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US BATTERY CHARGING RECOMMENDATIONS

U.S. Battery Manufacturing Company, Inc. recommends the use of 'opportunity charging' or charging batteries and battery packs at every opportunity while in storage or service. Following this recommendation will assure that batteries are always at the highest possible State of Charge (SOC) to maximize performance and range and to minimize the battery's Depth of Discharge (DOD) to optimize performance and life.

The charging process is intended to fulfill several objectives. First, the charging process should replace the capacity (in amp-hours) removed from the battery during previous discharges. Second, the charging process should return additional capacity (in amp-hours) to offset the thermodynamic inefficiencies inherent in the charging process. This additional capacity can be measured as a charge factor calculated by: $\text{charge Ah in} / \text{discharge Ah out}$. The charge factor varies with temperature, condition and age of the battery but is usually in the range of 105 - 150%. Third, the charging process should charge the battery at a voltage and/or charge rate at the end of charge that will result in controlled gassing of the electrolyte. This gassing is required to mix the electrolyte to prevent stratification. Without proper mixing of the electrolyte, the heavier acid generated during charging can sink to the bottom of the cell and will adversely affect performance and life of the battery. Finally, the charging process should result in a fully charged battery with electrolyte specific gravity that is constant over several end-of-charge readings, consistent between and among the cells of the battery pack, and within the proper range for the battery type per U.S. Battery's specifications.

U.S. Battery is active in the development of new charging methods and regularly tests and evaluates new charger technologies. As part of U.S. Battery's charging recommendations, charging methods are categorized into three basic methodologies based on the number of charge stages used in the charging process. It should be noted that the basic charge stages should result in a fully charged battery at the end of the final charge stage. Using this criterion; float charging, maintenance charging, and equalization charging are not considered to be one of the basic charge stages. These basic charge stage methodologies can be defined as follows:

1. **Three-Stage Charging** – Charging using bulk charge, absorption charge, and finish charge (usually constant current - constant voltage – constant current).
2. **Two-Stage Charging** – Charging using bulk charge and absorption charge only (usually constant current - constant voltage).
3. **Single-Stage (Ferroresonant) Charging** – Charging using a single-stage charge with tapering current and voltage.

U.S. Battery's charging recommendations for deep cycle flooded lead-acid (FLA) and sealed absorptive glass mat (AGM) batteries are attached. Note that the charging parameters recommended for each of these depend on both the battery type and charger type. These charging parameters are often controlled by specific charge algorithms that can be selected or programmed by the user. Users should consult the charger manufacturer and/or U.S. Battery for proper selection or programming of algorithm controlled chargers. U.S. Battery prefers the use of Three-Stage Charging with dV/dt charge termination to minimize the charge time required for full charge and to reduce the risk of abusive undercharging or overcharging of batteries and battery packs.



US Battery Flooded Deep Cycle Battery Charging Recommendations

Three-Stage Charger (Constant Current-Constant Voltage-Constant Current)*

Following is the charging recommendation and charging profile using 3 stage* chargers for US Battery deep cycle products.

*Equalization and float charge modes are not considered to be one of the stages in a charging profile.

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|---------------------------|--|
| 1. Bulk Charge | Constant current @~10% of C/20 Ah in amps to 2.40+/-0.05 volts per cell
(e.g. 7.20 volts +/-0.15 volts per 6 volt battery) |
| 2. Absorption Charge | Constant voltage (2.40+/-0.05 vpc) to 3% of C/20 Ah in amps |
| 3. Finish Charge | Constant current at 3% of C/20 Ah to 2.55+/-0.05 volts per cell (e.g. 7.65 volts +/-0.15 volts per 6 volt battery)
Charge termination can be by maximum time (2-4 hr) or dV/dt (4 mv/cell per hour) |
| • (Optional Float Charge) | Constant voltage of 2.17 vpc (e.g. 6.51 volts per 6 volt battery) for unlimited time |
| • Equalization Charge | Constant voltage (2.55+/-0.05 vpc) extended for 1-3 hours after normal charge cycle (repeat every 30 days) |

Notes: Charge time from full discharge is 8-12 hours.
Absorption charge time is determined by the battery but will usually be ~3 hours at 2.40 volts per cell.
Finish charge time is typically 2-4 hours.
Float time is unlimited at 2.17 volts per cell.
Specific gravity at full charge is 1.270 minimum

Two-Stage Charger (Constant Current-Constant Voltage)*

Following is the charging recommendation and charging profile using 2 stage chargers for US Battery deep cycle products.

