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Verifying Safe Levels Of Hydrogen Diffusion In Wet Aluminum Electrolytic Capacitors

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Aluminum electrolytic capacitors are widely used in the industry due to their relative high ratio of energy density to cost. In fact, they are used in such a wide variety of applications that many design engineers might overlook some aspects of the capacitor’s behavior based on its underlying technology.

For example, it is important for design engineers planning to use wet aluminum electrolytic capacitors to consider and mitigate the diffusion of hydrogen. This article looks at hydrogen diffusion, how to determine the resulting levels of hydrogen that a wet electrolytic capacitor will produce in an application and whether these levels are safe.

Safety in this case means below the thresholds that would lead to ignition or even detonation of the hydrogen. This discussion is mainly relevant to applications in which the capacitor is housed in a sealed enclosure and subject to a possible source of ignition. The example used here to illustrate the discussion is a Xenon flash bulb application.

Capacitor Selection Criteria

All engineers must consider characteristics other than voltage and capacitance when picking a capacitor for their circuit. The engineer needs to consider at least the following characteristics to ensure that the capacitor that they selected will work in their application:

- Ripple current capabilities of the capacitor
- Frequency response
- The operating life of the capacitor.

Sometimes, the engineer needs to know how a capacitor is made to ensure that it is safe to use in their application. To understand hydrogen diffusion, one has to understand the underlying construction characteristics of the electrolytic capacitor being used. In wet aluminum electrolytic capacitors, hydrogen diffusion occurs due to the normal evaporation of the dielectric and dielectric reforming over time.

Most engineers know that wet aluminum electrolytic capacitors consist of, in their simplest form, an aluminum oxide foil (anode) rolled up with an electrolytic impregnated paper and a second sheet of foil (cathode) all wound into a cylinder and placed in a can (Fig. 1).

They might also notice that a safety vent is placed on the can. Why is that safety vent there? The safety vent is placed in case of overpressure due to the overstress failure. Hydrogen diffuses over time due to evaporation and dielectric reforming. A small amount of gas will diffuse out of the can over time.

An engineer reached out to KEMET asking if there would be any problems using two of our ALS70 series capacitors in parallel in a Xenon flash application. Typically there should not be an issue using the capacitor in this type of application.

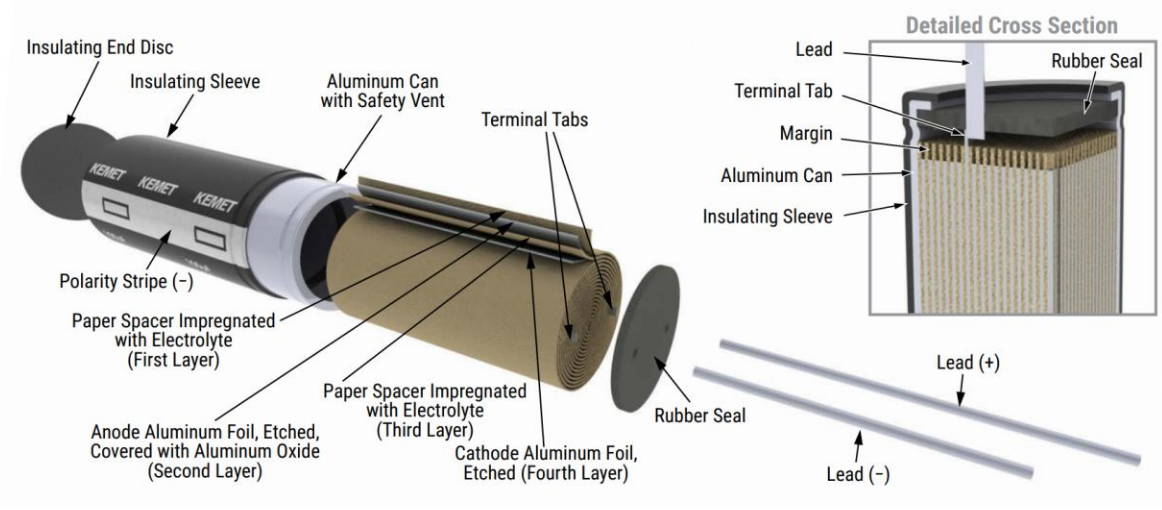


Fig. 1. Internal construction of a wet aluminum electrolytic capacitor.

However, in this particular case, we needed to consider the environment in which the engineer was planning to use the capacitors. The capacitors would be placed in an IP67-rated enclosure, so there would not be any ventilation. The Xenon flash discharge was to be triggered by an 11-kV discharge so it was important to ensure that there was no risk of explosion.

Once the concentration of hydrogen in air reaches 4%, it can become flammable. Once it reaches 12.5%, it can detonate. The engineer determined that the total volume of the enclosure was roughly 1900 cm^3. He was able to determine that each capacitor would need to diffuse roughly 100 cm^3 of hydrogen to detonate and less than 35 cm^3 to ignite over the course of their lifetimes.

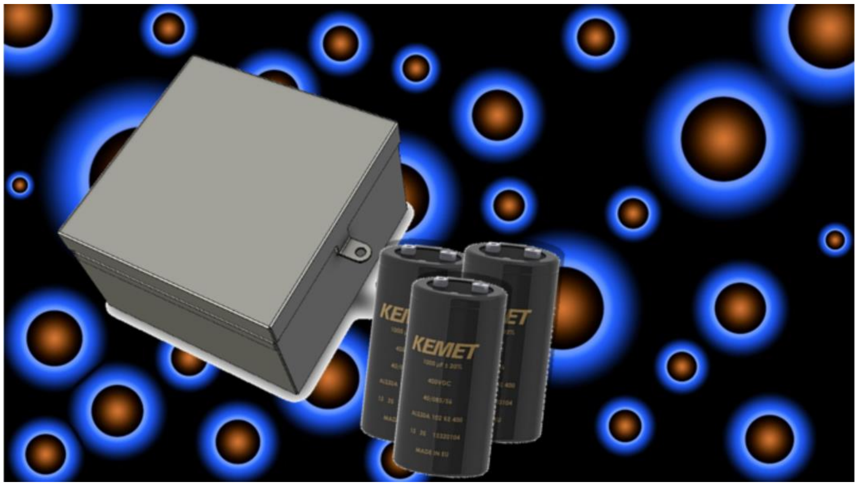


Fig. 2. For the Xenon flash application, using the ALS70 series wet aluminum electrolytic capacitors in an unvented enclosure like the one shown requires an assessment of whether the hydrogen diffused by the capacitors reaches a volume sufficient to ignite or detonate.

The capacitor that the customer was considering was an ALS70A332KF350 (see the reference), a 3300-µF, 350-V rated wet electrolytic with 20% tolerance, screw terminal mounting and case dimensions of 51 mm (diameter) and 105 mm (length). We'll delve more deeply into the specifications for this capacitor to determine the volume of hydrogen it will diffuse in the customer's application. But first, let's discuss how we determine that volume.

Calculating Hydrogen Diffusion

Based on KEMET studies of hydrogen generated in an application, the amount of hydrogen generated during use can be approximated by considering the following.

Hydrogen generated is related to the application voltage based on Faraday's Laws of Electrolysis. The quantity of charge in coulombs is given by the formula Q = I x t where Q is charge in coulombs, I is capacitor leakage current in amps and t is time in seconds. Then, the volume of H_2 generated during use in this example is 0.098 x I x t. The 0.098 multiplier is one that applies specifically to the ALS70A332KF350.

Just as a general example, consider a capacitor that operates for 5000 hours (18 million seconds) with a leakage current of 100 µA (0.0001 A). In that case

$$\text{Volume of } H_2 \text{ generated} = 0.098 \times 0.0001 \times 18{,}000{,}000 = 176 \text{ mL}$$

The H_2 generated will initially be contained inside the can and increase the internal pressure but some of it will also begin to diffuse out. Diffusion will continue even when the capacitor is not operating, and eventually all the H_2 generated will escape from the capacitor. In order to make any realistic prediction about the volume of H_2 produced it is essential to know the level of leakage current and duration of operation.

In our customer example, the engineer reached back to us with some concerning information. Based on his calculations using the information above, he would be generating 3L of hydrogen per month. Here are his calculations:

The engineer assumed the use of two ALS70A332KF350 capacitors, which based on the above discussion generate hydrogen at a rate of 0.000098 L/C. As noted in the ALS70A332KF350 data sheet, leakage current is 0.006 A (6000 µA) and the time assumed for product operation is 1 month which equals 30.4375 days or 2,629,800 seconds. Given those values, the capacitors will generate the following volume of hydrogen:

$$\text{Hydrogen leakage: } 2 \times (0.000098 \times 0.006 \times 2{,}629{,}800) = 3.0926448 \text{ L} = 3092.6448 \text{ mL}$$

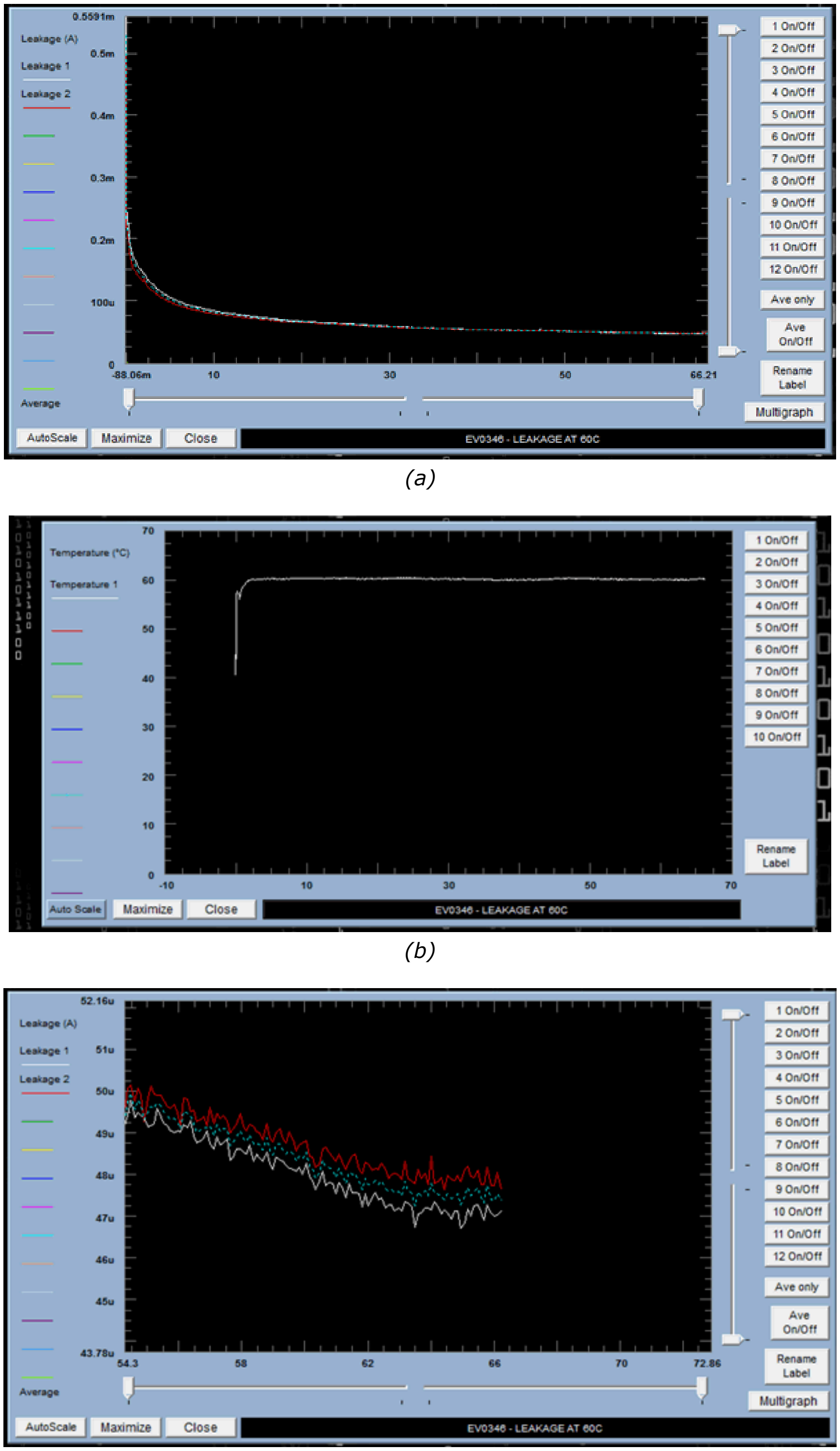
This calculated value raises a red flag because it far exceeds the volume of hydrogen required to detonate. But is the calculated value realistic?

As mentioned before, it is essential to know the level of leakage current and duration of operation. Our research and development team took two ALS70A332KF350 capacitors and put them in an oven under its maximum rated voltage (350 Vdc) and 60ºC ambient temperature. These conditions were chosen because leakage current tends to increase with voltage and temperature.

Prior to the test, the engineer provided environmental conditions for the capacitor which included ambient air temperature ranging from -40ºC to +60ºC. The main thing that they had to do was get an approximate value of the leakage current under the application. It is correct that leakage current increases with temperature, but it's also correct that leakage current will decrease in time during the application even at high temperature.

The 6 mA that is stated in the catalog is measured at 5 minutes. However, in the tests we conducted we measured a value of just 48 µA over a test period of around 72 hours. It should be noted that leakage current decreases with time and reaches a stable value—48 µA in our test case—which remains quite constant for a long period of time.

Fig. 3 presents the measurements of leakage current performed by our R&D department, when two ALS70A332KF350 parts were tested under full rated voltage (350 Vdc), and at a temperature of 60ºC to get the leakage value.



(a)

(b)

(c)

Fig. 3. Leakage current for two ALS70A332KF350 parts tested under full rated voltage (350 Vdc) and at a temperature of 60ºC. These various measurements show that the level of leakage current stabilizes over time (a), the test temperature was maintained for a 72-hour period (b), and how leakage current ultimately drops to 48 µA (c).

We redid the calculations for hydrogen diffusion using the updated leakage current value.

Actual Hydrogen leakage = 2 x (0.098 X 0.000048 X 2,629,800) = 24.74 mL

By converting 24.74 mL to 24.74 cm^3, we were able to determine that the hydrogen leakage would be less than the 100 cm^3 determined to detonate and less than the 35 cm^3 determined to ignite making use of this ALS70 series capacitor safe in this design.

Summary

In normal operation, aluminum electrolytic capacitors will necessarily generate evolved hydrogen gas that must be evaluated to ensure a safe and reliable design.

Reference

ALS70A332KF350 datasheet.

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About The Author

Wilmer Companioni is passionate about bringing engaging and entertaining technical messaging to the industry in which he has chosen to dedicate his career. He has over 10 years in electronics design and over seven years combined in sales and marketing, including the last five at KEMET tackling various roles in technical marketing.

Samuel Accardo is a field application engineer (FAE) at KEMET. The FAE position gives him the opportunity to use the knowledge and training he gained from his degrees in electrical engineering and mass communication. Prior to joining KEMET, Sam was a student at Louisiana State University and worked as a project manager/developer for a technology company and an advertising sales manager at LSU Student Media. Sam's interest in technology comes from his desire as a child to take apart everything he owned in order to see how it worked and technology's ability to improve the quality of life.

For further reading on capacitors, see the How2Power Design Guide, locate the Component category and select "Capacitors".