What can be learned from visual inspections of stationary lead-acid batteries? Real world examples.

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Abstract
IEEE Std. 450™-2010[1] and IEEE Std. 1188™ – 2005[2] amended by IEEE Std. 1188a™ – 2014[3] and other battery related standards such as NERC PRC-005[4] require a visual inspection of the battery. What exactly does this mean?

This paper will describe a methodological approach to visual inspection that if followed will help the user spot potential problems. The procedure is liberally illustrated by photographs and descriptions of actual problems experienced by the authors and the causes and effects will be discussed.

Introduction
The authors call the visual inspection procedure detailed in this paper the "From the Top Down" procedure and the methodology is designed to make sure that nothing is missed. It also encompasses one's other senses that can be important in battery inspection, those of smell, feel, and hearing.

A key to battery inspection is knowing what should be there and what it should look like. Then, if one sees, experiences or senses something different, they would know what could be an issue. Also, having the ability to know what caused the anomaly is important.

Obviously, Vented Lead-Acid (VLA) batteries are easier to inspect than Valve-Regulated Lead-Acid (VRLA) batteries mainly because the containers are usually transparent and the internal structure and elements can be visually examined. The same is not true for VRLA batteries. Therefore any of the internal battery examinations detailed below would not be applicable to VRLA batteries. In addition, some VRLA batteries have the terminals on the front of the unit but when examining the terminals and inter-cell connectors use the same approach as for a top terminal battery. The pictures are mostly those of the authors and apologies are made for any others that have been inadvertently used without proper attribution. Where possible, manufacturer's names have been removed. Most, if not all, of the problems and defects shown, have been evident with all manufacturers.

Procedure
General
There is an old adage that "if you can see it, you can inspect it," so one of the most important pieces of test equipment in this case is a good flashlight with a non-conducting casing. A magnifying glass also helps. If you are to see all around the battery and underneath you will need an inspection mirror. Most of these are of the telescopic design with metal parts which are difficult to insulate. There is one, marketed by Grainger and others, that has a plastic handle and a metallic flexible shaft that is easy to insulate. Also arm yourself with a camera as you may need it to record any anomalies. Note. Make sure you have a customer's permission to have a have a camera on site and to take photographs.

The Battery Room/Space

This is not directly related to the battery itself but is a vital part of this procedure and this is where other than visual senses come in to play.