*Equalization and float charge modes are not considered to be one of the stages in a charging profile.

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|---------------------------|--|
| 1. Bulk Charge | Constant current @~10% of C/20 Ah in amps to 2.45+/-0.05 volts per cell
(e.g. 7.35 volts +/-0.15 volts per 6 volt battery) |
| 2. Absorption Charge | Constant voltage (2.45+/-0.05 vpc) to 3% of C/20 Ah in amps then hold for 2-3 hours and terminate charge
Charge termination can be by maximum time (2-4 hr) or dV/dt (4 mv/cell per hour) |
| • (Optional Float Charge) | Constant voltage 2.17 vpc (6.51 volts per 6 volt battery) for unlimited time |
| • Equalization Charge | Constant voltage (2.55+/-0.05 vpc) extended for 1-3 hours after normal charge cycle (repeat every 30 days) |

Notes: Charge time from full discharge is 9-12 hours.
Absorption charge time is determined by the battery but will usually be ~3 hours at 2.45 volts per cell.
Float time is unlimited at 2.17 volts per cell.
Specific gravity at full charge is 1.270 minimum

Single Stage (Ferroresonant) Charger*

Following is the charging recommendation and charging profile using single stage (ferroresonant) chargers for US Battery deep cycle products.

*Equalization and float charge modes are not considered to be one of the stages in a charging profile.

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|---------------------------|---|
| Bulk Charge | Ferroresonant charge characteristics with starting current at 10-12% of C/20 Ah in amps
and tapering to ~3% of C/20 Ah in amps at Finish with voltage of 2.55+/-0.05 vpc
Charge termination can be by maximum time (~12 hr) or dV/dt (4 mv/cell per hour) |
| • (Optional Float Charge) | Constant voltage 2.17 vpc (6.51 volts per 6 volt battery) for unlimited time |
| • Equalization Charge | Ferroresonant charge extended for 1-3 hours (w/ dV/dt disabled) after normal charge cycle
(repeat every 30 days) |

Notes: Charge time from full discharge is 9-12 hours.
Ferroresonant chargers use a saturable core reactor to deliver a tapering charge current profile
Float time is unlimited at 2.17 volts per cell.
Specific gravity at full charge is 1.270 minimum

Battery temperature adjustment: reduce the voltage by 0.028 Volts per cell for every 10°F above 80°F,
increase by the same amount for temperatures below 80°F.

Deep cycle batteries need to be equalized periodically. Equalizing is an extended, low current charge performed after the normal charge cycle.
This extra charge helps keep all cells in balance. Actively used batteries should be equalized once per month.
Manually timed chargers should have the charge time extended approximately 3 hours.
Automatically controlled chargers should be unplugged and reconnected after completing a charge.



US Battery AGM Battery Charging Recommendations

Three-Stage Charger (Constant Current-Constant Voltage-Constant Current)*

Following is the charging recommendation and charging profile using 3 stage* chargers for US Battery AGM products.

*Equalization and float charge modes are not considered to be one of the stages in a charging profile.

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|---------------------------|---|
| 1. Bulk Charge | Constant current @~10% of C/20 Ah in amps to 2.40+/-0.05 volts per cell
(e.g. 7.20 volts +/-0.15 volts per 6 volt battery) |
| 2. Absorption Charge | Constant voltage (2.40+/-0.05 vpc) to 3% of C/20 Ah in amps |
| 3. Finish Charge | Constant current at 3% of C/20 Ah to 2.45+/-0.05 volts per cell then terminate charge
(e.g. 7.35 volts +/-0.15 volts per 6 volt battery) |
| • (Optional Float Charge) | Constant voltage 2.23+/-0.03 vpc (6.70 volts per 6 volt battery) for unlimited time |
| • Equalization Charge | Constant voltage (2.45+/-0.05 vpc) extended for 1-3 hours after normal charge cycle (repeat every 30 days) |

Notes: Charge time from full discharge is 8-12 hours.

Absorption charge time is determined by the battery but will usually be ~3 hours at 2.40 volts per cell.

Finish charge time is typically 2-4 hours.

Float time is unlimited at 2.23 volts per cell.

Two-Stage Charger (Constant Current-Constant Voltage)*

Following is the charging recommendation and charging profile using 2 stage chargers for US Battery AGM products.

*Equalization and float charge modes are not considered to be one of the stages in a charging profile.

