



TECHNICAL BRIEF

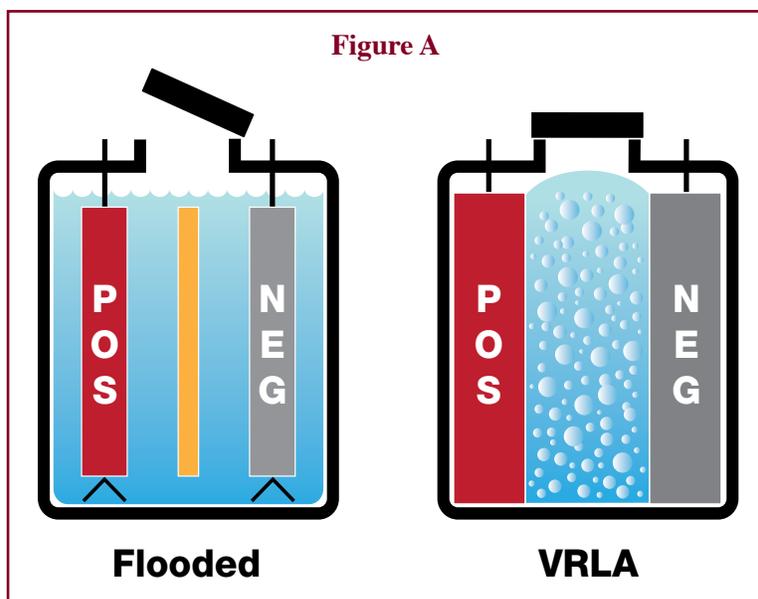
Trojan Deep-Cycle Gel™ Usage and Benefits

This technical brief will overview Trojan Battery Company's Deep-Cycle Gel technology, as well as compare its usage and benefits to deep cycle flooded and AGM technologies.

Trojan Deep-Cycle Gel™ Usage and Benefits

Trojan Battery Company's Deep-Cycle Gel battery is designed for deep discharge and heavy cycling applications. They most closely resemble the performance of flooded deep cycle batteries, sometimes referred to as wet or vented batteries.

Gel or gelled electrolyte batteries are a type of sealed battery that fall into the category of Valve Regulated Lead Acid (VRLA). VRLA batteries provide some advantages over flooded lead acid (FLA) batteries, such as being non-spillable, requiring no maintenance (no watering or equalization charge), and offering a low self-discharge rate (batteries stay better charged or "fresher" when stored vs. FLA batteries - see Figure A).



These advantages make VRLA batteries ideal for clean or health and safety-sensitive (HSE) environments as well as for applications in remote areas.

VRLA batteries work by recombining the hydrogen and oxygen gas generated during the recharge cycle back into water. The recombination is over 99% efficient, so almost no water is lost. While the sealed pressure relief valves keep the container slightly pressurized (1-4 psi), the batteries may vent gas during excessive recharge or shorting and should never be placed in an airtight container.

Flooded lead acid batteries are the most commonly used battery for energy storage when it comes to automotive, standby and motive power applications. There are typically three different types of flooded lead-acid batteries:

- Starting
- Dual Purpose (Starting/Cycling)
- Deep Cycle

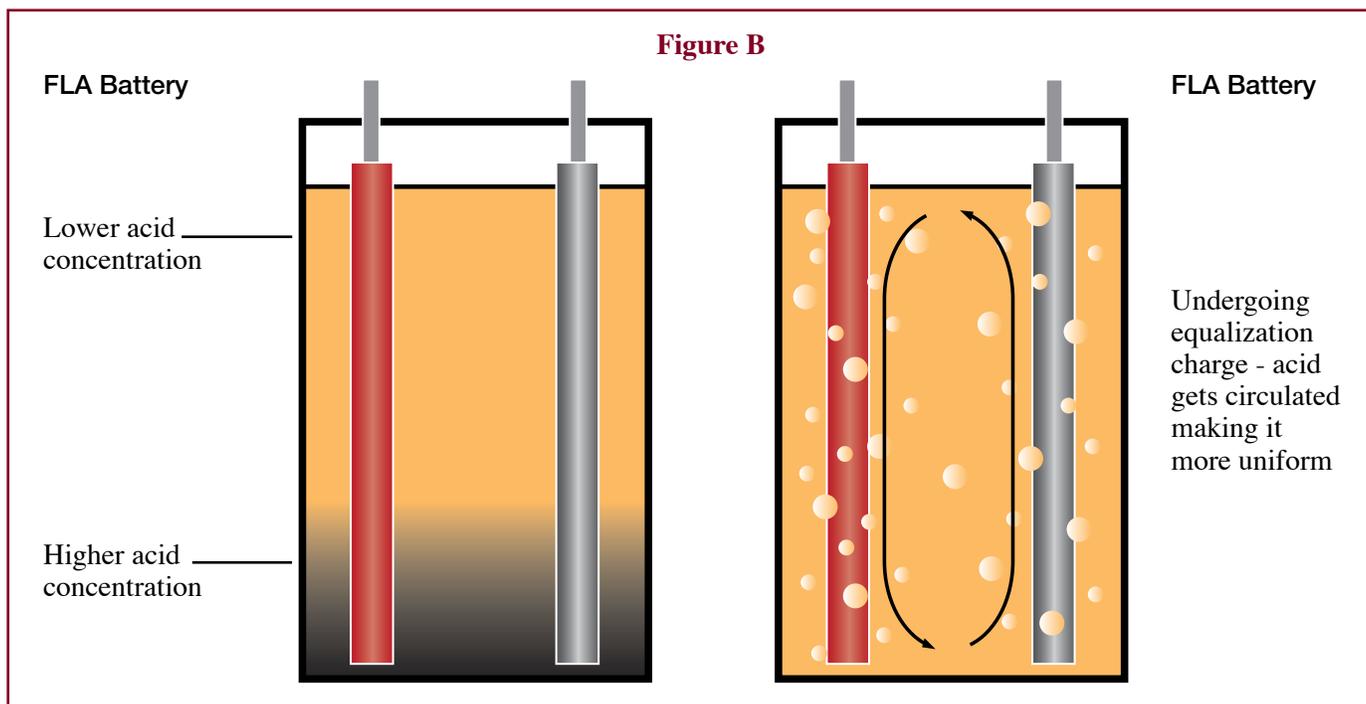
Definitions are available at the end of this brief.

Key Deep-Cycle Gel™ design features that optimize deep cycle performance:

Electrolyte will not stratify – no need to overcharge or equalize batteries

Gel batteries are non-spillable because the liquid acid is mixed with fumed silica forming a gelled electrolyte. The acid remains immobilized throughout the charge-discharge cycle.

In flooded lead acid batteries (FLA), the acid is in liquid form. Over time and through many charge-discharge cycles, particularly if the battery has been undercharged, the acid tends to accumulate near the bottom of the battery since it is heavier than water. The higher concentrated acid corrodes the battery plates and creates a layer of lead sulfate, which reduces the capacity of the battery. In flooded batteries, this effect is overcome by overcharging or equalizing the battery, forcing the generation of hydrogen and oxygen gas which ‘stirs’ the electrolyte, making the acid concentration more uniform throughout the battery (see Figure B).



In a flooded battery, the hydrogen and oxygen gas generated escapes and needs to be replaced with water.

Resistant to electrical shorts which reduces battery life

Gel batteries are considered ‘acid-starved’ which means the acid is consumed before all the active material in the plates is consumed, limiting very deep discharges which may cause the plate to shed or slough off active material. The microporous separator is also made of a very rigid resin which inhibits ‘leading shorts’ from accumulating and creating a path of material between the positive and negative plates. Flooded deep cycle batteries also have a microporous separator

Plates contain a high density paste, yielding longer life

Similar to flooded deep cycle batteries, Gel batteries contain a high density paste which has less tendency to shed or slough off the grid. Unlike Gel batteries, many AGM batteries contain a low density paste which is more prone to shedding. The high density paste also contains more active material to be used throughout the life of the battery.

Highly durable deep cycle plates

Trojan utilizes a proprietary alloy and heavy duty grid design that, combined with a proprietary electrolyte formulation, delivers a dramatically longer cycle life than leading Gel competitors.

Key differences between Deep-Cycle Gel and deep cycle flooded batteries:

Gel Advantages

- Maintenance-free (except for periodic cleaning)
- Non-spillable – cannot leak acid
- Low self-discharge (~3% per month)
- Shock and vibration resistant (higher cell compression)
- Low-temperature tolerant (less electrolyte volume to freeze or expand)
- Will not stratify

Gel Disadvantages

- Higher initial cost (high purity of materials, intricate manufacturing process)
- Lower capacity than flooded cells (more weight per amp-hour)
- Water cannot be replaced after overcharge
- Automatic temperature compensated, voltage regulated chargers must be used; sensitive to overcharge

Applications

Trojan Deep-Cycle Gel is designed for high performance in demanding deep discharge applications, such as:

- Access & Aerial Work Platform
- Floor Scrubber
- Golf/Utility Vehicles
- Marine trolling and house power
- Material Handling
- Recreational Vehicles (RV)
- Remote Monitoring & Instrumentation
- Renewable Energy (Solar & Wind)
- Other commercial deep cycle applications.

As with deep cycle flooded batteries, Gel batteries are not ideally suited or very efficient for starting applications.

How Deep-Cycle Gel batteries differ from AGM

AGM (Absorbed Glass Mat) batteries are another type of VRLA battery and are non-spillable because the liquid acid (electrolyte) is absorbed in a glass mat, a sponge-like material that separates the positive and negative plates. Similar to Gel batteries, AGM batteries can vent gas if overcharged and should never be placed in an airtight container. AGM batteries exhibit some unique properties such as lower internal resistance which enables quicker recharge time and excellent starting capabilities. Since AGM batteries have the ability to supply medium to high current draws, they are a maintenance-free alternative to the Dual Purpose FLA batteries.

Key differences between Deep-Cycle Gel and AGM batteries:

Gel Advantages

- Better for deep cycle applications (no stratification)
- Higher and more consistent capacity throughout the life of the battery
- Long cycle life
- High-temperature tolerant (recombination rate is slower reducing the chances of thermal runaway where the heat generated from the recombination accelerates the recombination process, thus generating more heat)

AGM Advantages

- Higher discharge current and charging efficiency (lower internal resistance)
- High initial capacity

Gel Disadvantages

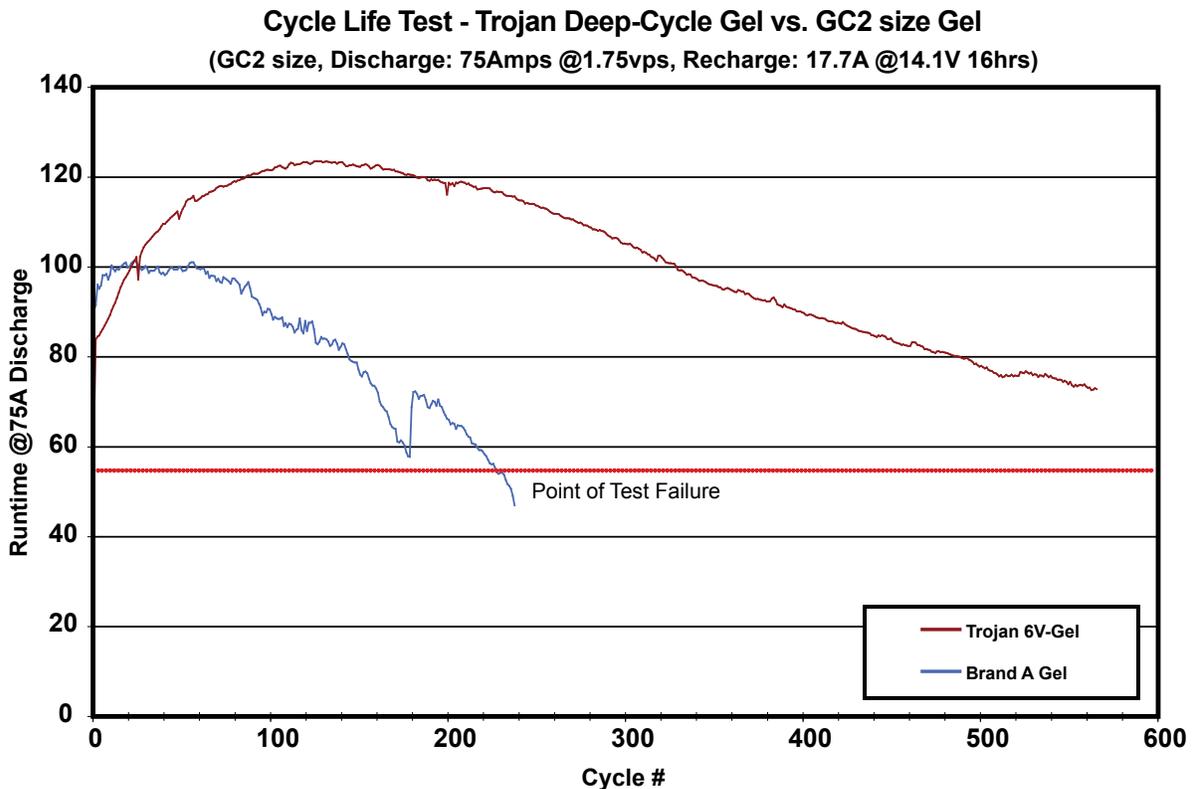
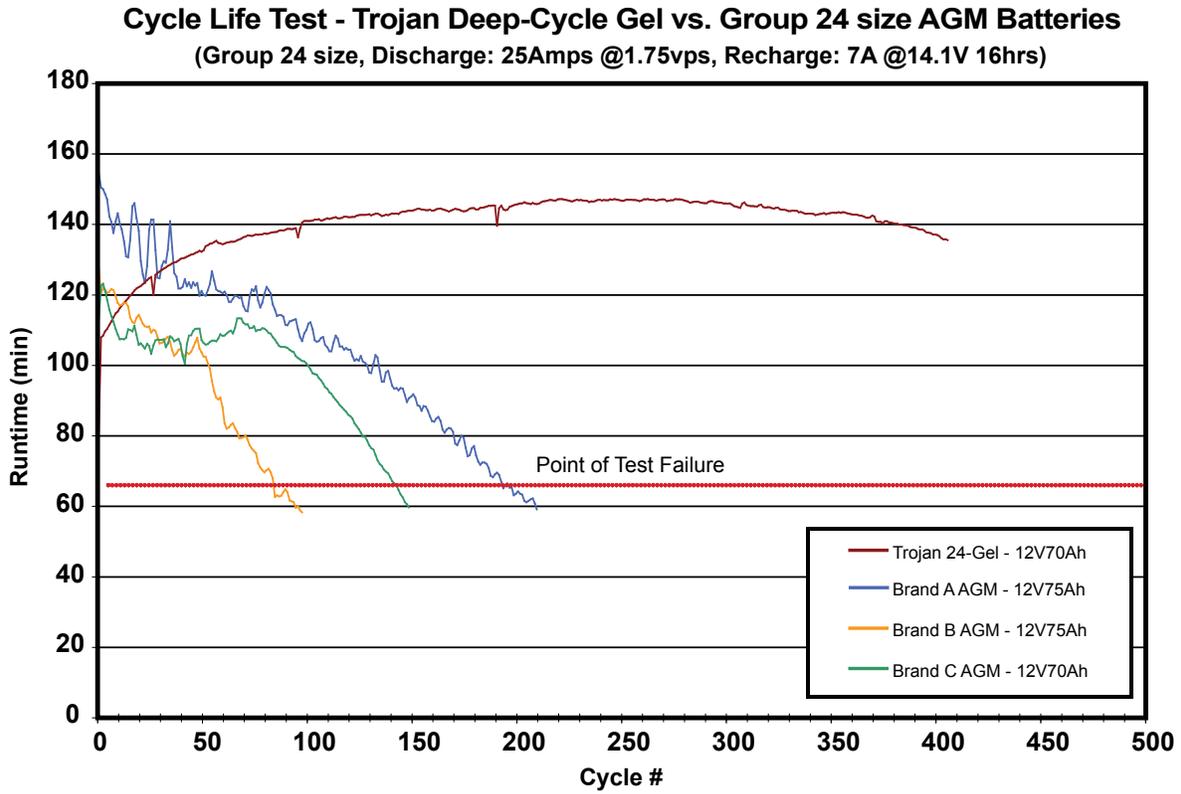
- Higher internal resistance
- Higher initial cost

AGM Disadvantages

- More prone to shorting (acid will stratify, fragile separator allows growth of microscopic materials to grow between the positive and negative plates)
- Decreasing capacity over the life of the battery
- Shorter cycle life (low density paste)
- Susceptible to thermal runaway (at higher temperatures and overcharging, drying out the electrolyte and potentially damaging the battery)

Cycle Life Testing

The cycle life charts below demonstrate the superior long life Trojan Battery's Deep-Cycle Gel™ products provides against both AGM technology and other Gel competitor products.



Flooded Lead Acid (FLA) Battery Definitions

Starting FLA

Starting FLA batteries are used in automotive, gas-powered golf/utility vehicles, and marine and RV applications, in which the battery is used primarily to supply energy to a starting (cranking) motor. While starting FLA batteries can provide some reserve capacity, e.g. energy for radios or CB's, it is not recommended that starting FLA batteries be cycled or discharged deeply, as they are not designed for such use and will not last long in such applications.

Dual Purpose FLA

Dual Purpose Starting/Deep Cycle FLA batteries are used typically in marine and RV applications that require both starting and deep cycling power. These batteries provide excellent cranking capabilities along with low current draw cycling.

Deep Cycle FLA

Deep cycle FLA batteries are used in many different applications, such as aerial work platforms, floor machines, golf cars, marine, RV, and renewable energy, providing ongoing power for the device, vehicle, or craft. These batteries are designed to supply medium to low current over a long period of time to a much higher degree of depth of discharge. Furthermore, deep cycle FLA batteries are designed to be cycled many more times than dual purpose batteries.

Equalizing (Flooded batteries only)

Equalizing is an overcharge performed on FLA batteries after they have been fully charged. Equalizing reverses the buildup of negative chemical effects, like stratification, a condition wherein acid concentration is greater at the bottom of the battery than at the top, thus causing corrosion and a loss of capacity. Equalizing also helps to remove sulfate crystals that might have built up on the plates. If left unchecked, this condition, called sulfation, will reduce the overall capacity and life of the battery.

It is often recommended that batteries be equalized periodically, from once a month to once or twice per year, more often if stored in a hot environment. However, Trojan Battery only recommends equalizing when low or wide ranging specific gravity ($\pm .015$) is detected after fully charging a battery.

Choosing the best battery for your application

This table is designed to help guide you on which battery is the best fit for your application. There are two different attributes that need to be determined before using this table.

They are:

- 1) What are your deep cycling needs?
 - a. Light, Moderate, or Heavy* depth of discharge (DoD -the percent the battery is discharged)
- 2) Do you need the battery to start an engine?
 - a. Small engines or no starting requirements: Moderate
 - b. Large Engines: Heavy

NOTES:

* It is never recommended to exceed 80% DoD

If you have both heavy starting and deep cycle requirements, it is suggested to have a separate starting and deep cycle battery bank.

Deep Cycle Need	Heavy 50 - 80% DoD	Gel FLA Deep Cycle	
	Moderate 30 - 50% DoD	Gel FLA Deep Cycle FLA Dual Purpose AGM	AGM FLA Dual Purpose
	Light <30% DoD	Gel AGM FLA Starting FLA Dual Purpose	AGM FLA Dual Purpose FLA Starting
		Moderate (no requirements on small engines)	Heavy (large engines)
		Starting Need	