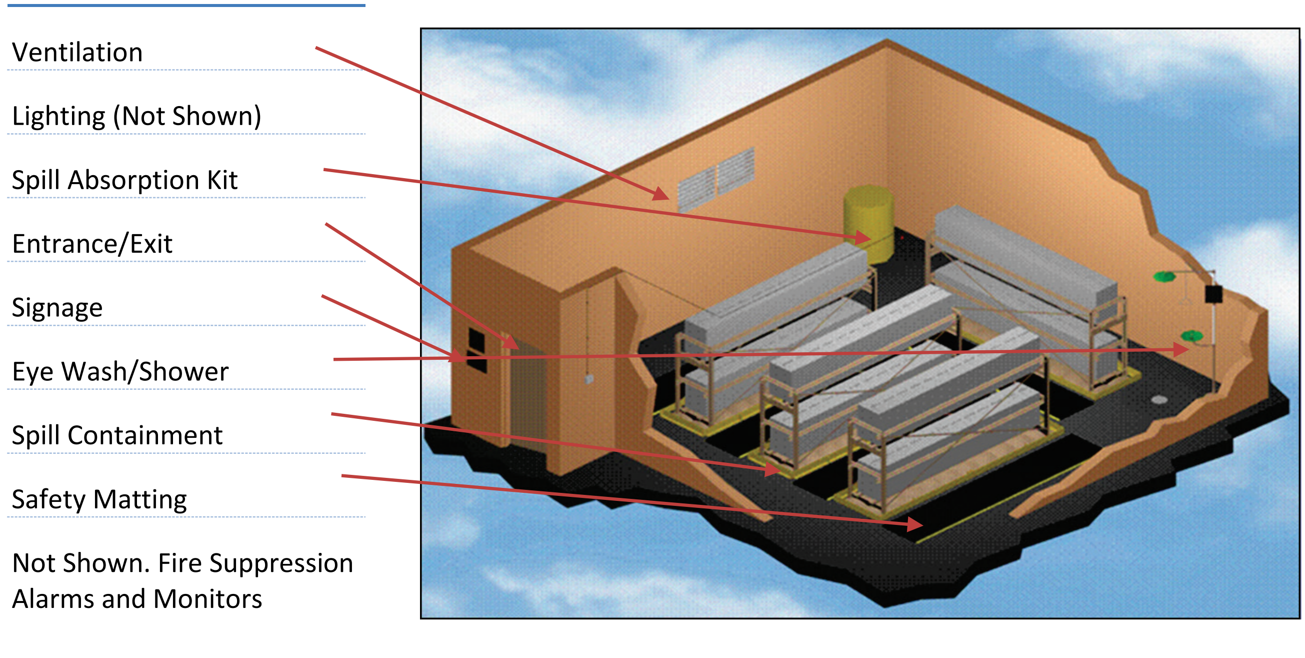

Figure 1. Typical battery room

As you enter the room containing the battery look to see that all the required signage is in place. This includes warning and directional signs. Check that emergency lightning is functioning. Examples are shown in Figure 2.

Figure 2. Some warning signs.

Smell

On entering the battery room/space, determine if there are unusual smells, especially a rotten egg smell. This is an indication of the presence of hydrogen sulfide gas which is highly corrosive to copper, silver and aluminum as low as 300 parts-per-million (ppm) concentration. It is also irritating to the eyes, skin and respiratory tract causing headache, dizziness and nausea. In higher concentrations of greater than 700 ppm it can be fatal. If you smell this odor, immediately exit the battery room and and notify emergency personnel. The cause of the problem is gas being released by the battery caused by overcharging or the battery being in thermal runaway. It is important to remove the battery from the charging source as soon as possible.

Other unusual odors could be from a hot/burning transformer or electronics, hot PVC or other plastics or an acidic smell. It is important to find the source of any of these smells.

Listen

Are there any unusual sounds? These could be a noisy transformer, choke, cooling or ventilation fans, a hissing sound of battery gassing or an audible alarm. Once again determine the source and take appropriate action. Silence is not always good as it could indicate that a charger, UPS, or Heating, Ventilation and Air-Conditioning (HVAC) may not be functioning properly.

Feel and Touch

Feel battery associated cabling to see if there is any unusual heating that could indicate loose connections of a higher than rated current being handled. Do this in a safe manner and use a thermal scanner on all live parts. Are there any temperature issues or gradients? Is cold or hot air blowing on the battery? Could direct sunlight be falling on the battery?

Visual Inspection

Battery Room/Space

The battery space should be free from clutter and not look like a storage room. It is important to ensure that nothing impedes access to the battery or egress from the room. Make sure that the location of battery and power disconnects are known and labeled. Also, note the location of a phone that can be used in case of an emergency and know the number to call.

Any battery visual inspection should include a check of the battery related ancillary equipment. This equipment is determined by the type of battery and the requirements of the local Authority Having Jurisdiction (AHJ).

- Is the exit clear and unobstructed?
- Is there the proper type of fire extinguisher present with the inspection tag up-to-date?
- Is there an eyewash station/drenching shower present and is the inspection tag up-to-date?
- Is the ventilation fan functioning?
- Is there a hydrogen detector present, is it in calibration and is it compromised in any way? Examples of compromise would be a wrong placement or ceiling tiles being removed.
- Is there a spill absorption and clean up kit in the location?
- Is there adequate Personnel Protective Equipment (PPE) available?
- Is there adequate and proper lighting which is installed properly and not directly above the battery?

The Battery Rack/Cabinet

Check the integrity of the battery rack or cabinet looking to see if it is properly secured and grounded. Look for any signs of corrosion or loose structural connections. Tighten if necessary. For a battery cabinet, make sure that ventilation holes are not blocked and that ventilation fans are operating correctly.

The Battery Itself. "From the Top Down."

During this procedure have a notebook or recording device and a camera handy to note or record any anomalies. Obviously it is easier to inspect the battery if it is on an open rack. A cabinetized battery will be harder to inspect and the battery may have to be segmented into sections of less than 50 volts for safety reasons. You may also have to employ the inspection mirror and flashlight. The same segmentation may apply to an open rack battery if the take-off terminals are at the same end and it is possible to accidently reach across them.

Start by standing at one end of the battery and look along the terminals to see if there is any post distortion or growth. Then start at the positive end of the string which should be labeled "number one" and walk along the battery and examine each cell or unit cover noting the condition of the flame arrestors or vent caps. Are any missing or broken? Are there any cracks, especially emanating from the positive posts or raised posts? Cover cracks or raised posts could be an indication of positive plate growth or a manufacturing defect. (See below for battery plate inspection.) At the same time, record the battery date code, serial numbers and any other pertinent information that is visible on the battery cover or front. See Figures 3 and 4 for examples of raised post and cover cracks.

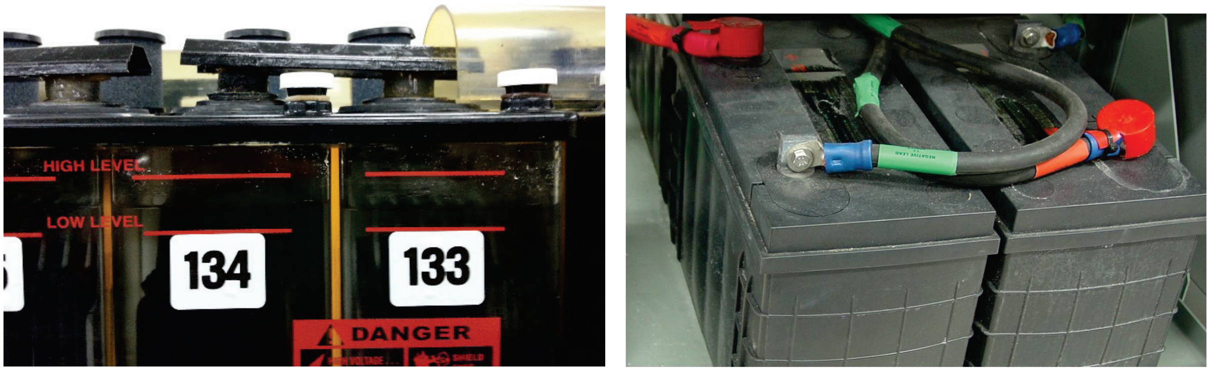

Figure 3. Raised Positive Posts

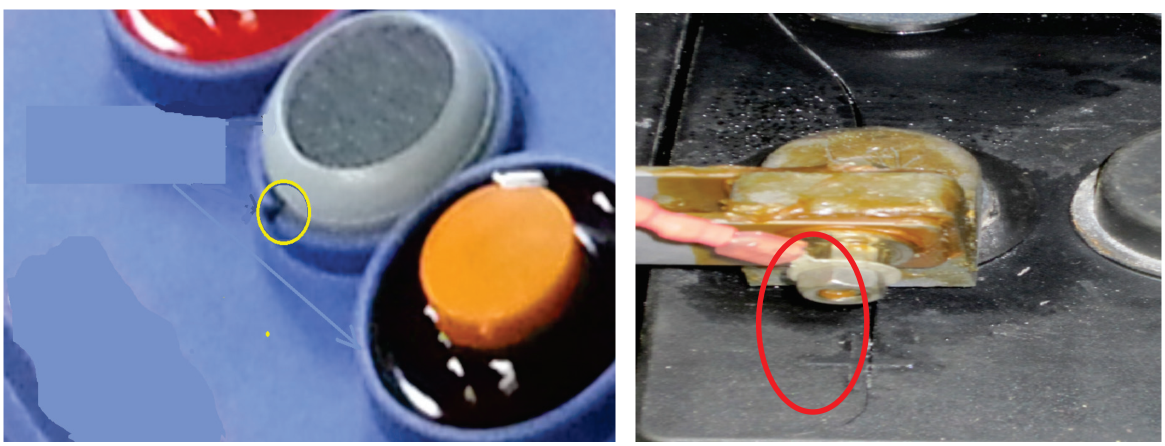

Figure 4. Container Cover Cracks.