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|---------------------------|---|
| 1. Bulk Charge | Constant current @~10% of C/20 Ah in amps to 2.45+/-0.05 volts per cell
(e.g. 7.35 volts +/-0.15 volts per 6 volt battery) |
| 2. Absorption Charge | Constant voltage (2.45+/-0.05 vpc) to 3% of C/20 Ah in amps then hold for 2-3 hours |
| • (Optional Float Charge) | Constant voltage 2.23+/-0.03 vpc (6.70 volts per 6 volt battery) for unlimited time |
| • Equalization Charge | Constant voltage (2.45+/-0.05 vpc) extended for 1-3 hours after normal charge cycle (repeat every 30 days) |

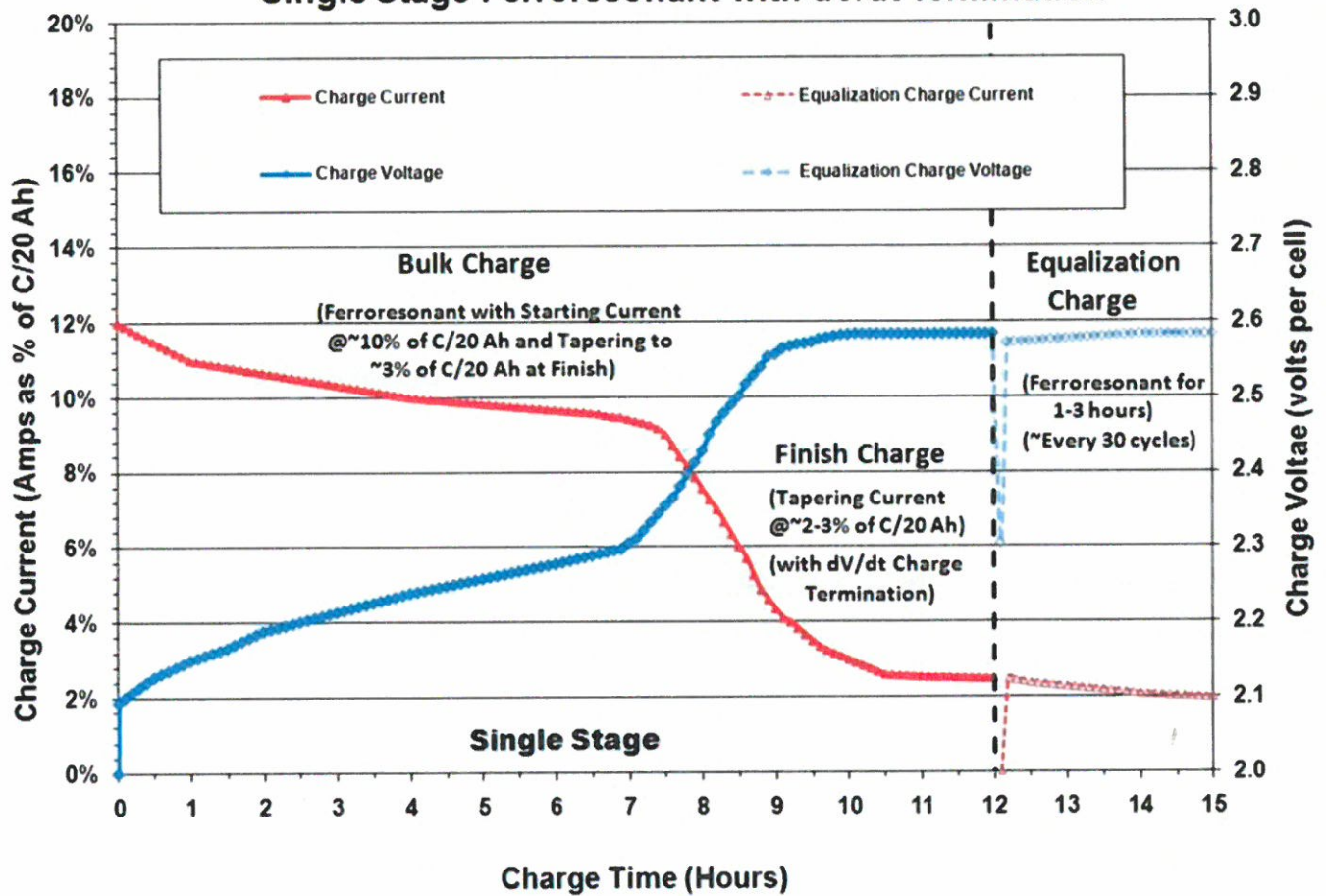
Notes: Charge time from full discharge is 9-12 hours.

