolysis - Chemical dissociation of water into hydrogen and oxygen gas caused by passage of an electrical current.

Electrolyte - Medium which provides the ion transport function between the positive and negative electrodes of a cell.

Equalizing charge - Charge applied to a battery which is greater than the normal float charge and is used to completely restore the active materials in the cell, bringing the cell float voltage and the specific gravity of the individual cells back to equal values.

Float charge - Method of charging in which a secondary cell is continuously connected to a constant-voltage supply that maintains the cell in a fully charged condition.

Gassing - Evolution of gas from one or more electrodes resulting from electrolysis of water during charge or from self-discharge. Significant gassing occurs when the battery is nearing the fully charged state while recharging or when the battery is on equalizing charge.

Potential difference - Work which must be done against electrical forces to move a unit charge from one point to the other, also known as electromotive force (EMF).

Primary cell or battery - Cell or battery which is not intended to be recharged and is discarded when the cell or battery has delivered its useful capacity.

Secondary battery - A battery that after discharge may be restored to its charged state by passage of an electrical current through the cell in the opposite direction to that of discharge. (Also called storage or rechargeable.)

Separator - Electrically insulating layer of material which physically separates electrodes of opposite polarity. Separators must be permeable to ions in the electrolyte and may also have the function of storing or immobilizing the electrolyte.

Specific gravity - Ratio of the weight of a solution to an equal volume of water at a specified temperature. Used as an indicator of the state of charge of a cell or battery.

Sulfation - Formation of lead sulfate crystals on the plates of a lead-acid battery.

Terminal - External electric connections of a cell or battery, also referred to as "terminal post" or "post."

Thermal runaway - A condition that occurs in a battery (especially valve-regulated types) when charging energy results in heat generation within the battery greater than the heat dissipated, causing an uncontrolled rise in battery temperature. This can cause failure through cell dry-out, shortened life, and/or melting of the battery.

Trickle charge - Method of charging in which a secondary cell is either continuously or intermittently connected to a constant current supply in order to maintain the cell in fully or nearly fully charged condition.

Voltage - Electromotive force or potential difference, expressed in volts (V).

2.0 Overview of Batteries

2.1 Battery Cell Construction Antimony / Calcium / Selenium / Tin Alloying

The grid structure in both pasted and tubular plate batteries is made from a lead alloy. A pure lead grid structure is not strong enough by itself to stand vertically while supporting the active material. Other metals in small quantities are alloyed with lead for added strength and improved electrical properties. The most commonly alloyed metals are antimony, calcium, tin, and selenium.

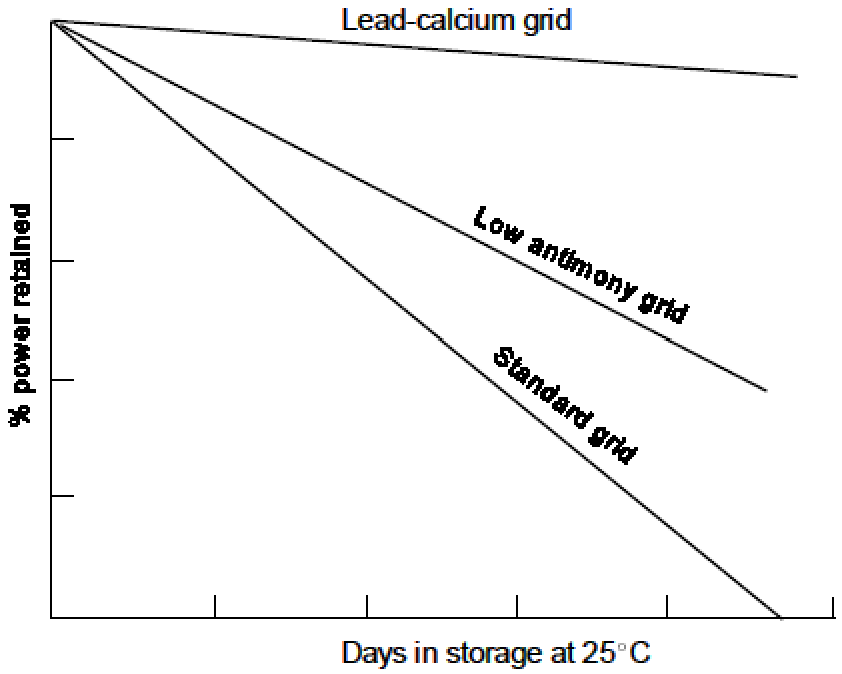
The two most common alloys used today to harden the grid are antimony and calcium. Batteries with these types of grids are sometimes called "lead-antimony" and "lead-calcium" batteries. Tin is added to lead-calcium grids to improve cyclability. The major differences between batteries with lead-antimony and lead-calcium grids are as follows:

1. Lead-antimony batteries can be deep cycled more times than lead-calcium batteries.

2. Flooded lead-antimony batteries require more frequent maintenance as they near end-of-life since they use an increasing amount of water and require periodic equalization charges.

3. Lead-calcium batteries have lower self-discharge rates as shown in the illustration below and therefore, will draw less current while on float charge than lead-antimony batteries.

4. Lead-calcium positive plates may grow in length and width because of grid oxidation at the grain boundaries. This oxidation is usually caused by long-term overcharging, which is common to UPS and other batteries on constant-float changing. Grids may grow in size sufficiently to cause buckling or rupture of their containers.



Another type of grid alloy is lead-selenium. In reality, this battery is actually a low lead-antimony grid with a slight amount of selenium. Lead-selenium has characteristics that fall somewhere between lead-calcium and lead-antimony.

When pure lead is mixed with an alloy there may be undesirable characteristics introduced in the performance of the battery. Modern day battery manufacturers try to reduce the amount of antimony and calcium by introducing doping agents such as selenium, cadmium, tin, and arsenic. When batteries containing arsenic and antimony are charged (especially overcharged) the poisonous gases arsine (AsH3) and stibine (SbH3) may be released.

2.2 Capacity and Battery Ratings

In general terms, the *capacity* of a cell/battery is the amount of charge available expressed in *ampere-hours* (Ah). An ampere is the unit of measurement used for electrical current and is defined as a coulomb of charge passing through an electrical conductor in one second. The capacity of a cell or battery is related to the quantity of active materials in it, and the amount of electrolyte and the surface area of the plates. The capacity of a battery/cell is measured by discharging at a constant current until it reaches its terminal voltage (usually about 1.75 volts). This is usually done at a constant temperature, under standard conditions of 25C (77F). The capacity is calculated by multiplying the discharge current value by the time required to reach terminal voltage.

The most common term used to describe a battery's ability to deliver current is its *rated capacity*. Manufacturers frequently specify the rated capacity of their batteries in ampere-hours at a specific discharge rate. For example, this means that a lead-acid battery rated for 200 Ah (for a 10-hour rate) will deliver 20 amperes of current for 10 hours under standard temperature conditions (25C or 77F). Alternatively, a discharge rate may be specified by its charge rate or C-rate, which is expressed as a multiple of the rated capacity of the cell or battery. For example, a battery may have a rating of 200 Ah at a C/10 discharge rate. The discharge rate is determined by the equation below:

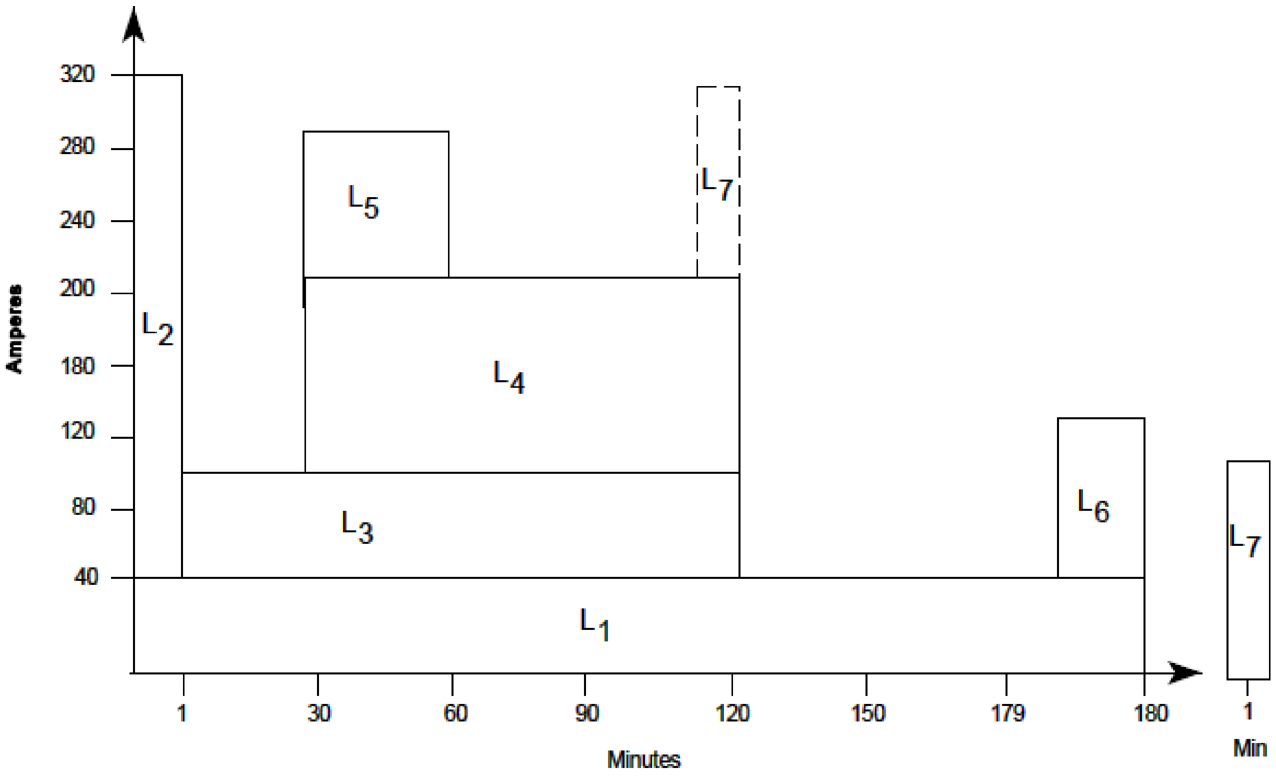
$$\text{C/10 rate (amperes)} = \text{200 Ah/10 h} = \text{20 amperes.}$$

Battery capacity varies with the discharge rate. The higher the discharge rate, the lower the cell capacity. Lower discharge rates result in higher capacity. Manufacturer's literature on batteries will normally specify several discharge rates (in amperes) along with the associated discharge time (in hours). The capacity of the battery for each of these various discharge rates can be calculated as discussed above.