Next check if there are any signs of venting or seepage from around the posts, vent caps or cover. This may not be apparent as a liquid but may be a whitish deposit. Unusual venting could be a sign of over-charging or defective post-seals or pressure relief valves. A clear liquid on the top of a VLA battery, especially around the flame arrestors or withdrawal tubes may just be the result of sloppy watering. Use pH test strips to see if it is indeed electrolyte. See Figure 5.

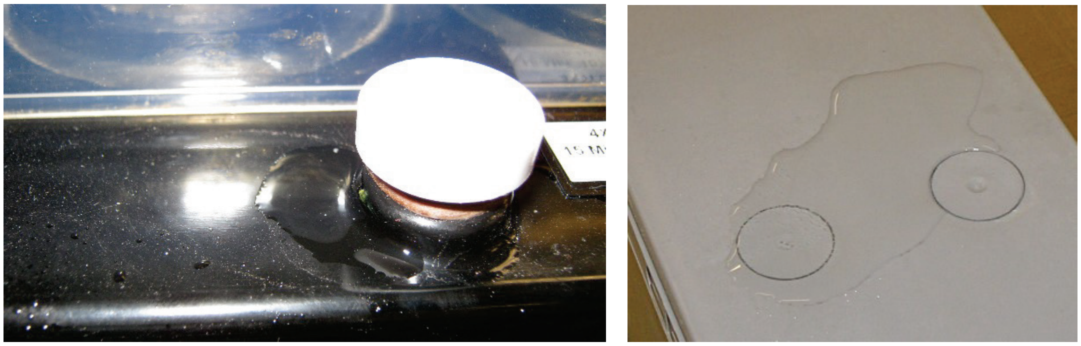

Figure 5. Electrolyte or Water on Top of Battery Container.

Inspect the posts and inter cell/unit connectors for any signs of corrosion, discoloring, or heating. If so, the cause can be further investigated, Battery take-offs using mechanical lugs are subject to loosening. If crimp lugs have inspection holes, check the bare cable for any signs of heating or corrosion. Check that there is sufficient strain relief on the cables so as not to put pressure on the post.

Moving down the battery, inspect the cell/unit containers for signs of crazing, cracking, seepage or leakage. Use an inspection mirror if necessary to check the bottom of each cell/unit particularly around the rack rails. See Figure 6. With VRLA batteries, look for any indication of unusual container swelling. VRLA battery containers may exhibit slight swelling which may be a natural occurrence but look to see if any units in the string show more pronounced swelling than other units in the string. This could be an indication of thermal problem, a shorted cell, a faulty pressure relief valve (PRV) or excessive positive plate growth. Any unusual swelling should immediately be further investigated. See Figure 7.

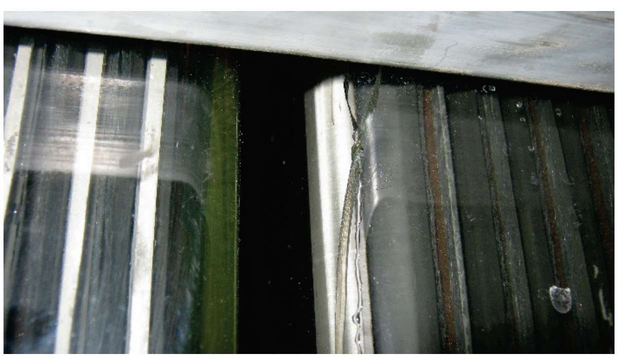

Figure 6. Cracked Cell

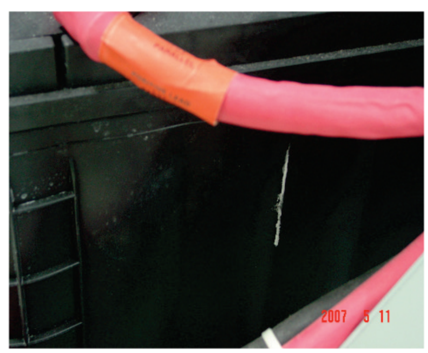

Figure 7. Swollen VRLA with electrolyte seepage.

Electrolyte Level

For VLA batteries check that the electrolyte level is above the “low” level. The ideal level is about two thirds between the low and high marks. Any electrolyte that is below the low level should immediately be brought above the low level by adding deionized or distilled water. Any unusual loss of water in a battery should be further investigated It could be caused by the battery being over charged. In a lead-antimony battery this may be normal toward the end of battery life. See Figure 8.

Figure 8. Low electrolyte levels

Battery Plates – Sulfation

Using a flashlight check the battery plates. The positive plates should be a nice dark chocolate brown and the negative plates should be a greyish color. See Figure 9. Look for any bright lead sulfate crystals on the positive plates. If these are evident it is a sign that the battery is being undercharged and that the cells active material is reduced. Minor or soft sulfation may be reversed by boost charging the battery but more serious or hard sulfation is usually not reversible. See Figure 10.

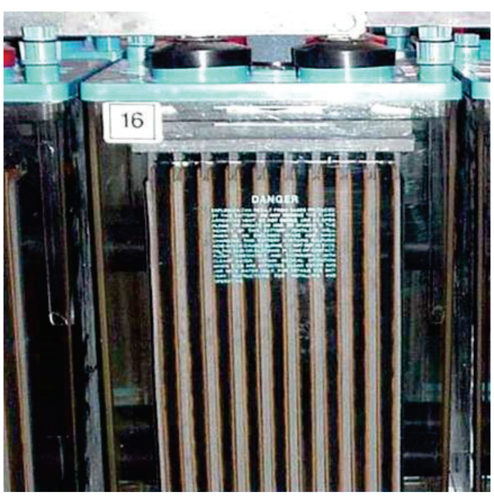

Figure 9. What plates should look like.

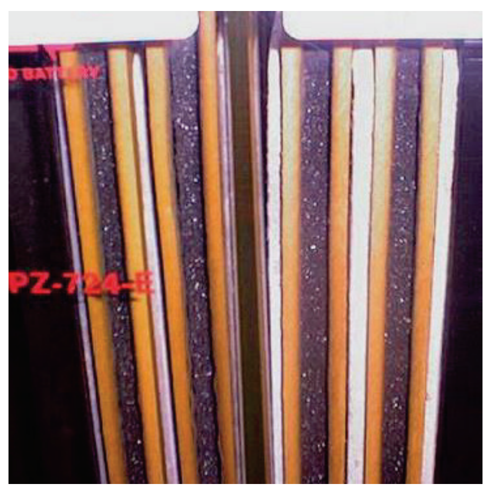

Figure 10. Sulfated plates.

Positive Plate Growth

In a lead-calcium battery, plate growth is a natural phenomenon. However it should be a gradual growth and not too apparent in a newer battery. Look for excessive positive plate growth as this is a problem and causes loss of capacity of the battery and eventually causes shorting between the positive and negative plates. See Figure 11. In particular look for cracking of the positive plates. See Figure 12.

Figure 11. Extreme Positive plate growth.

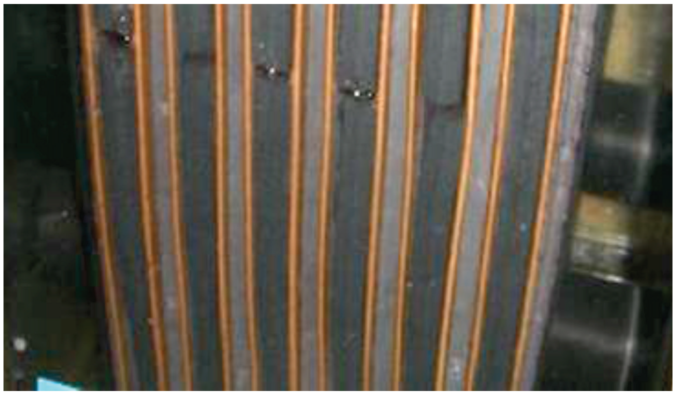

Figure 12. Cracked positive plates.

Hydration

Look to see if there is a milky white discoloration on the transparent container. See Figure 13. This would be an indication of hydration because of the presence of lead hydrate. This is caused by the fact that the battery has been fairly deeply discharged and not recharged in a timely manner. The lead hydrate deposits on the plates and migrates through the separators causing numerous short circuits. This process is irreversible and the battery is destroyed.

Figure 13. Hydrated battery cell.

Copper Contamination

Look for any pinkish colored discoloration on the negative strap and plates. See Figure 14. This is known as copper contamination and is caused by dissolved copper being electroplated onto the negative strap and plates because copper, usually from the copper inserts in the battery posts, somehow gets exposed to the electrolyte and dissolves. This condition will lead to loss of battery capacity and eventual failure. The battery should be replaced as soon as possible.

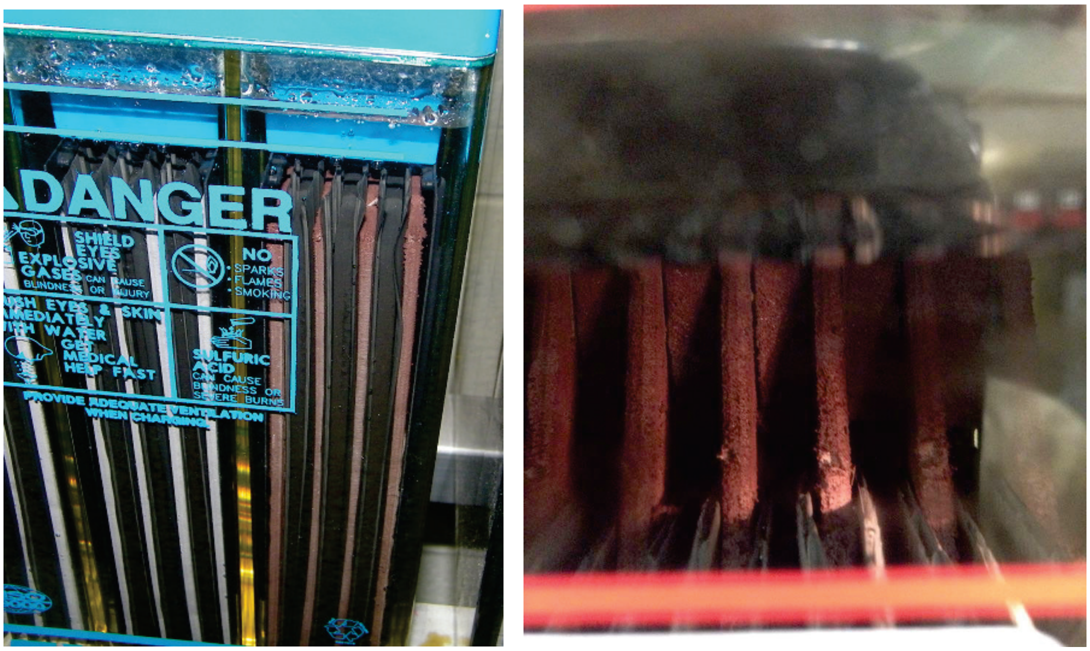

Figure 14. Examples of copper contamination

Oil in the Electrolyte

Look for any brownish discoloration near the top of the electrolyte or on the inside walls of the container. It has been known for excessive oil in the separator material to leach out into the electrolyte. This can usually be confirmed by removing the flame arrestor where it will be evident on the tube. Although this doesn't look good, it is mainly cosmetic and does not normally affect the operation of the battery. See Figure 15.

Figure 15. Oil in Electrolyte

Plate Bowing

Examine the plates and see if there is any bowing or curvature of the plates. This can be caused in the manufacturing process and if not too excessive it is not detrimental to the performance of the battery. See Figure 16. It can also be caused by the improper insulated plate support spacers being used in the manufacture of the battery. See Figure 17. Once again it may not be detrimental but the authors advise that the battery be replaced to avoid future failure.

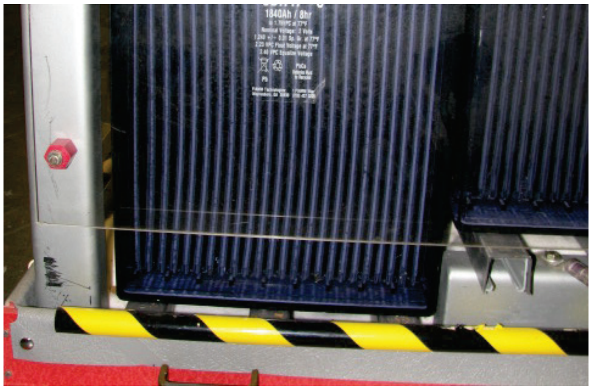

Figure 16. Bowed Plates.

