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WHITE PAPER:

TUBULAR VS FLAT PLATE

REV A

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This document outlines the key technical advantages of Discover Advanced Tubular Batteries vs Flat Plate Batteries used in renewable and stationary applications. These different battery types get their name from the design of the positive plate. The "tubular" positive plate design is composed of a series of parallel tubes filled with active material whereas the positive plates in the "flat" plate design is a rugged lead alloy grid which is filled with a paste active material. To understand the differences in the performance of the two types, it is helpful to know how grid design, casing, terminal and electrolyte, to mention some criteria, influence the way batteries perform in service.

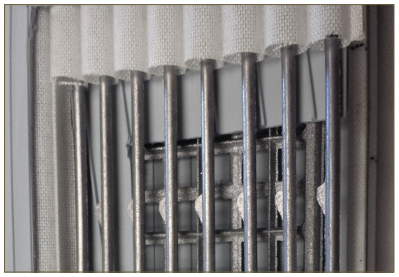
CHARACTERISTICS OF TUBULAR BATTERIES

Tubular Plates Grid

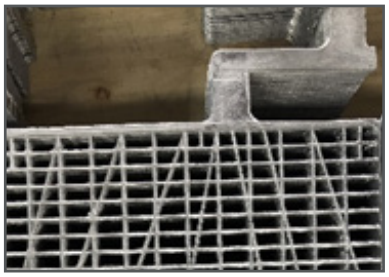
Positive tubular plates do not have horizontal bars, rather they contain a series of vertical spines for vertical current transport. This lowers the voltage loss in the plate and slows the process of corrosion due to its circular design. The active material is encapsulated in a non-woven polyester gauntlet to prevent plate shedding and provide the highest cycling expectancy amongst lead acid technologies, particularly in Partial State of Charge (PSOC) operation.

Flat Plate Battery

The rhombic shape in a flat plate battery is exposed to stronger corrosion due to having a larger surface and grid like structure of the vertical/horizontal bars.



Tubular Positive Plate



Flat Positive Plate

WHY DO DISCOVER TUBULAR BATTERIES LAST LONGER?

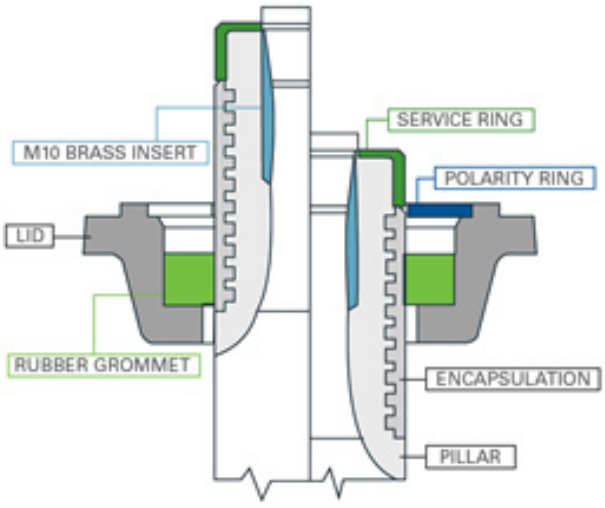
Terminal

Positive plate grid growth is a common concern in lead acid batteries, frequently seen after 4-5 years of use in stationary and renewable applications.

Discover Tubular batteries feature a terminal design that safely absorbs terminal growth due to positive plate expansion and reduces lid cracks and acid leakage during continuous charge and discharge. Sliding poles are constructed with a max tolerance of 20mm, sufficient for 20 years in operation. Battery designs without terminal growth taken into consideration reduces service life significantly.

Flat Plate Battery

Not available with sliding pole design. Positive plate growth pushes out positive pole eventually causing cracking and electrolyte leakage.



Sliding Pole Terminals

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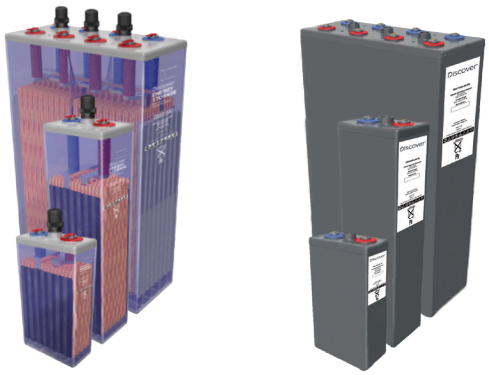
Casing

Discover Tubular batteries are manufactured in thick, reinforced SAN and ABS containers. The thick wall construction with excellent mechanical strength withstands battery expansion (bulging) during cycling and prevents capacity loss. Tubular flooded models include mud pans underneath the case to accommodate positive plate growth and mossing at the negative terminal and strap as batteries age.

Flat Plate Battery
Flat plate batteries generally have thin case walls and require compression to prevent expansion.



Tubular Flooded and Gel Cells.

Active Material

During discharge active mass density can increase over 80%. The swelling of active material reduces plate and active mass contact leading to rapid capacity loss.

