BATTERY EXPLOSION OR BATTERY RUPTURE

HOW TO RECOGNIZE THE DIFFERENCE

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Abstract

This paper is going to discuss the unusual incident of when a VLA (vented lead acid) battery cell physically self-destructs during normal operating conditions, with what appears to be no outside influence. Some might call this a cell explosion and some might call it a cell rupture. To the untrained observer the results may look the same, but they are not. The resultant "looks" of the cell are subtle but distinctly different, and easily identifiable. This paper is going to show you how to correctly identify what occurred so that you can take the proper corrective actions in order to prevent a recurrence of the incident.

In order to provide something that will enable you to visualize what we are going to explain, we will use a three-year-old eight-hundred Ah, sixty cell string, in an EP rack, that has a spill containment system, and a battery monitor as our battery, and will list observations of what you would observe in one of these events. We then include multiple pictures that clearly show the differences between an explosion and a rupture so that you can see how easy it is to recognize the differences.

Introduction

A battery jar that physically self destructs during normal float operation without any apparent external assistance does not occur often but it does happen, and when it does, the result is often misidentified because of a lack of understanding of the resultant physical differences between a cell that explodes and one that ruptures. As all reading this surely understand, unless the root cause is correctly identified, it is impossible to prevent a recurrence of the failure.

Battery observations with explanations

An employee discovers that one of the cells in the battery string has failed open and free electrolyte is on the floor. Even though the battery has a spill containment system under it, a substantial amount of electrolyte had gotten past that barrier and out onto the floor. That individual reacts properly and immediately places temporary spill containment barriers around the spill and covers the electrolyte with absorbent material from the spill containment kit in the room in order to prevent a spread of the electrolyte. No environmental issues were created. They then notify their supervisor of the issue, and they in turn notify you because you are the individual responsible for investigating this type of event. You go to the site and you observe, photograph, and consider the following.

1. There is an area of the floor next to the battery rack and spill containment system where the materials from the emergency spill kit were applied to contain and neutralize the electrolyte.
2. There is a section of plastic, approximately 8" by 6", missing from the upper portion of the front of the cell, and that piece of plastic is laying on the floor a few feet away from the cell. That

piece of plastic is in the area where the electrolyte had been contained and the neutralizing/absorbent material applied.

3. The plastic retainer webs on both posts have marks which appear to be singe marks.
4. Both sides of the cell have sections of the plastic missing from just below the cover.
5. The front external post seal slide is slightly elevated.
6. The recombination vent body is laying on the floor. The "insides" of the recombiner are missing.
7. Laying on the top of the plates is a piece of red plastic which is determined to be the bottom section of the recombination vent.
8. Also laying on the top of the plates is a piece of clear plastic. This is determined to be from the side of the jar.
9. Laying on the cover is another red piece of plastic which is later determined to be a part from the inside of the recombiner.
10. The cell contains electrolyte, and the level is slightly below the area where the plastic opened in the front of the cell. This level is about two thirds of the way up from the bottom.
11. The battery monitor does not show anything unusual, and the cell that is damaged still shows an acceptable voltage.
12. Your initial thought is that the pressure relief valve in the recombiner failed and the resultant increase in internal pressure caused the cell to rupture.

Because this damaged and physically open cell could be considered a hazard, you have it immediately removed and disposed of.

With just what you observed you can determine that the cell did not rupture, but rather it exploded. An explosion always occurs in the headspace and is observed by most of the damage in a VLA cell occurring in that upper area of the cell, usually with most of the lower portion of the jar remaining intact, and there will be electrolyte remaining in the cell. An explosion always exhibits a violent action has occurred, with parts and pieces separated and scattered. A rupture exhibits a gradually occurring action, the electrolyte is usually gone from the cell, and the side or sides of the jar are either still connected to the cover, or in the immediate vicinity (right beside) the jar or rack.

To explain the above conclusion that this was not a rupture, I offer the following explanations for each of the observations listed above.

1. That the electrolyte was beyond the spill containment demonstrates that there was a propellant (force) behind the electrolyte to move it out there. If the cell had ruptured the electrolyte would have flowed downward and been contained in the spill containment system.
2. That the section of plastic from the front of the jar was located a few feet away from the battery demonstrates that there was energy (force) behind the plastic to propel it a distance from the jar. If this had been a rupture, and if the plastic separated from the jar, it would have fallen beside the cell or rack.
3. The marks that appear to be singe marks on the webbed plastic post retainers demonstrates that there was an arc or a flame in the head space that scorched that material.
4. That both of the sides have plastic missing confirms an explosion. This is a violent action.
5. That a post seal is elevated indicates that the cell cover was forced upward by the sudden expansion from the explosion. Figure 8 shows how the external post identifiers can be elevated

due to the cover being forced upward. Figure 5 shows the cover separated upward from the sides.