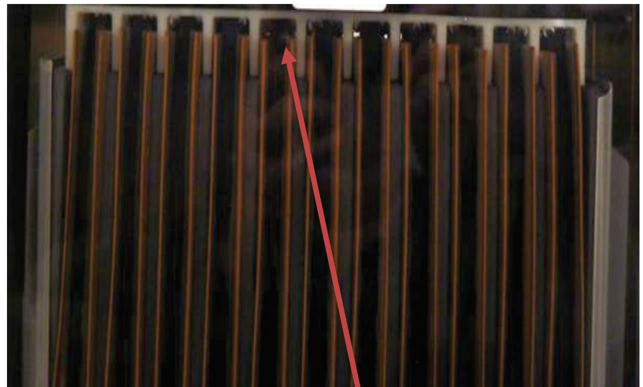

Figure 17. Incorrect insulated plate supports.

Shed Active Material and Foreign Matter

Examine the battery, particularly the bottom for signs of shed active material which may eventually cause a short between plates. See Figure 18. Also, look for foreign or unusual material within the battery. See Figure 19. If the shed material or foreign objects do not appear to be a danger of causing an internal short within the cell/unit then the battery will probably function properly. The presence of a short can be confirmed by using a voltmeter. If possible, take a photograph of the foreign material and send to the manufacturer for comment.

Figure 18. Shed active material.

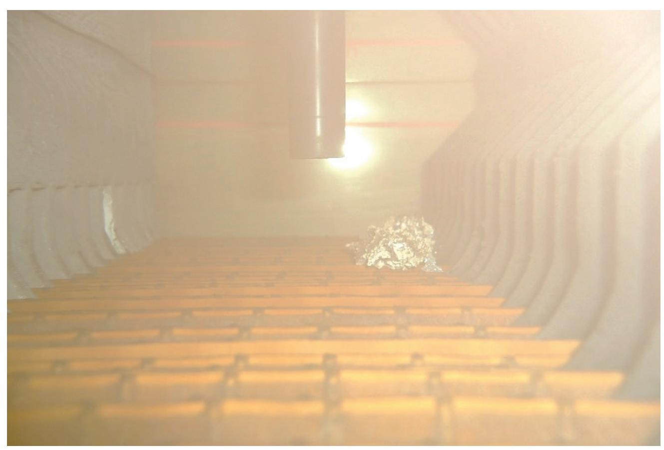

Figure 19. Foreign material on top of battery plates.

Cloudy Container Material.

This phenomenon is usually unique to PVC containers and although it looks bad it is not really a problem. See Figure 20.

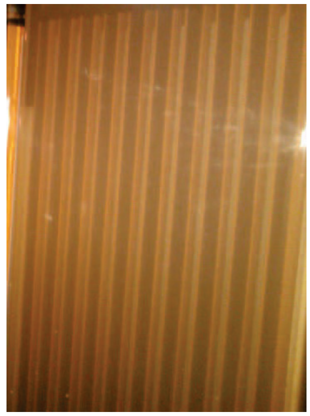

Figure 20. Discolored container.

Dendrites

Dendritic growth. This is the formation of small crystals or treelike structures around the electrodes in what should be an aqueous solution. See Figure 21. Initially these dendrites may cause an increase in self-discharge. Ultimately, dendrites can pierce the separator, causing a short circuit.

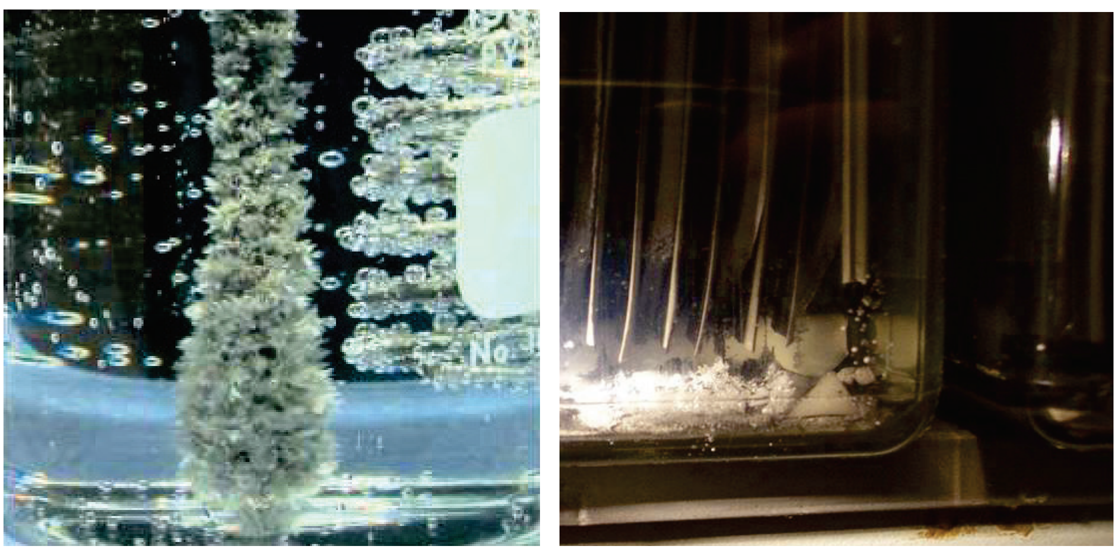

Figure 21. Example of dendrites.

Separator Tears

Look for tears or other abnormalities in the separator material. See Figure 22. This is usually a manufacturing defect and could indicate a problem or potential problem. The worst case would be a short circuit cell.

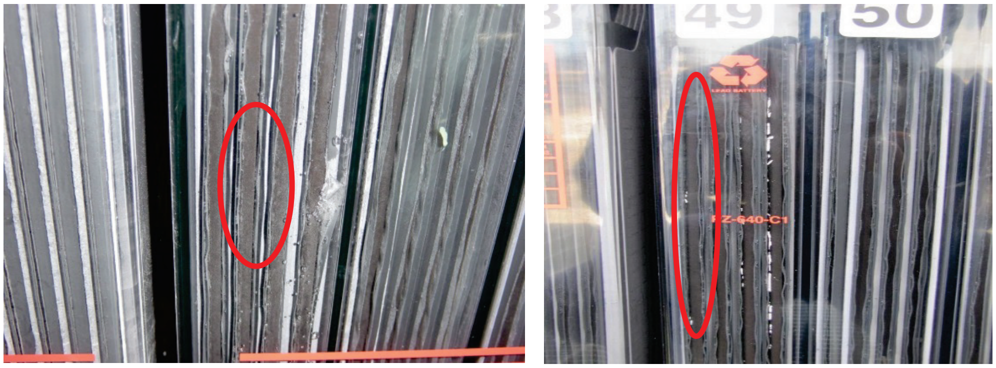

Figure 22. Examples of separator tears.

Spill Containment

Look closely at the spill containment if used, to see if there are any signs of electrolyte stains. If there are any stains try to find the source. It could be because of careless electrolyte withdrawal but it could indicate a leak. See Figure 23. Also, check to see if any of the pillows have been turned as this may indicate a hidden problem.

Figure 23. Spill containment system.

Figure 24. Floor stain.

The floor

Examine the floor all around the battery rack or the bottom of the battery cabinet to see if there are any signs of battery leakage. See Figure 24. If necessary, investigate further.

References

1. IEEE Std. 450™ - 2010. IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.
2. IEEE Std. 1188™ – 2005. IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead- Acid (VRLA) Batteries for Stationary Applications.
3. IEEE Std. 1188a™ – 2014. IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications Amendment 1: Updated VRLA Maintenance Considerations.

   All IEEE Standards can be obtained from the Institute of Electrical and Electronics Engineers, Inc., 3 Park Avenue, New York, NY 10016-5997, USA.
4. Standard PRC-005-6 – Protection System, Automatic Reclosing, and Sudden Pressure Relaying Maintenance. Copyright 2016 North American Electric Reliability Corporation. All rights reserved. Washington Office, 1325 G Street, NW Suite 600, Washington, DC 20005| 202-400-3000.