Tubular plates feature a circular tube design that compresses the active material with the battery grid to prevent battery expansion during the discharge process. Each tube on a tubular plate is formed with a non-woven polyester gauntlet to ensure strong contact between the active mass and the grid which provides counter pressure for battery expansion during discharge in order to prevent capacity loss.
Flat Plate Battery
Flat plate grid structure does not have a mechanism to container active material swelling which may lead to battery case swelling and capacity loss.

Tubular Cell Design.

Specific Gravity

Specific gravity is defined as the ration of the weight of a specific volume of sulfuric acid to the weight of an equal volume of water when measured at the same temperature. The lower specific gravity of 1.24 in Discover Advanced Tubular Cells reduces grid corrosion, provides lower self-discharge rates and longer service life. Lower specific gravity is generally to find in high quality renewable systems and back-up applications such as power utility and telecommunication. In comparison, higher specific gravity provides higher capacity with shorter service life.

Operating Temperature

Tubular batteries are better prepared for cycling operation at high temperatures than flat plate batteries:

- Less heat build-up which is especially critical in Valve Regulated Lead Acid technologies
- Reduces risk of battery dry out failures with more space for water within each cell
- Mechanical stability in plates provide more consistency in cyclic performance
- Lower Specific Gravity for higher operating temperatures

THE REAL COST OF TUBULAR

For this comparison two highly regarded manufacturers for flat plate technology were selected. Compared Battery A represents a 2V AGM battery and Battery B represents a 6V AGM battery. For this purpose of comparison, a 10kWh daily load with three days autonomy was the design target. This means the batteries need to store as close to usable 30 kWh as possible. The results below show if initial cost was the only consideration then flat plate technology would be the clear winner. The battery investment in relation to cycle life provides a more holistic way to assess the values as well costs.

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CORRECTIVE ACTIONS

System Nominal DC Voltage	48	48	48
Battery Type	Tubular Gel	AGM flat plate	AGM flat plate
Battery System Designed Depth of Discharge (DoD)	50%	50%	50%
System Energy Storage Requirement (useful kWh)	30	30	30

BATTERY SPECIFICATIONS

Battery Manufacturer	Discover Battery	Compared Battery A	Compared Battery B
Model	2VRE-3200TG	AGM 1150 2V	AGM L16
Battery/Cell Nominal Voltage	2	2	6
Battery/Cell Ahr rating (@20hr rate)	1265	1150	415
Expected Cycle Life at System DoD rating	2950	1500	1300
Retail Cost per Battery	$900	$600	$610

ENERGY STORAGE SYSTEM SUMMARY

Number of Batteries Required	24	24	24
Number of Parallel Battery Strings	1	1	3
System Energy Storage Capacity (kWh)	61	55	60
System Useful Energy Storage Capacity (kWh)	30	28	30

INITIAL CAPITAL COST (CAPEX) SUMMARY

Initial Battery System Cost	$21,600	$14,400	$14,640
Initial $/kWh of Energy Storage (useful kWh)	$711	$522	$490

8 YEAR CAPITAL COST (CAPEX) SUMMARY

Number of Planned System Purchase (365 daily cycling/ expected battery cycle life)	1	2	2
8 Year Total Battery System Cost	$21,600	$28,800	$29,280
8 Year $/kWh of Energy Storage (useful kWh)	$711	$1,043	$980

8 YEAR ENERGY STORAGE (OPEX) OPERATING COST

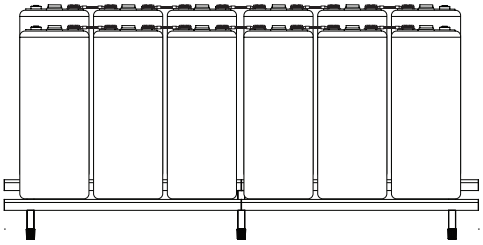
Energy Storage Cost per Cycle (Depreciation cost of each complete cycle)	$7.32	$9.86	$10.03

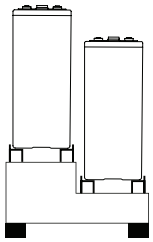
Over the cycle life of the tubular batteries, the flat plate batteries will likely have had to be replaced once. The Total Costs of Ownership (TCO) over 8 years daily cycling are reduced by approximately 30% compared Tubular vs Flat plate.

SYSTEM INTEGRATION

Discover® OPzV cells are available as a complete solution for 24VDC and 48VDC energy storage systems. The knock-down kit includes tubular battery cells, racking, intercell and inter-row connectors.

For more information please visit: https://discoverbattery.com/product-search





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SUMMARY

Due to the advanced tubular battery design, the total cost of ownership is 30% lower than flat plate batteries when cycle and service life performances are taken into consideration. Discover Tubular Batteries provide twice as much cycle life at 50% Depth of discharge compared to lead-acid flat plate batteries. The electrical and mechanical capabilities of tubular batteries outperform flat plate batteries for renewable and stationary applications. As a result, in applications which require a long service life, tubular plate batteries provide the best and most reliable power for the money spent amongst lead-acid technologies.