6. The recombiner being located on the floor with its internals missing demonstrates that there was a violent rapid event, which blew the recombiner out of the cell, and basically ripped it apart. An explosion.
7. That there is a red plastic piece laying on the plates which you identified as the base of the recombiner by studying the other recombiners, indicates that this was a violent action.
8. The clear piece of plastic that is laying on top of the plates is a missing piece from the right-hand side of the jar. It is normal during an explosion for pieces of the sides of the jar will be seperated from the plastic below it, and go out, hit the side of the cell right next to it, and bounce back into the exploded cell. Figures 5 and 8 show this.
9. The piece of plastic on the cover, based upon its color is suspected to be from the inside of the recombiner found on the floor. After a later performed dissection of a complete recombiner, it is verified that it is an internal component of the recombiner. This confirms that the recombiner was violently ejected from the cell.
10. That there is electrolyte in the cell supports the conclusion that this was an explosion as it is normal for electrolyte to remain in the cell. Normally just below the lowest missing part of the cell walls. Figures 4, 5, 7, & 8 show this.
11. That the monitor does not display anything unusual confirms that the conduction path in the cell is intact, and the battery is being charged. This is no different than a cell whose electrolyte level has been allowed to go lower than recommended.
12. The initial thought that the failure of the pressure relief valve would allow the head space pressure to reach such a high pressure that the cell would self-destruct turns out to be not possible. I do not know of any recombiner manufacturer's valve being able to do that. If they do fail, they will fail open, they do not fail closed.

As a point of information for those that are not familiar with recombination vents, almost all recombiner manufacturers presently offer models that have pressure relief valves inside. A pressure relief valve allows the recombiner to hold the hydrogen and oxygen inside the unit a little longer than if no valve is present, which allows for more time for the gasses to interact with the catalyst material than units that do not have these. This allows them to be advertised as "more efficient". Every manufacturer can build their units with or without these valves, and depending upon their customers instructions they build them as desired. No matter if they have or do not have a pressure relief valve, they provide a substantial maintenance benefit both through labor savings, and a safety improvement. This is acknowledged in the 2022 revision to the IEEE1635/ASHRAE21 document[1].

It does need to be understood that by forcing those gasses to remain in the head space longer, instead of letting them continue upward and out of the cell, a gas trap is created in the head space. This gas trap does not occur with standard vents, or with recombiners that do not have pressure relief valves in them as the gasses just naturally flow upward.

What does it take for a cell to explode?

For a cell to explode there are two requirements. The first requirement is a combustible mixture of hydrogen and oxygen in the headspace of the cell. The headspace is defined as all the area above the electrolyte level. The second requirement is an ignition source, which must occur within that headspace when the gas mixture is combustible. If both requirements are not present at the same time, it is impossible for an explosion to occur.

You can place a lit match inside the headspace of a cell that does not have a combustible mixture and nothing will happen, because there is no "fuel" to burn. Also, if the vent is open, and there is a combustible mixture, the expanding air will just come up through the open vent and usually no damage will be done to the cell. Motive power battery service technicians that are required to burn lead straps when replacing a cell in a tray, often just place their torch over the open vent and let the gasses ignite and exit the cell. That allows them to use their open flame within inches of the open vent without worrying about an unexpected pop extinguishing their torch during the lead burning process, and it saves time.

There are only two internally generated means that I am aware of that can create an ignition source within the head space of a cell. The first is an arc created by an opening of a metallic conduction path under a load when there is a combustible gas present. This occurs when a load is applied to the cell that exceeds the capability of the metal path (think internal post or internal plate to lug connections) melts apart. The second ignition source is ESD (electrostatic discharge).

ESD that impacts a battery can be generated by multiple sources. One source is from a plastic sheet that is used to cover the battery for whatever reason, and then when it is being removed upon completion of the task, it is pulled across the battery during removal. Plastic being dragged across plastic can create static. Also, think about someone that has static electricity on them, coming into contact with a battery cell, that has a hydrogen trap, and their static gets into the cell. The IEEE 450[2], 1106[3], & 1188[4] all recommend neutralizing static buildup just prior to working on a battery in order to minimize this risk. The instruction to neutralize static before working on a battery was listed in the IEEE-450-1987[5], so the danger of an ESD is not a new awakening as it has been understood and warned about for over 35 years now.