The rated capacity for lead-acid batteries is usually specified at the 8-, 10-, or 20-hour rates (C/8, C/10, C/20). UPS batteries are rated at 8-hour capacities and telecommunications batteries are rated at 10-hour capacities.

2.3 Sizing and Selection of Batteries

A simple duty cycle diagram is shown below:



Other considerations include;

1. Physical characteristics, such as size and weight of the cells, container material, vent caps, intercell connectors, and terminals
2. Planned life of the installation and expected life of the cell design
3. Frequency and depth of discharge
4. Ambient temperature
5. Maintenance requirements for the various cell designs
6. Shock characteristics of the cell design.

2.4 Battery versus Cell

A battery is a device that converts the chemical energy contained in its active materials into electrical energy by means of an electrochemical reaction. While the term "battery" is often used, the basic electrochemical element being referred to is the cell. A battery consists of two or more cells electrically connected in series to form a unit. In common usage, the terms "battery" and "cell" are used interchangeably.

2.5 Cell and Battery Voltage

In order for a cell or battery to be able to deliver electrical current to an external circuit, a potential difference must exist between the positive and negative electrodes. The potential difference (usually measured in volts) is commonly referred to as the voltage of the cell or battery. A single lead-acid cell can develop a maximum potential difference of about 2 V under load. A completely discharged lead-acid cell has a potential difference of about 1.75 V, depending on the rate of discharge.

2.6 Simple Battery Components

The *negative electrode* supplies electrons to the external circuit (or load) during discharge. In a fully charged lead-acid storage battery the negative electrode is composed of sponge lead (Pb). The *positive electrode* accepts electrons from the load during discharge. In a fully charged lead-acid battery the positive electrode is composed of lead dioxide (PbO_2). It should be noted that the electrodes in a battery must be of dissimilar materials or the cell will not be able to develop an electrical potential and thus conduct electrical current. The *electrolyte* completes the internal circuit in the battery by supplying ions to the positive and negative electrodes. Dilute sulfuric acid (H_2SO_4) is the electrolyte in lead-acid batteries. In a fully charged lead-acid battery, the electrolyte is approximately 25% sulfuric acid and 75% water.

The separator is used to electrically isolate the positive and negative electrodes. If the electrodes are allowed to come in contact, the cell will *short-circuit* and become useless because both electrodes would be at the same potential. The type of separator used varies by cell type. Materials used as separators must allow ion transfer between the electrolyte and electrodes. Many separators are made of a porous plastic or glass fiber material. The above components are housed in a container commonly called a *jar* or *container*.

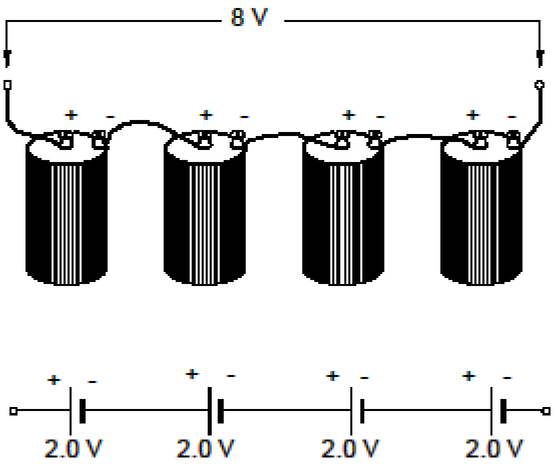
2.7 Primary and Secondary Cells and Batteries

Batteries are either primary or secondary. Primary batteries can be used only once because the chemical reactions that supply the electrical current are irreversible. Secondary (or storage) batteries can be used, charged, and reused. In these batteries, the chemical reactions that supply electrical current are readily reversed so that the battery is charged.

Primary batteries are common since they are cheap and easy to use. Familiar primary battery uses are in flashlights, watches, toys, and radios. The most common use for secondary (storage) batteries is for starting, lighting, and ignition (SLI) in automobiles and engine-generator sets. Other applications include uninterruptible power supplies (UPSs) for emergency and backup power, electric vehicles (traction), telecommunications, and portable tools.

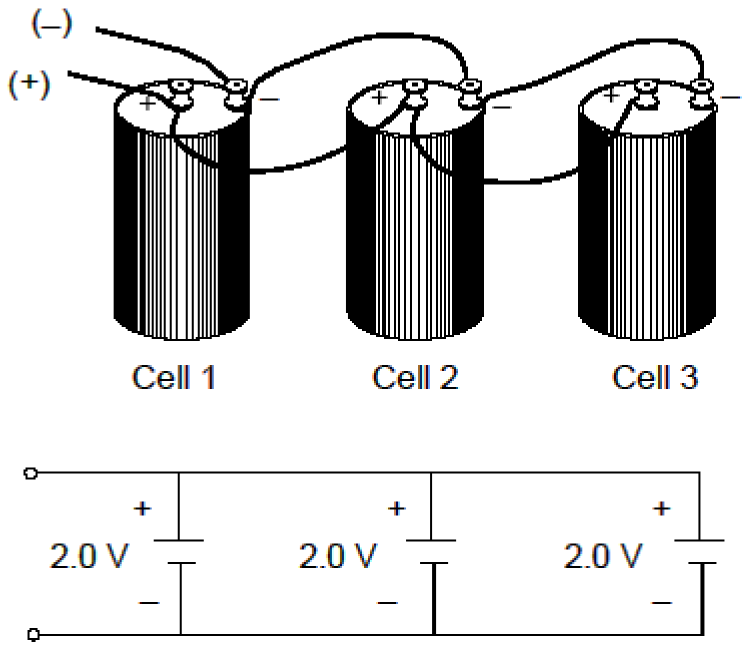
2.8 Series and Parallel Battery Connections

Cells and batteries may be connected in series, parallel, or combinations of both. Cells or batteries connected in series have the positive terminal of one cell or battery connected to the negative terminal of another cell or battery. This has the effect of increasing the overall voltage but the overall capacity remains the same. For example, the 12-V lead-acid automobile battery contains 6 cells connected in series with each cell having a potential difference of about 2 V. Another example of cells or batteries connected in series is shown below.



Series Cells

Cells or batteries connected in parallel have their like terminals connected together. The overall voltage remains the same but the capacity is increased. For example, if two 12-V automotive batteries were connected in parallel, the overall voltage for the batteries would still be 12 V. However, the connected batteries would have twice the capacity of a single 12-V battery. Another example of cells or batteries connected in parallel is shown below.



Parallel Cells

Batteries may also be connected in a series/parallel combination. Batteries are added in series until the desired voltage is obtained, and in parallel until the battery bank meets capacity requirements. Only like cells or batteries should be connected together. Connecting cells or batteries of different rating or manufacturer may produce undesirable or even dangerous results.

3.0 Charging

3.1 Battery Charging Requirements

Poor charging practice is responsible for shortening the life of a battery more than any other cause. Charging may be accomplished by various methods, but the objective of driving current through the battery in the opposite direction of discharge remains the same. The most important aspect of charging is matching the charger to the battery application. When choosing a charger, it is necessary to consider the type of battery, the way in which the battery will be discharged, the time available for charge, the temperature extremes the battery will experience, and the number of cells in the battery (output voltage). It is important to consult the battery manufacturer at the time of purchase to determine the appropriate charging method.

In general, lead-acid batteries may be recharged at any rate that does not produce excessive gassing, overcharge, or high temperatures. Discharged batteries may be recharged at a high current initially. However, once the battery approaches its full charge the current must be decreased to reduce gassing and excessive overcharging.

A wide variety of schemes exist for charging lead-acid batteries. Although a complete discussion of various charging techniques is beyond the scope of this Primer, a general description of the more common methods follows.

