Lead-Acid Battery Sulfation

lead sulfate - The insoluble lead salt or sulfuric acid, PbSO, that forms in lead-acid batteries

Sulfation is a buildup of lead sulfate crystals and is the number one cause of early battery failure in lead-acid batteries. Sulfation occurs when a battery is deprived of a full charge, it builds up and remains on battery plates.

Sulfation and desulfation

Lead–acid batteries lose the ability to accept a charge when discharged for too long due to sulfation, the crystallization of lead sulfate. They generate electricity through a double sulfate chemical reaction. Lead and lead dioxide, the active materials on the battery's plates, react with sulfuric acid in the electrolyte to form lead sulfate. The lead sulfate first forms in a finely divided, amorphous state, and easily reverts to lead, lead dioxide and sulfuric acid when the battery recharges. As batteries cycle through numerous discharges and charges, some lead sulfate is not recombined into electrolyte and slowly converts to a stable crystalline form that no longer dissolves on recharging. Thus, not all the lead is returned to the battery plates, and the amount of usable active material necessary for electricity generation declines over time.

Sulfation occurs in lead–acid batteries when they are subjected to insufficient charging during normal operation. It impedes recharging; sulfate deposits ultimately expand, cracking the plates and destroying the battery. Eventually so much of the battery plate area is unable to supply current that the battery capacity is greatly reduced. In addition, the sulfate portion (of the lead sulfate) is not returned to the electrolyte as sulfuric acid. It is believed that large crystals physically block the electrolyte from entering the pores of the plates. Sulfation can be avoided if the battery is fully recharged immediately after a discharge cycle. A white coating on the plates may be visible (in batteries with clear cases, or after dismantling the battery). Batteries that are sulfated show a high internal resistance and can deliver only a small fraction of normal discharge current. Sulfation also affects the charging cycle, resulting in longer charging times, less efficient and incomplete charging, and higher battery temperatures.

SLI batteries (starting, lighting, ignition; i.e., car batteries) suffer most deterioration because vehicles normally stand unused for relatively long periods of time. Deep cycle and motive power batteries are subjected to regular controlled overcharging, eventually failing due to corrosion of the positive plate grids rather than sulfation.

There are no known, independently verified ways to reverse sulfation. There are commercial products claiming to achieve desulfation through various techniques (such as pulse charging), but there are no peer-reviewed publications verifying their claims. Sulfation prevention remains the best course of action, by periodically fully charging the lead-acid batteries.

Causes of battery sulfation:

1. Batteries sit too long between charges. As little as 24 hours in hot weather and several days in cooler weather.
2. Battery is stored without some type of energy input.
3. Charging of a battery to only 90% of capacity will allow sulfation of the battery using the 10% of battery chemistry not reactivated by not completing the charging cycle.
4. Low electrolyte level - battery plates exposed to air will immediately sulfate.
5. Incorrect charging levels and settings. Recommended charge algorithm is a 3-phase charge cycle (Bulk, Absorption & Float) and a charge rate equal to 10% of the C20 (20 hr AH rating) of the battery bank. See State of Charge & charging information.
6. A battery sitting for extended periods in a partial or discharged state is more likely to retain a build up of sulfation, which hardens and is more difficult to remove through equalizations.

In normal use, battery plates are getting sulfated all the time. When a battery is being discharged the lead active material on the plates will react with the sulfate from the electrolyte forming a lead sulfate on the plates. When there is no lead active material and or sulfate from the electrolyte remaining the battery then is completely discharged. After a battery reaches this state, it must be recharged. During recharge, the lead sulfate is reconverted into lead active material and the sulfate returned to the electrolyte.

When the sulfate is removed from the electrolyte the specific gravity is reduced and the reverse takes place when the sulfate is returned to the electrolyte. This is why the state of charge can be determined with the use of a hydrometer or refractometer.

If a battery is left in a discharged condition the lead sulfate will harden and have a high electrical resistance. This is what is normally called a sulfated battery. The lead sulfate may become so hard that normal recharging will not break it down. Most charging sources, engine alternators and battery chargers, are voltage regulated. Their charging current is controlled by the battery's state of charge. During charging, battery voltage rises until it meets the charger's regulated voltage, lowering the current output along the way.

When hard sulfate is present, the battery shows a false voltage, higher than it's true voltage, fooling the voltage regulator into thinking that the battery is fully charged. This causes the charger to prematurely lower it's current output, leaving the battery discharged. Charging at a higher than normal voltage and low current may be necessary to break down the hardened sulfate.

Hardened sulfate also forms in a battery that is constantly being cycled in the middle of its capacity range (somewhere between 80% charged and 80% discharged), and is never recharged to 100%. Over time, a portion of the plate's active materials turns into hard sulfate. If the battery is continually cycled in this manner, it will lose more and more of its capacity until it no longer has enough capacity to perform the task for which it was intended. An equalizing charge, applied routinely every three to four weeks, should prevent the sulfate from hardening.