The recombiners in this hypothetic battery are the normal standard height units. There are different height units. If the battery had been covered with a plastic drop cloth, when it was removed there would be plenty of opportunities for plastic to be pulled across plastic. This information is being provided so that you will be aware of this potential static creating material. Lower profile units can reduce that risk, but will not eliminate it. If a battery needs to be covered for whatever reason, using a non-conductive material to do that is recommended. If a plastic cover must be used, I recommend first covering the battery with the non-conductive material and then the plastic sheets. It also should be understood that a shorter recombiner will create less obstruction during the performance of normal maintenance activities.

What caused this cell to explode?

The most likely cause of the ignition source is ESD. Being able to prove where the ESD came from is beyond the scope of this document. The intent of this documents is to show you how to identify the differences between the two types of failure.

What can cause a cell to rupture?

With cells that rupture, there will typically be one side that opens as the result of a gradual pressure being applied in one section of the cell from the inside of the cell, and the free electrolyte will run down the side of the jar. It will not be ejected some distance away. Normally the side of the jar will open at the bottom and the top will remain attached to the cover. There are however times when the side will separate from the cover, but the plastic will fall to the floor right beside the cell or rack. This excess pressure on the jar can only occur when something that occurs inside of the jar causes the side of the jar to be forced outward enough that the plastic cracks and then separates from the rest of the jar. The only two reasons that I am familiar with are the electrolyte freezing which then expands when frozen, which pushes the side of the jar away (Figure 1), and the second one is that the positive plates grow to such a point that they extend to the point where they push outward to the edge of the jar and force the side of the jar to separate from the rest of the cell.

What cannot cause a cell to rupture?

The failure of a pressure relief valve in a recombiner will not cause a cell to rupture. The reasons that a majority of the recombination vent manufacturers use pressure relief valves is that they provide a slight efficiency increase over the previous designs, which did not have those valves. I mention this fact because as you saw, item 13 considered that the cause of the incident was an excess internal pressure caused by failure of the pressure relief in that recombiner. I included this thought because someone might misdiagnose an explosion as a rupture and assign an incorrect cause to the event.

Recombination vents are designed so that if a pressure relief valve fails, it will fail open. They do not fail closed. There probably have been hundreds of thousands of recombination vents installed around the world over the past few decades and I have yet to learn of a single failure of a jar that was caused by a recombination vent valve failure. This is not to insinuate that a recombiner cannot fail, but it is to state that its failure cannot cause a pressure that will rupture a cell.

Show and tell pictures

The following pictures will show cells that ruptured and then cells that exploded. As you will see there is a decided difference in how the cells look, and the differences are easily identified.

Figure 1. Ruptured cell caused by electrolyte freezing, bottom pushed out, side still connected to the cover, no violence displayed, parts pretty much intact but separated

Figure 2. Ruptured cell, cause unknown, side is still attached to the cover, no parts ejected, no violence displayed, parts intact but separated

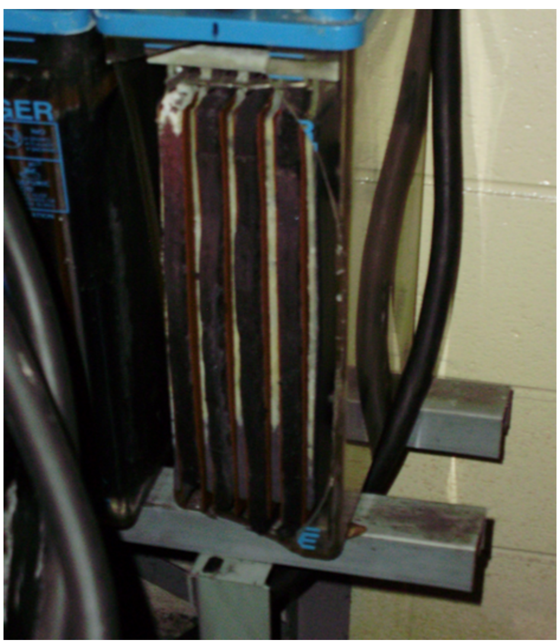

Figure 3. Ruptured cell, cause unknown, most of front missing, but uppermost portion is still attached to the cover, not caused by an explosion, no violence exhibited