3.2 Constant Current Battery Charging

Constant-current charging simply means that the charger supplies a relatively uniform current, regardless of the battery state of charge or temperature. Constant-current charging helps eliminate imbalances of cells and batteries connected in series. Single-rate, constant-current chargers are most appropriate for cyclic operation where a battery is often required to obtain a full charge overnight. At these high rates of charge there will be some venting of gases. Positive grid oxidation will occur at elevated temperatures or extended overcharge times. Normally the user of a cyclic application is instructed to remove the battery from a single-rate, constant-current charger within a period of time that permits full charge yet prevents excessive grid oxidation.

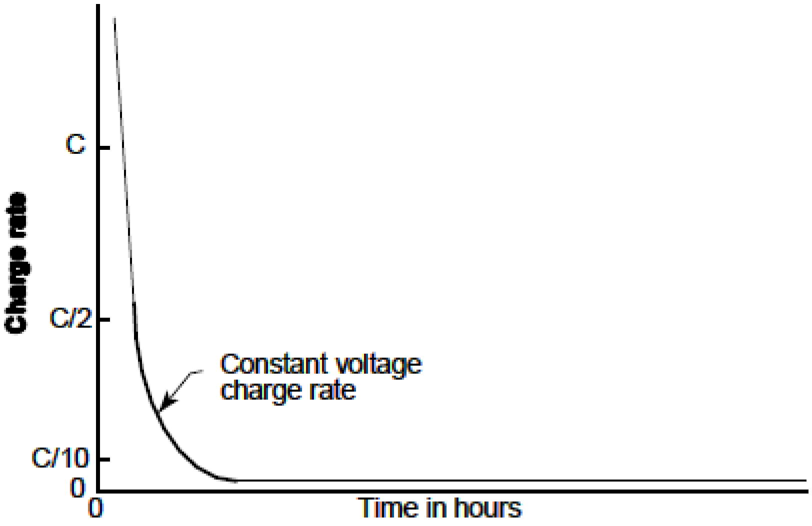
Another type of constant-current charger is the split-rate charger. A split-rate charger applies a high initial current to the cell and then switches to a low rate based on time of charge, voltage, or both. The choice of switching method and switch point may be affected by the relative priority of minimizing venting (early switching) versus maintaining good cell balance (later switching). In some split rate chargers, the charger will alternate between the high and low rate as the battery approaches full charge. Split-rate chargers are useful when the discharge cannot be classified as float or cyclic, but lies somewhere between the two applications.

3.3 Constant Voltage Charging Requirements

Constant-voltage (often called constant-potential) chargers maintain nearly the same voltage input to the battery throughout the charging process, regardless of the battery's state of charge. Constant-voltage chargers provide a high initial current to the battery because of the greater potential difference between the battery and charger. A constant-voltage charger may return as much as 70% of the previous discharge in the first 30 minutes. This proves useful in many battery applications involving multiple discharge scenarios. As the battery charges its voltage increases quickly. This reduces the potential that has been driving the current, with a corresponding rapid decrease in charge current as depicted in the illustration below. As a result, even though the battery reaches partial charge quickly, obtaining a full charge requires prolonged charging.

Given this behavior, constant-voltage chargers are frequently found in applications that normally allow extended charging periods to attain full charge. Constant-voltage chargers should not be used where there is frequent cycling of the battery. Repeated discharges without returning the cell to its full charge will eventually decrease the battery capacity and may damage individual cells.

Constant-voltage chargers are most often used in two very different modes: as a fast charger to restore a high percentage of charge in a short time or as a float charger to minimize the effects of overcharge on batteries having infrequent discharges.



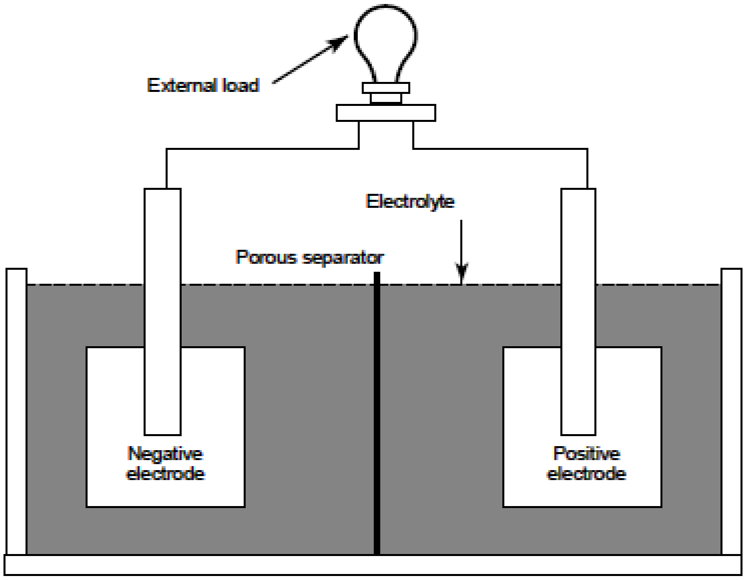
3.4 Float Charging - Battery

Float charging is most commonly used for backup and emergency power applications where the discharge of the battery is infrequent. During float charging the charger, battery, and load are connected in parallel. The charger operates off the normal power supply which provides current to the load during operation. In the event of normal power supply failure, the battery provides backup power until the normal power supply is restored. Since most equipment requires alternating current, a rectifier circuit is usually added between the battery and the load. Float chargers are typically constant-voltage chargers that operate at a low voltage. Operating the charger at a low voltage, usually less than about 2.4 V per cell, keeps the charging current low and thus minimizes the damaging effects of high-current overcharging.

For valve-regulated batteries, an important consideration when float charging is the possible occurrence of a phenomena called "thermal runaway". The best way of preventing thermal runaway is through the use of a temperature-compensated battery charger. A temperature-compensated charger adjusts the float voltage based upon battery temperature. Temperature-compensated chargers will increase the reliability and prolong the life of the battery/charger system. They are especially useful for batteries located in areas where temperatures may be significantly above ambient conditions

3.5 Trickle Charging - Battery

A trickle charge is a continuous constant-current charge at a low (about C/100) rate which is used to maintain the battery in a fully charged condition. Trickle charging is used to recharge a battery for losses from self-discharge as well as to restore the energy discharged during intermittent use of the battery. This method is typically used for SLI and similar type batteries when the battery is removed from the vehicle or its regular source of charging. Trickle charging is also used widely for portable tools and equipment such as flashlights and battery powered screwdrivers.



4.0 Battery Maintenance

4.1 General

Proper maintenance will prolong the life of a battery and will aid in assuring that it is capable of satisfying its design requirements. A good battery maintenance program will serve as a valuable aid in determining the need for battery replacement. Battery maintenance should always be performed by trained personnel knowledgeable of batteries and the safety precautions involved.

Most of the following material concerns flooded, non-maintenance-free batteries. However, so called "maintenance-free" and valve-regulated batteries also require some maintenance. They do not require water addition or checking of specific gravity, but they may require periodic cleaning, monitoring of cell and battery total float voltage, load (capacity) t7esting, terminal resistance measurement, or cleaning and torque verification of terminal bolts depending on the importance of the application.

Flooded lead-acid batteries can function for 10 years or longer if properly maintained. The six general rules of proper maintenance are

1. Match the charger to the battery requirements.
2. Avoid over discharging the battery.
3. Maintain the electrolyte at the appropriate level (add water as required).
4. Keep the battery clean.
5. Avoid overheating the battery.
6. Provide an equalizing charge periodically to weak batteries/cells.

4.2 Effects of Discharge Rate and Temperature on Battery Capacity and Life

The rate at which a battery is discharged and its operating temperature have a profound effect on its capacity and life. An example of the effect of discharge rate on battery capacity is shown in Figure A for traction batteries. This figure shows that batteries discharged at a low rate will be able to deliver a higher capacity than those discharged at a high rate.

The depth of discharge also affects the life of a battery. As shown in Figure B for a typical traction battery, discharges beyond about 80% of capacity can be expected to shorten battery life.

Colder operating temperatures will yield a little extra life, but also lower the capacity of lead acid cells. High temperatures yield higher capacity (see Figure C) but have a detrimental effect on life.

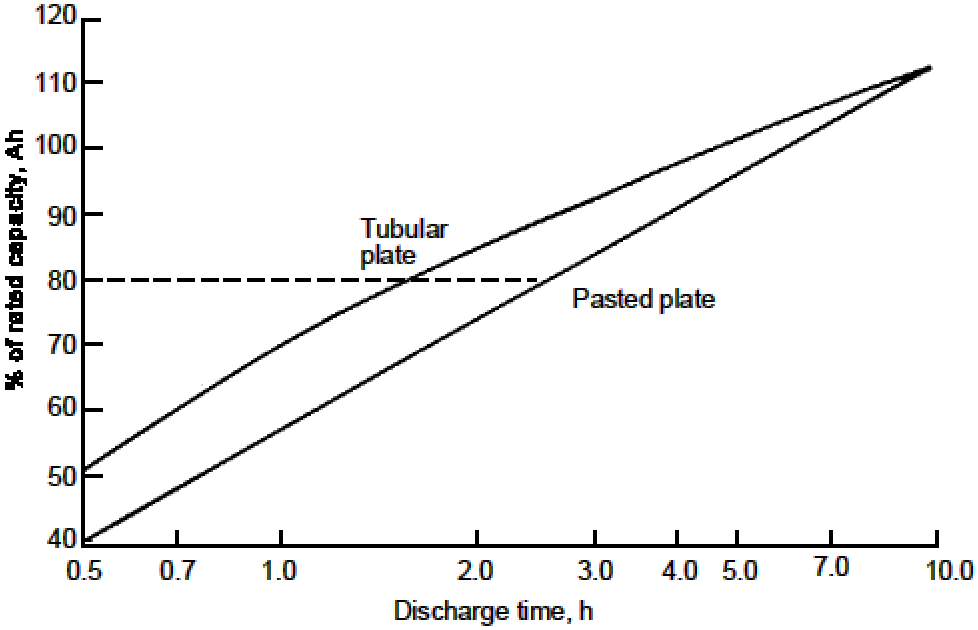


Figure A
Typical effects of discharge rate on battery capacity

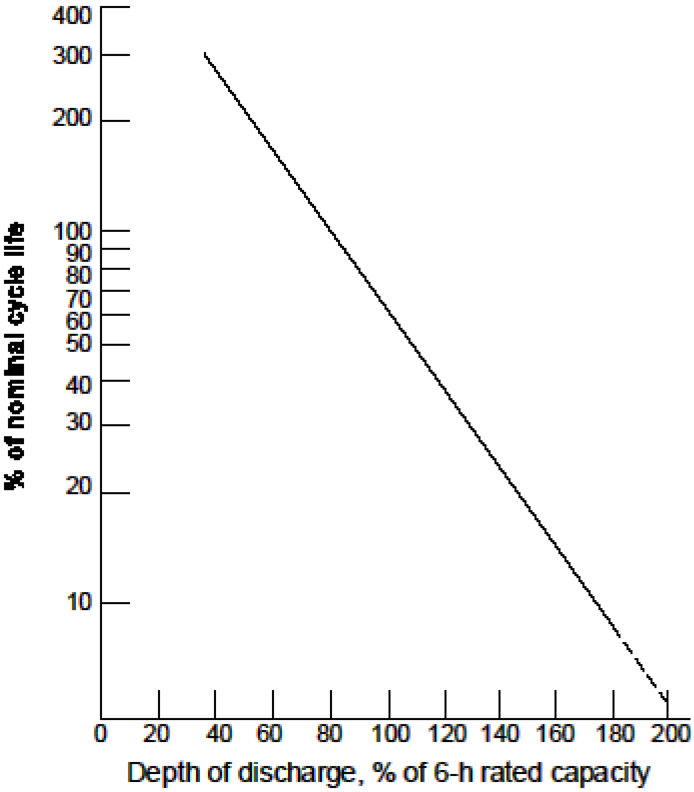


Figure B
Typical effects of depth of discharge on traction battery life

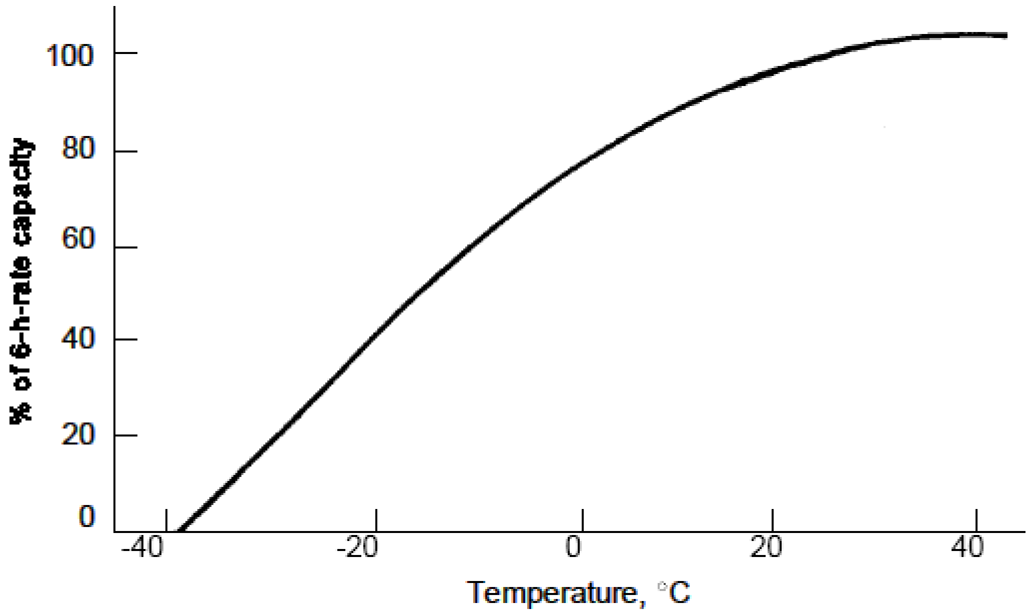


Figure C
Typical effects of operating temperatures on traction battery capacity

4.3 High Temperature Considerations for Batteries

One of the most detrimental conditions for a battery is high temperature, particularly above 55C, because the rates of corrosion, solubility of metal components, and self discharge increase with increasing temperature. High operating temperature during cycle service requires higher charge input to restore discharge capacity and self discharge losses. More of the charge input is consumed by the electrolysis reaction because of the reduction in the gassing voltage at the higher temperature. While 10% overcharge per cycle maintains the state of charge at 25 to 35C, 35 to 40% overcharge may be required to maintain state of charge at the higher (60 to 70C) operating temperatures. On float service, float currents increase at the higher temperatures, resulting in reduced life. Eleven days float at 75C is equivalent in life to 365 days at 25C. Batteries intended for high-temperature applications should use a lower initial specific gravity electrolyte than those intended for use at normal temperatures. Manufacturers should be consulted on acceptable temperature ranges for operation of their batteries and on the associated effects of temperature. Nickel-cadmium batteries may be more suitable for higher-temperature applications.

4.4 Over Discharging - Battery

In order to obtain maximum life from lead-acid batteries, they should be disconnected from the load once they have discharged their full capacity. The cutoff voltage of a lead-acid cell is usually around 1.75 V. However, the cutoff voltage is very sensitive to operating temperature and discharge rate. Like batteries discharged at a high rate will have a lower cutoff voltage than those discharged at a low rate. Greater capacities are obtained at higher temperatures and low discharge rates. The manufacturer should specify cutoff voltages for various operating temperatures and discharge rates.

Over discharge may cause difficulties in recharging the cell by increasing the battery's internal resistance. Also, over discharging may cause lead to be precipitated in the separator and cause a short in the cell or between cells.

4.5 Maintaining Battery Electrolyte Levels

During normal operation, water is lost from a flooded lead-acid battery as a result of evaporation and electrolysis into hydrogen and oxygen, which escape into the atmosphere. One Faraday of overcharge will result in a loss of about 18 g of water. Evaporation is a relatively small part of the loss except in very hot, dry climates. With a fully charged battery, electrolysis consumes water at a rate of 0.336 cm per ampere-hour overcharge. A 5000-Ah battery overcharged 10% can thus lose 16.8 cm , or about 0.3%, of its water each cycle. It is important that the electrolyte be maintained at the proper level in the battery. The electrolyte not only serves as the ionic conductor, but is a major factor in the transfer of heat from the plates. If the electrolyte is below the plate level, then an area of the plate is not electrochemically efficient; this causes a concentration of heat in other parts of the battery. Periodic checking of water consumption can also serve as a rough check on charging efficiency and may warn when adjustment of the charger is required.

Since replacing water can be a major maintenance cost, water loss can be reduced by controlling the amount of overcharge and by using hydrogen and oxygen recombining devices in each cell where possible. Addition of water is best accomplished after recharge and before an equalization charge. Water is added at the end of the charge to reach the high level line. Gassing during overcharge will stir the water into the acid uniformly. In freezing weather, water should not be added without mixing as it may freeze before gassing occurs. Only distilled water should be added to batteries. Although de-mineralized or tap water may be approved for some batteries, the low cost of distilled water makes it the best choice. Automatic watering devices and reliability testing can reduce maintenance labor costs further. Overfilling must be avoided because the resultant overflow of acid electrolyte will cause tray corrosion, ground paths, and loss of cell capacity. Although distilled water is no longer specified by most battery manufacturers, good quality water, low in minerals and heavy metal ions such as iron, will help prolong battery life.

5.0 Lead Acid Batteries

5.1 Electrochemistry of Lead Acid Battery Cell

All lead-acid batteries operate on the same fundamental reactions. As the battery discharges, the active materials in the electrodes (lead dioxide in the positive electrode and sponge lead in the negative electrode) react with sulfuric acid in the electrolyte to form lead sulfate and water. On recharge, the lead sulfate on both electrodes converts back to lead dioxide (positive) and sponge lead (negative), and the sulfate ions (SO_4^{2}) are driven back into the electrolyte solution to form sulfuric acid. The reactions involved in the cell follow.

At the positive electrode:

$$PbO_2 + 3H^+ + HSO_4^- + 2e^- \underset{Charge}{\overset{Discharge}{\rightleftarrows}} PbSO_4 + 2H_2O \quad (1.685\ V).$$

At the negative electrode:

$$Pb + HSO_4^- \underset{Charge}{\overset{Discharge}{\rightleftarrows}} PbSO_4 + H^+ + 2e^- \quad (0.356\ V).$$

Over cell:

$$PbO_2 + Pb + 2H_2SO_4 \underset{Charge}{\overset{Discharge}{\rightleftarrows}} 2PbSO_4 + 2H_2O \quad (2.041\ V).$$

Therefore the maximum open-circuit voltage that can be developed by a single lead-acid cell is 2.041 V.

5.2 Flooded Lead Acid Battery

Flooded cells are those where the electrodes/plates are immersed in electrolyte. Since gases created during charging are vented to the atmosphere, distilled water must be added occasionally to bring the electrolyte back to its required level. The most familiar example of a flooded lead-acid cell is the 12-V automobile battery.

5.3 Lead Acid Battery Active Materials

The active materials in a battery are those that participate in the electrochemical charge/discharge reaction. These materials include the electrolyte and the positive and negative electrodes. As mentioned earlier, the electrolyte in a lead-acid battery is a dilute solution of sulfuric acid (H_2SO_4). The negative electrode of a fully charged battery is composed of sponge lead (Pb) and the positive electrode is composed of lead dioxide (PbO_2).

5.4 Lead Acid Battery Applications

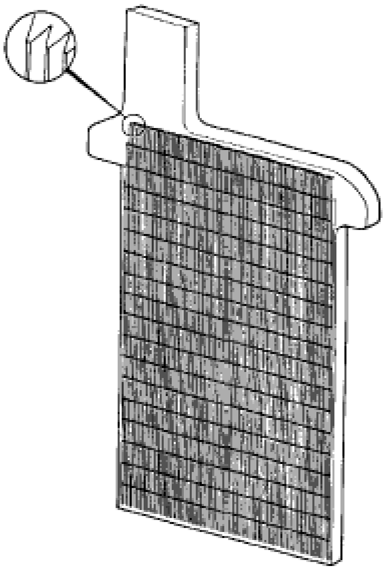
There are numerous applications for the use of lead-acid storage batteries. They range from the extremely large battery systems used in load leveling by electrical utility companies to the relatively small batteries used in hand tools. Batteries may need to undergo deep and frequent cycling such as those used for electric vehicle power or they may remain on "float" as in an emergency lighting application and only rarely be discharged. Clearly, these applications cannot all use the same battery. Restraints on parameters such as operating temperature, desired capacity, voltage and power requirements, etc., affect the type of battery chosen.

All the above considerations are taken into account by determining the battery's duty cycle. The duty cycle is the required operating parameters of a cell or battery including factors such as charge and discharge rates, depth of discharge, cycle length, and length of time in the standby mode. The duty cycle must be known and included in the battery design engineering specification. The duty cycle and battery chosen will also determine the type of charger used.

The major categories of lead-acid battery applications are starting, lighting, and ignition (SLI); industrial, including traction and stationary applications; and small portable equipment.

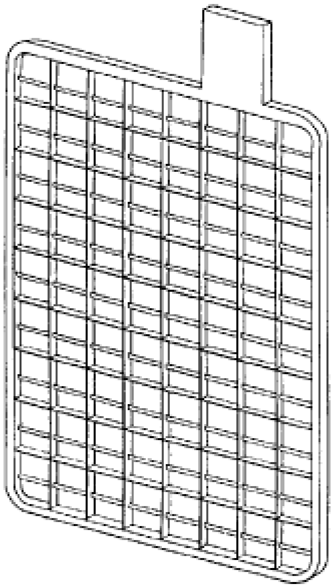
5.5 Negative and Positive Plate Construction

The simplest method for the construction of lead-acid battery electrodes is the plant plate, named after the inventor of the lead-acid battery. A plant plate is merely a flat plate composed of pure lead. Since the capacity of a lead-acid battery is proportional to the surface area of the electrodes that is exposed to the electrolyte, various schemes are employed to increase the surface area of the electrodes per unit volume or weight. Plant plates are grooved or perforated to increase their surface area. A typical plant plate is shown below.



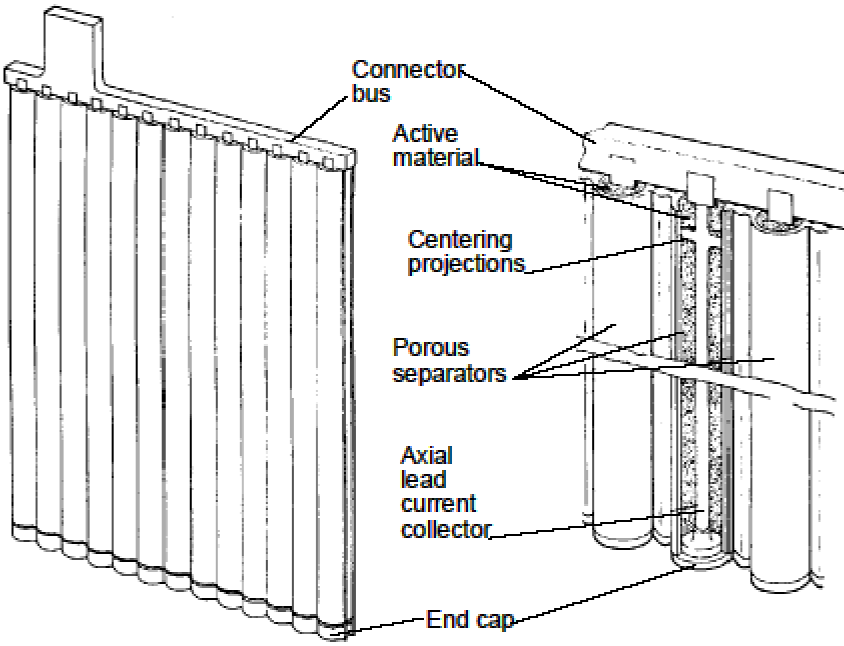
Plate

The most commonly used method to increase surface area is to make the active material into a paste that acts like a sponge where the electrolyte fills all the pores. The paste, or active material, is mounted into a frame or grid structure that mechanically supports it and serves as the electrical conductor carrying the current during both the charge and discharge cycle. The most commonly used plate today is the pasted plate, also known as the flat plate. This grid structure is a lattice-work that resembles the cross section of a honeycomb, with the paste filling all of the rectangular windows on the structure. The picture below shows a typical construction of a pasted plate grid. The flat plate construction is used as the negative electrode plate in almost all cases, and serves as the positive plate in most standby applications.



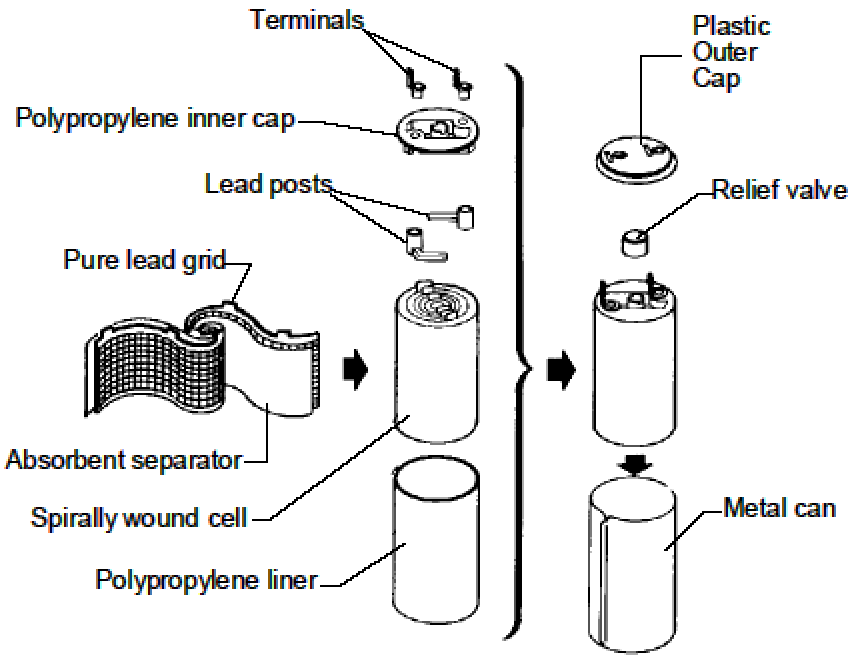
Pasted Grid plate

Positive electrodes are usually of pasted plate or tubular construction. Tubular electrodes are popular positive plates for heavy cycling applications. This construction uses a frame structure consisting of a series of vertical spines connected to a common bus. The paste is held in micro-porous, non-conductive tubes which are placed over the individual spines. A simplified view of tubular plate construction is shown in below. Regardless of the plate type used, the capacity of any battery is increased by adding multiple plates in parallel.



5.6 Portable Battery

Portable lead-acid batteries are usually of the sealed type constructed similarly to that depicted in below. Their operation cannot usually be described as cyclic or float, but is somewhere in-between. Batteries in this category may be frequently deep cycled or remain unused for a relatively long time. Typical applications are portable tools, toys, lighting and emergency lighting, radio equipment, and alarm systems. Most portable batteries may be recharged to 8090% of their original capacity in less than an hour using a constant-voltage charger.



5.7 Sealed Lead Acid Batteries

These types of batteries confine the electrolyte, but have a vent or valve to allow gases to escape if internal pressure exceeds a certain threshold. During charging, a lead-acid battery generates oxygen gas at the positive electrode.

Sealed lead-acid batteries are designed so that the oxygen generated during charging is captured and recombined in the battery. This is called an oxygen recombination cycle and works well as long as the charge rate is not too high. Too high of a rate of charge may result in case rupture, thermal runaway, or internal mechanical damage.

The valve-regulated battery is the most common type of sealed battery. It was developed for stationary and telecommunication battery applications. These types of sealed batteries have a spring-controlled valve that vents gases at a predetermined pressure. Typical pressure thresholds are from 2 to 5 psig, depending on the battery design. Although the term "valve regulated" is often used synonymously to describe sealed lead-acid batteries, not all sealed batteries are valve-regulated. Some battery designs employ replaceable vent plugs or other mechanisms to relieve excess pressure. Sealed batteries were developed to reduce the maintenance required for batteries in active service. Since electrolyte levels are preserved by trapping and recombining off-gasses, there should not be any need to add distilled water over the life of the battery. These batteries are often misnamed "maintenance free." In fact, all maintenance practices applicable to unsealed type batteries are applicable to sealed type batteries. The only exception is that electrolyte levels cannot, and should not need to be, maintained.

Sealed type batteries are often avoided for backup power source applications for several reasons. One reason is that the state of charge of sealed type batteries cannot be ascertained by the usual specific gravity measurement. Reliable alternative methods to measure the state of charge for sealed type batteries are under development. A second reason is their sensitivity to high temperatures.

6.0 Nickel-Cadmium Battery Ni-Cd

6.1 Ni-Cd Battery Applications

Sealed Ni-Cd cells may be used individually, or assembled into battery packs containing two or more cells. Small cells are used for portable electronics and toys, often using cells manufactured in the same sizes as primary cells. When Ni-Cd batteries are substituted for primary cells, the lower terminal voltage and smaller ampere-hour capacity may reduce performance as compared to primary cells. Miniature button cells are sometimes used in photographic equipment, hand-held lamps (flashlight or torch), computer-memory standby, toys, and novelties.

Specialty Ni-Cd batteries are used in cordless and wireless telephones, emergency lighting, and other applications. With a relatively low internal resistance, they can supply high surge currents. This makes them a favourable choice for remote-controlled electric model airplanes, boats, and cars, as well as cordless power tools and camera flash units. Larger flooded cells are used for aircraft starting batteries, electric vehicles, and standby power.

Voltage:

Ni-Cd cells have a nominal cell potential of 1.2 volts (V). This is lower than the 1.5 V of alkaline and zinc-carbon primary cells, and consequently they are not appropriate as a replacement in all applications. However, the 1.5 V of a primary alkaline cell refers to its initial, rather than average, voltage. Unlike alkaline and zinc-carbon primary cells, a Ni-Cd cell's terminal voltage only changes a little as it discharges. Because many electronic devices are designed to work with primary cells that may discharge to as low as 0.90 to 1.0 V per cell, the relatively steady 1.2 V of a Ni-Cd cell is enough to allow operation. Some would consider the near-constant voltage a drawback as it makes it difficult to detect when the battery charge is low.

Ni-Cd batteries used to replace 9 V batteries usually only have six cells, for a terminal voltage of 7.2 volts. While most pocket radios will operate satisfactorily at this voltage, some manufacturers such as Varta made 8.4 volt batteries with seven cells for more critical applications.

12 V Ni-Cd batteries are made up of 10 cells connected in series.

6.2 Comparison with Other Batteries

Recently, nickel-metal hydride and lithium-ion batteries have become commercially available and cheaper, the former type now rivaling Ni-Cd batteries in cost. Where energy density is important, Ni-Cd batteries are now at a disadvantage compared with nickel-metal hydride and lithium-ion batteries. However, the Ni-Cd battery is still very useful in applications requiring very high discharge rates because it can endure such discharge with no damage or loss of capacity.

Advantages:

When compared to other forms of rechargeable battery, the Ni-Cd battery has a number of distinct advantages:

- The batteries are more difficult to damage than other batteries, tolerating deep discharge for long periods. In fact, Ni-Cd batteries in long-term storage are typically stored fully discharged. This is in contrast, for example, to lithium ion batteries, which are less stable and will be permanently damaged if discharged below a minimum voltage.
- Ni-Cd batteries typically last longer, in terms of number of charge/discharge cycles, than other rechargeable batteries such as lead/acid batteries.
- Compared to lead-acid batteries, Ni-Cd batteries have a much higher energy density. A Ni-Cd battery is smaller and lighter than a comparable lead-acid battery. In cases where size and weight are important considerations (for example, aircraft), Ni-Cd batteries are preferred over the cheaper lead-acid batteries.
- In consumer applications, Ni-Cd batteries compete directly with alkaline batteries. A Ni-Cd cell has a lower capacity than that of an equivalent alkaline cell, and costs more. However, since the alkaline battery's chemical reaction is not reversible, a reusable Ni-Cd battery has a significantly longer total lifetime. There have been attempts to create rechargeable alkaline batteries, or specialized battery chargers for charging single-use alkaline batteries, but none that has seen wide usage.
- The terminal voltage of a Ni-Cd battery declines more slowly as it is discharged, compared with carbon-zinc batteries. Since an alkaline battery's voltage drops significantly as the charge drops, most consumer applications are well equipped to deal with the slightly lower Ni-Cd cell voltage with no noticeable loss of performance.
- The capacity of a Ni-Cd battery is not significantly affected by very high discharge currents. Even with discharge rates as high as 50°C, a Ni-Cd battery will provide very nearly its rated capacity. By contrast, a lead acid battery will only provide approximately half its rated capacity when discharged at a relatively modest 1.5C.
- Nickel-metal hydride (NiMH) batteries are the newest, and most similar, competitor to Ni-Cd batteries. Compared to Ni-Cd batteries, NiMH batteries have a higher capacity and are less toxic, and are now more cost effective. However, a Ni-Cd battery has a lower self-discharge rate (for example, 20% per month for a Ni-Cd battery, versus 30% per month for a traditional NiMH under identical conditions), although low self-discharge NiMH batteries are now available, which have substantially lower self-discharge than either Ni-Cd or traditional NiMH batteries. This results in a preference for Ni-Cd over NiMH batteries in applications where the current draw on the battery is lower than the battery's own self-discharge rate (for example, television remote controls). In both types of cell, the self-discharge rate is highest for a full charge state and drops off somewhat for lower charge states. Finally, a similarly sized Ni-Cd battery has a slightly lower internal resistance, and thus can achieve a higher maximum discharge rate (which can be important for applications such as power tools).

Disadvantages:

- The primary trade-off with Ni-Cd batteries is their higher cost and the use of cadmium. This heavy metal is an environmental hazard, and is highly toxic to all higher forms of life. They are also more costly than lead-acid batteries because nickel and cadmium cost more.
- One of the biggest disadvantages is that the battery exhibits a very marked negative temperature coefficient. This means that as the cell temperature rises, the internal resistance falls. This can pose considerable charging problems, particularly with the relatively simple charging systems employed for lead-acid type batteries. Whilst lead-acid batteries can be charged by simply connecting a dynamo to them, with a simple electromagnetic cut-out system for when the dynamo is stationary or an over-current occurs, the Ni-Cd battery under a similar charging scheme would exhibit thermal runaway, where the charging current would continue to rise until the over-current cut-out operated or the battery destroyed itself. This is the principal factor that prevents its use as engine-starting batteries. Today with alternator-based charging systems with solid-state regulators, the construction of a suitable charging system would be relatively simple, but the car manufacturers are reluctant to abandon tried-and-tested technology.

Availability:

Ni-Cd cells are available in the same sizes as alkaline batteries, from AAA through D, as well as several multi-cell sizes, including the equivalent of a 9 volt battery. A fully charged single Ni-Cd cell, under no load, carries a potential difference of between 1.25 and 1.35 volts, which stays relatively constant as the battery is discharged. Since an alkaline battery near fully discharged may see its voltage drop to as low as 0.9 volts, Ni-Cd cells and alkaline cells are typically interchangeable for most applications.

In addition to single cells, batteries exist that contain up to 300 cells (nominally 360 volts, actual voltage under no load between 380 and 420 volts). This many cells are mostly used in automotive and heavy-duty industrial applications. For portable applications, the number of cells is normally below 18 cells (24V). Industrial-sized flooded batteries are available with capacities ranging from 12.5Ah up to several hundred Ah.

Charging:

Ni-Cd batteries can be charged at several different rates, depending on how the cell was manufactured. The charge rate is measured based on the percentage of the amp-hour capacity the battery is fed as a steady current over the duration of the charge. Regardless of the charge speed, more energy must be supplied to the battery than its actual capacity, to account for energy loss during charging, with faster charges being more efficient. For example, an "overnight" charge, might consist of supplying a current equals to one tenth the amperehour rating (C/10) for 14-16 hours; that is, a 100 mAh battery takes 10mA for 14 hours, for a total of 140 mAh to charge at this rate. At the rapid-charge rate, done at 100% of the rated capacity of the battery in 1 hour (1C), the battery holds roughly 80% of the charge, so a 100 mAh battery takes 120 mAh to charge (that is, approximately 1 hour and fifteen minutes). Some specialized batteries can be charged in as little as 10-15 minutes at a 4C or 6C charge rate, but this is very uncommon. It also exponentially increases the risk of the cells overheating and venting due to an internal overpressure condition: the cell's rate of temperature rise is governed by its internal resistance and the square of the charging rate. At a 4C rate, the amount of heat generated in the cell is sixteen times higher than the heat at the 1C rate. The downside to faster charging is the higher risk of overcharging, which can damage the batteryand the increased temperatures the cell has to endure (which potentially shortens its life).

The safe temperature range when in use is between −20°C and 45°C. During charging, the battery temperature typically stays low, around 0°C (the charging reaction absorbs heat), but as the battery nears full charge the temperature will rise to 45° 50°C. Some battery chargers detect this temperature increase to cut off charging and prevent over-charging.

When not under load or charge, a Ni-Cd battery will self-discharge approximately 10% per month at 20°C, ranging up to 20% per month at higher temperatures. It is possible to perform a trickle charge at current levels just high enough to offset this discharge rate; to keep a battery fully charged. However, if the battery is going to be stored unused for a long period of time, it should be discharged down to at most 40% of capacity (some manufacturers recommend fully discharging and even short-circuiting once fully discharged), and stored in a cool, dry environment.

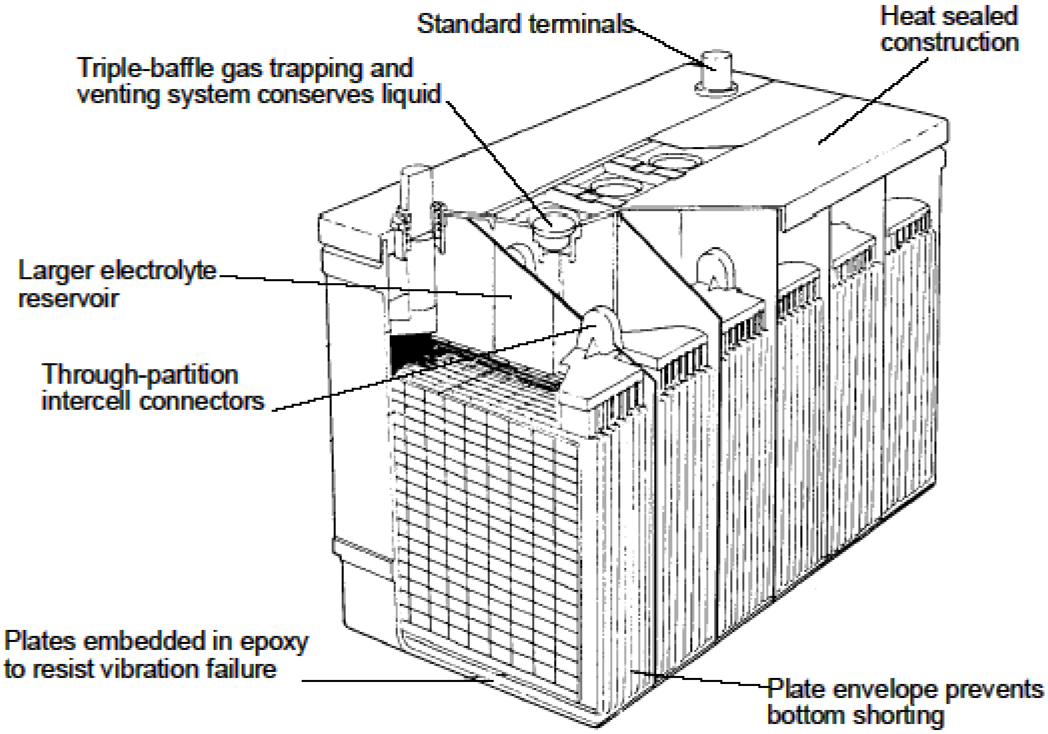
Charging method:

A Ni-Cd battery requires a charger with a slightly different voltage than for a lead-acid battery, especially if the battery has 11 or 12 cells. Also a charge termination method is needed if a fast charger is used. Often battery packs have a thermal cut-off inside that feeds back to the charger telling it to stop the charging once the battery has heated up and/or a voltage peaking sensing circuit. At room temperature during normal charge conditions the cell voltage increases from an initial 1.2 V to an end-point of about 1.45 V. The rate of rise increases markedly as the cell approaches full charge. The end-point voltage decreases slightly with increasing temperature.

7.0 Miscelaneous

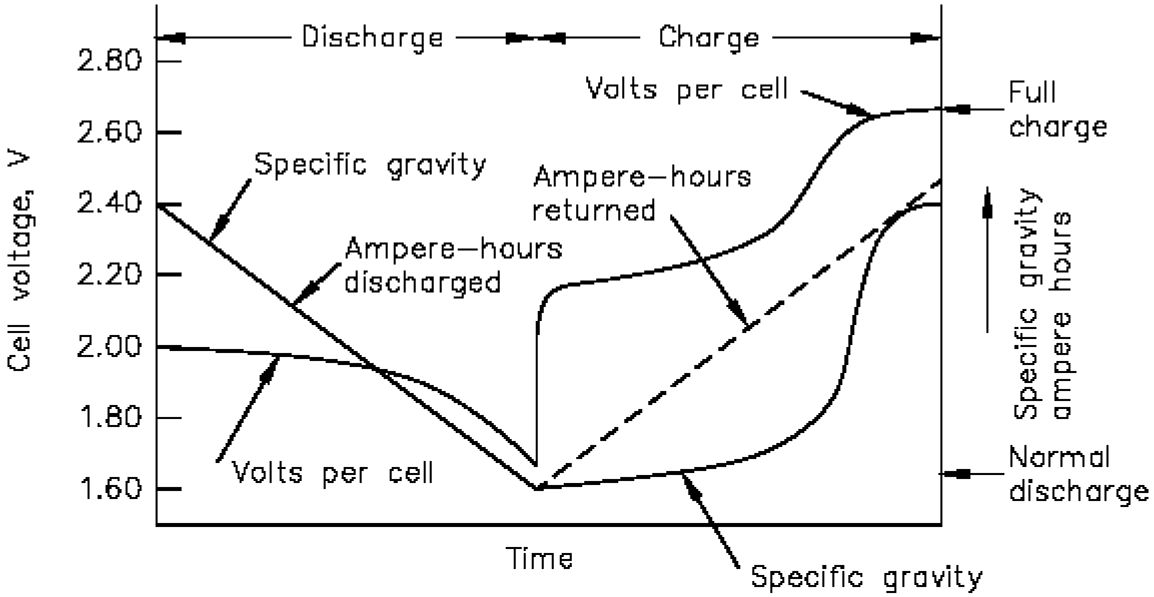
7.1 SLI Battery Application

SLI batteries are used by most people every day and are produced in greater numbers than any other type of lead-acid storage battery. These are used to start automobiles and most other kinds of internal combustion engines. They are not suitable for deep discharge applications, but excel for uses needing a high current for a brief time. They are usually charged in a "partial float" manner, meaning that the battery only receives a float charge while the vehicle is running. A cutaway view of a typical SLI battery is shown in below. SLI batteries are usually of the flat pasted plate design.



7.2 Specific Gravity of Battery Electrolyte

One of the key parameters of battery operation is the specific gravity of the electrolyte. Specific gravity is the ratio of the weight of a solution to the weight of an equal volume of water at a specified temperature. Specific gravity is used as an indicator of the state of charge of a cell or battery. However, specific gravity measurements cannot determine a battery's capacity. During discharge, the specific gravity decreases linearly with the ampere-hours discharged as indicated in the illustration below.



Changes in voltage and specific gravity during charge and discharge

Therefore, during fully charged steady-state operation and on discharge, measurement of the specific gravity of the electrolyte provides an approximate indication of the state of charge of the cell. The downward sloping line for the specific gravity during discharge is approximated by the equation below:

Specific gravity = cell open-circuit voltage - 0.845

or

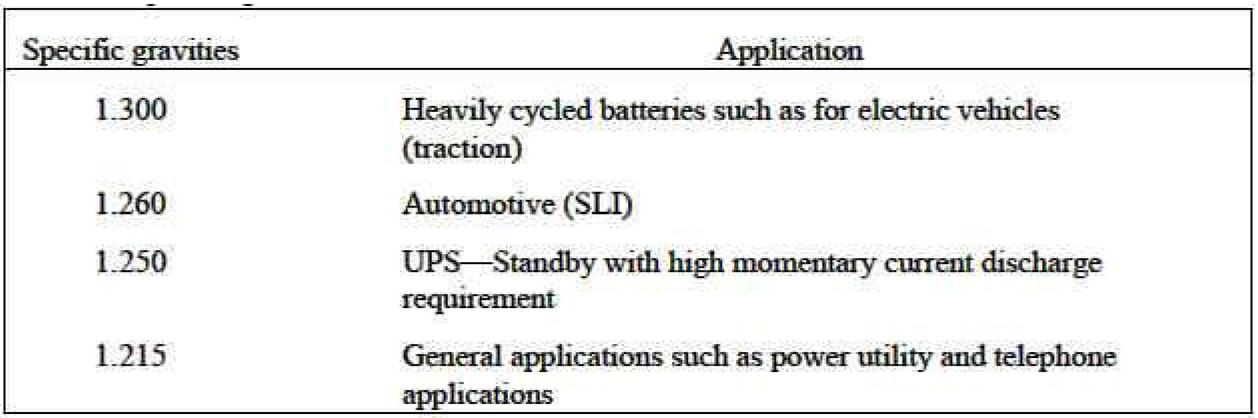
Cell open circuit voltage = specific gravity + 0.845.

The above equations permit electrical monitoring of approximate specific gravity on an occasional basis. As mentioned earlier, specific gravity measurements cannot be taken on sealed lead-acid batteries. Measurement of the cell open-circuit voltage has been used as an indicator of the state of charge of a sealed battery. More reliable methods for determining the state of charge of sealed batteries are under development.

The specific gravity decreases during the discharging of a battery to a value near that of pure water and it increases during a recharge. The battery is considered fully charged when specific gravity reaches it's highest possible value.

Specific gravity does, of course, vary with temperature and the quantity of electrolyte in a cell. When the electrolyte is near the low-level mark, the specific gravity is higher than nominal and drops as water is added to the cell to bring the electrolyte to the full level. The volume of electrolyte expands as temperature rises and contracts as temperature drops, therefore affecting the density or specific gravity reading. As the volume of electrolyte expands, the readings are lowered and, conversely, specific gravity increases with colder temperatures.

The specific gravity for a given battery is determined by the application it will be used in, taking into account operating temperature and battery life. Typical specific gravities for certain applications are shown in Table 1.



Specific gravities	Application
1.300	Heavily cycled batteries such as for electric vehicles (traction)
1.260	Automotive (SLI)
1.250	UPS—Standby with high momentary current discharge requirement
1.215	General applications such as power utility and telephone applications

Table 1

In the selection of a battery for a given application, some of the effects of high or low specific gravity to be considered are:

Higher Gravity	**Lower Gravity**
More capacity	Less capacity
Shorter life	Longer life
Less space required	More space required
Higher momentary discharge rates	Lower momentary discharge rates
Less adaptable to "floating: operation	More adaptable to "floating" operation
More standing loss	Less standing loss

A solution of higher specific gravity is heavier per unit volume than one of lower specific gravity. Therefore the more concentrated electrolyte created during charging sinks to the bottom of the battery jar creating a gradient in specific gravity. The gassing that occurs on overcharge serves as a "mixer" and makes the specific gravity uniform throughout the cell. To avoid erroneous readings, specific gravity measurements should only be taken after an equalizing charge and subsequent float charge for at least 72 hours.

7.3 Solar Battery Enclosures

Solar Battery Enclosures are designed to accommodate batteries utilized within solar poser systems, provide protection from accidental injury, and control the introduction of undesired environmental contaminants, such as water, dirt, dust and foliage, and allow the escape of potentially harmful fumes produced by the batteries. Solar battery enclosures applications within the United States may be regulated or specified by federal, state, or local authorities with respect to the National Electrical Manufacturers Association or NEMA standards. NEMA is an industry recognized organization that hosts the development, publication and recommendations for the safety standards, performance, different classes, corrosion resistance, ability to protect from submersion and rain.of electrical equipment. For countries that are members of International Electrotechnical Commission or IEC, designers are directed use their applicable standards for classifying and specifying the requirements and protection ratings required for traffic control and other utility enclosures.

Solar battery enclosures are often fabricated from rigid polymers (plastics), ferrous and non-ferrous metals, natural or chemically processed wood. Regional or local climate will affect the desired specifications requirements.

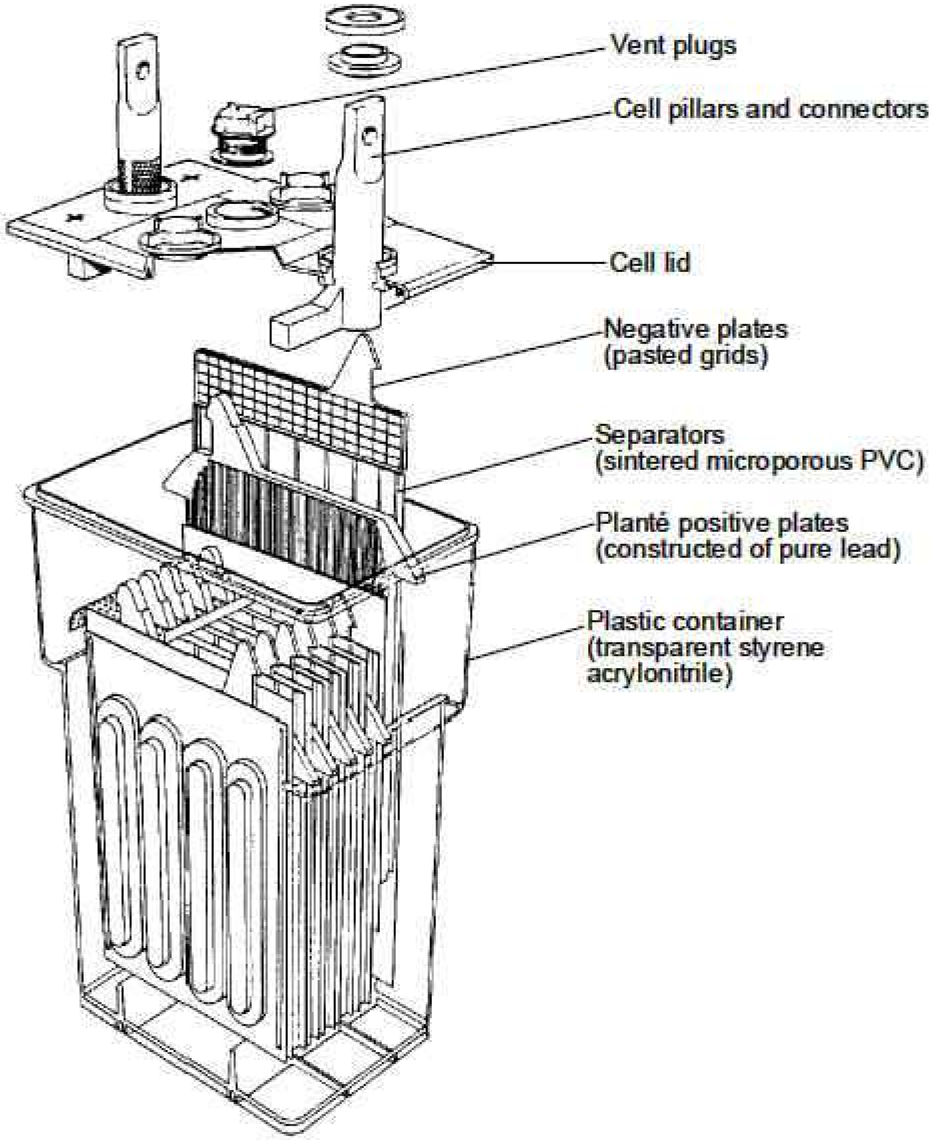
When local or state regulations are not available or specified for a solar battery enclosure, NEMA or IEC enclosures specifications should be followed.

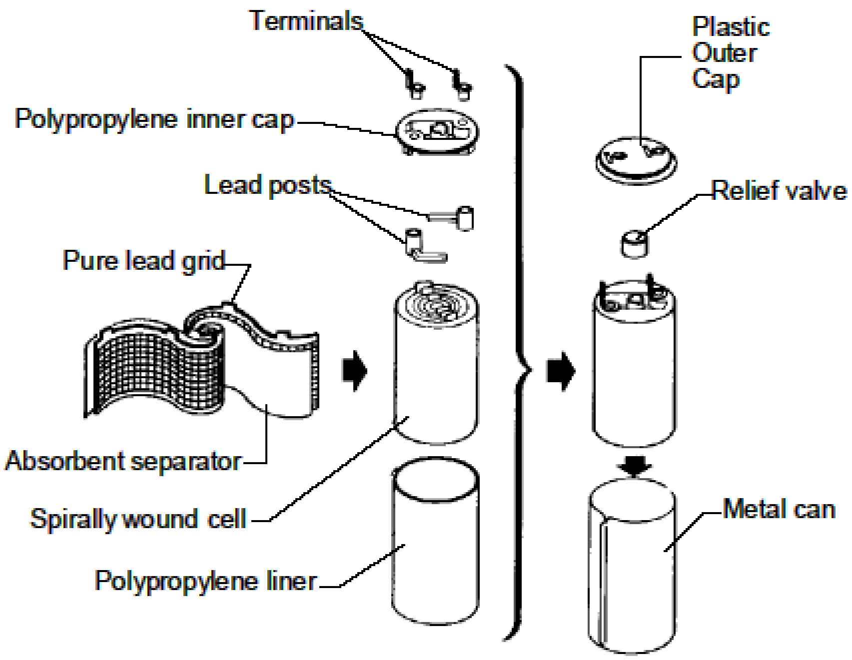

Courtesy Bison Profab


Courtesy Bison Profab

7.4 Stationary Battery

Stationary batteries come in a wide variety of designs for different applications. They are used for applications where power is necessary only on a standby or emergency basis. Stationary batteries are infrequently discharged. Stationary batteries remain on a continuous float charge so that they can be used on demand. The largest types of stationary batteries are those used for electrical load leveling. Load-leveling batteries store electrical energy for times of peak power demand and are taken off-line during times of low power demand. Stationary batteries are also used for backup emergency power, telecommunications equipment, and uninterruptible power supplies. Stationary batteries are manufactured in a variety of plate designs. An example of a stationary battery used for backup power is shown below.





Typical Cylindrical Sealed Lead Acid Battery

7.5 Traction Battery

Traction batteries are used to provide motive power for electric or hybrid vehicles. The major emphasis on traction battery design is the necessity of a high capacity to weight and volume ratio, since the vehicle must also carry its power source. Traction batteries are frequently deep cycled and require a fast charging rate for use usually within 24 hours. Typical applications are motive power for forklifts and electric carts. Traction batteries are usually of the tubular plate design, which performs more favorably during deep cycle operation.