Absorption charge time is determined by the battery but will usually be ~3 hours at 2.45 volts per cell.

Float time is unlimited at 2.23 volts per cell.

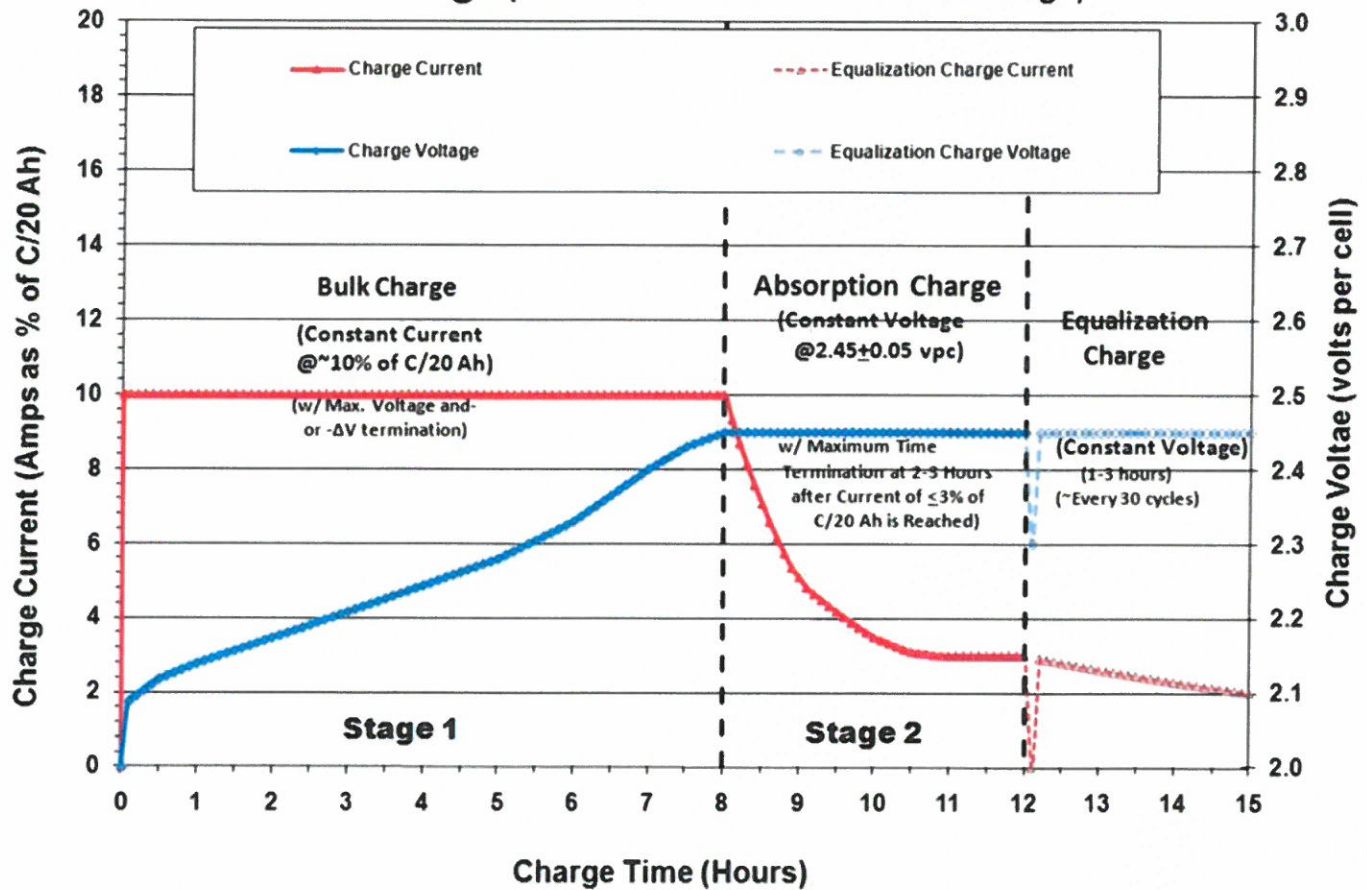


US Battery Recommended Charge Profile Single Stage Ferroresonant with dV/dt Termination





US Battery Recommended Charge Profile 2-Stage (Constant Current - Constant Voltage)





US Battery Recommended Charge Profile 3-Stage (Constant Current - Constant Voltage - Constant Current)