Figure 4. Explosion, damage propagated across the 3 cells, electrolyte still in these cells, low levels in other cells, part of cover and center vent missing, explosion originated in head space, damage limited to upper portion of cells, notice violence of event

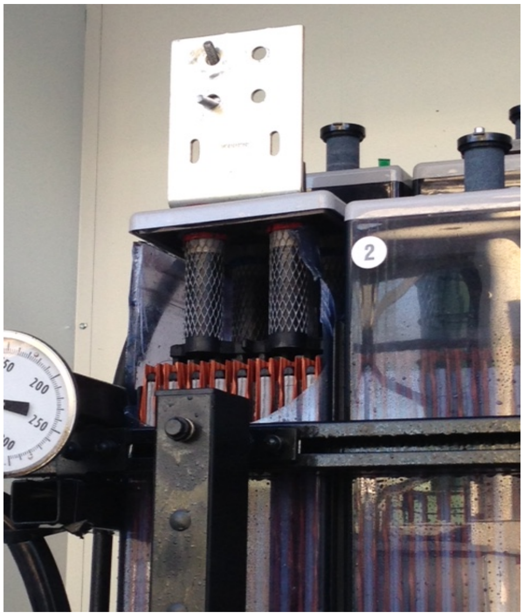

Figure 5. Explosion, upper front of jar missing, cover separated from the sides, damage is limited to the upper area of the jar, section of the side of the jar visible above side rail, electrolyte still in jar, violent event

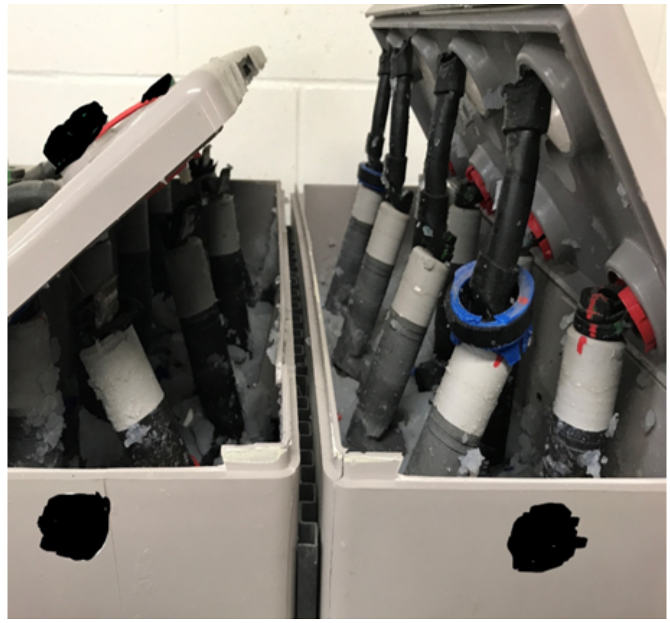

Figure 6. Explosion in VRLA string that occurred during cleaning of the covers with an item that created static, not VLA but it does show how dangerous static can be, and how violent an explosion in the head space of any type cell can be, ESD was the ignition source

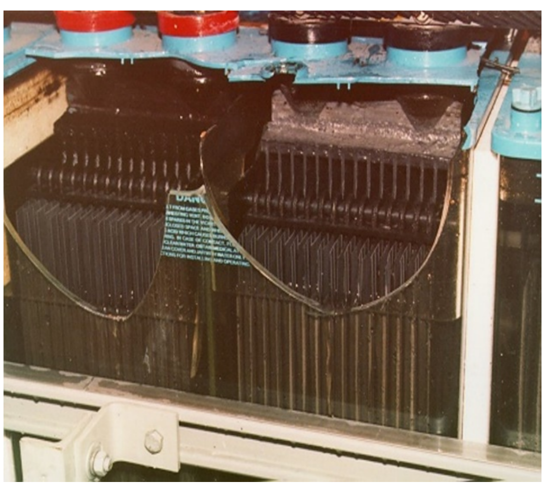

Figure 7. Explosion, cover and sides separated, pieces of side and cover missing, electrolyte still in cells, damage occurred in the upper portion of of the jars as occurs in all cells that explode, violent action

Figure 8. Explosion occurred during discharge test, nodular corrosion which is visible on the right rear positive post caused that post to open which created the arc that ignited the gas, as always with all cell explosions the damage is limited to the upper area of the cell, violent action

Figure 9. This positive post melted apart under load during first seconds of the unit trip. Notice metal splatter marks on bottom of this cover and side of jar. This cell DID NOT explode, because the mixture of gasses in the head space was not of the right combination that an ignition source could ignite it. The root cause failure investigation determined that nodular corrosion that had gone undetected during battery inspections was the cause of this battery failure. This battery had passed a recent discharge test, but because the discharge test was of a longer duration and lower current and did not include the inrush currents that would be required of the battery to support those instantaneous loads, this was not detected. If a modified performance test had been performed this would have been discovered during a planned outage instead of when the plant was operating. The generator required a rebuild, which as all involved in the utility industry understand, equals big $$$$$ repair costs, plus the lost revenue while the rebuild is being performed. Not a good day for the home team.

Figure 10. Lower portion of the positive post from the picture in Figure 12. Following the on-site portion of our root cause investigation, the cell that failed open, as well as other cells from the string that were identified as having advanced nodular corrosion issues, were replaced and those cells were sent to our facility for dissection. This picture was taken on one of the work benches. As can be seen the negative post and post seal is in a normal condition, and that the positive post acted like a fuse and simply melted apart. This incident occurred in Chile, and as an FYI, all the batteries and battery rooms at the four plants at this site, were spotless.

A common denominator in all the pictures of the cells that suffered from an explosion, is the violent tearing apart of the cell's sides away from the covers. All explosions occur in the head space above the electrolyte level, because that is where the gasses are that ignite. With exploded cells, another common denominator is that the damage, think plastic missing, is always from the upper section of the jar. You never see a section of the jar missing from the lowest parts of the jar from an explosion.

Ruptures are caused by an excessive pressure caused by pressure exerted from within the cell, typically by expansion of the elements within the cell. Ruptures can occur anywhere along the four sides of the jar, depending upon the cause of the pressure, but are usually observed with a pushing out of the wall/s near the bottom of the cell. Electrolyte from cells that rupture normally runs down the side of the jar, but with an explosion it is ejected away from the cell, as are some of the plastic pieces that separate from the jar. Typically, the sides of the jar during a rupture will still be connected to the cover, but those parts can be separated, and usually will fall beside the rack. They will not be blown away from the battery as there is no force being generated from within the headspace.

It does need to be understood that there are instances where nodular corrosion will cause cracks in the covers. These cracks will radiate away from the positive post area of the cover and can eventually reach the edge of the cover and transfer down the side of the jar itself, and create cracks in the jar, and then continue down the side of the jar until it reaches the electrolyte level, and electrolyte leaks out, but this would not be considered a rupture, but rather a leak. Any cracks in the covers indicate nodular corrosion, and that the positive posts are being attacked internally. This is not normally a field fixable issue.

Conclusion

I you just look at the picture of an incident, in most cases you can easily determine if the cell exploded or ruptured. If still in doubt, reach out to a subject matter expert that does not have a vested interest in your situation, to help you determine what occurred, and to help with forward thinking solutions if you desire.

Notes

I want to thank everyone that I reached out to either for pictures that showed either ruptured or exploded cells, or for their feedback on the pictures I provided, or their thoughts based upon their field experience in this industry with this subject, or for assistance in locating very old documentation that supports this paper. The majority of those that I reached out to either are presently (or were previously) involved in the hands-on maintenance and testing of stationary batteries.

Those that I reached out to are as follows. I am sure that I have overlooked some individuals that I spoke with, and I apologize to you but it is not intentional. Jose` Marrero, Curtis Ashton, Mike O'Brien, Bill Cantor, Scott Stone, Rob and Les Anderson, Mark Edwards, Dan McMenamin, George Pederson, Allen Byrne, Dennis Barber, Mike Cadieux, Tom Cantor, Kurt Uhlir, and William Sliter.

I also would like to inform everyone that I reached out to every battery manufacturer or vendor that provides recombination vents here in the US and asked if they knew of any cases, at any time in the recent or distant past where a recombiner failure caused a cell to rupture. Of all that responded not a single responder stated that they did. If anyone would like to discuss this issue in a more in-depth fashion, please feel free to contact me at pjd@batteryresearch.com and we can go from there.

References

1. IEEE Standard P1635™ - 2022 / ASHRAE Guideline 21 for (GPC21) IEEE/ASHRAE Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications
2. IEEE Std 450™-2020 IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications
3. IEEE 1106- 2005 IEEE Std 1106™-2015 IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented NickelCadmium Batteries for Stationary Applications
4. IEEE Std 1188™-2005 IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead- Acid (VRLA) Batteries for Stationary Applications
5. IEEE 450-1987 IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications