hours) to offset the thermodynamic inefficiencies inherent in the charging process. This additional capacity can be measured as a charge factor calculated by: charge Ah in / 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). Diagram 5
2. Two-Stage Charging – Charging using bulk charge and absorption charge only (Usually constant current - constant voltage). Diagram 6

U.S. Battery's charging recommendations for deep cycle flooded lead-acid (FLA) and sealed absorptive glass mat (AGM) batteries are found below. 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.

- **FLOODED LEAD ACID CHARGING RECOMMENDATIONS**

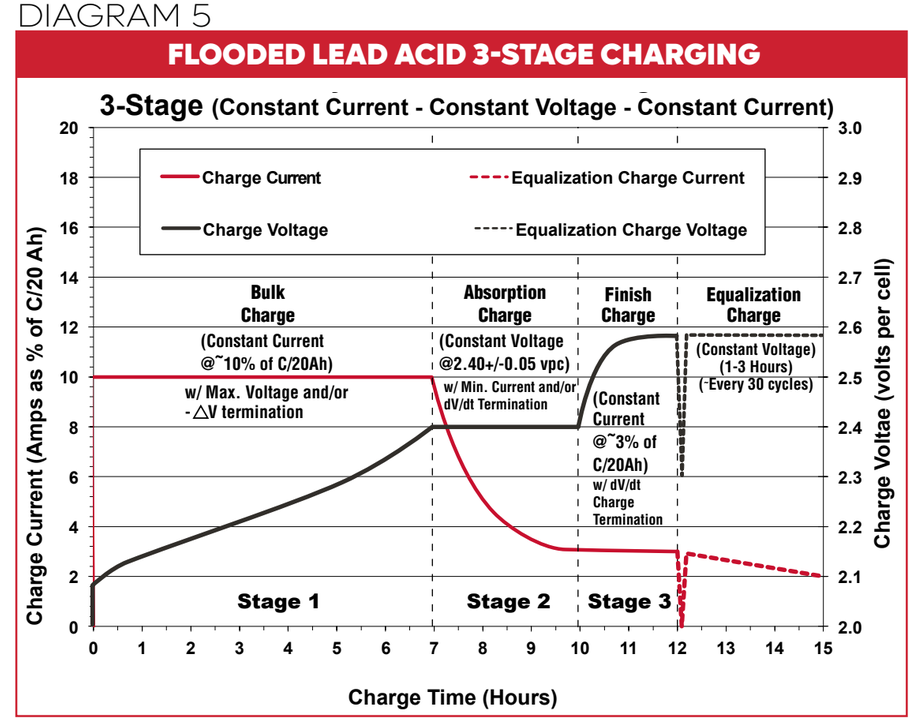
Three-Stage Charger (Constant Current-Constant Voltage-Constant Current)*

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.

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)
Absorption Charge	Constant voltage (2.40+/-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 (2-4hr) or dV/dt (4 mv/cellper hour)
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 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 2.40 volts per cell. Float time is unlimited at 2.17 volts per cell. Specific gravity at full charge is 1.270 minimum

DIAGRAM 5



4 CHARGING AND EQUALIZING

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.

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)
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 (2-4hr) 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

DIAGRAM 6

FLOODED LEAD ACID 2-STAGE CHARGING

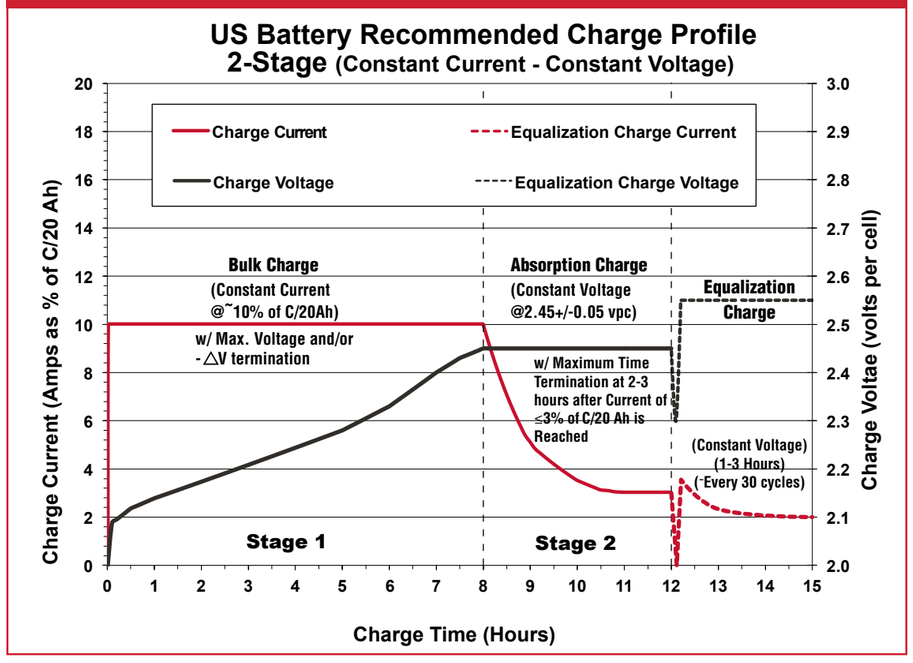


TABLE 4:
Example of voltage settings for deep-cycle flooded lead acid batteries using a 2-stage charger

2-Stage Charger Settings for Deep-Cycle Flooded/Wet Batteries						
System Voltage*	6 Volt	8 Volt	12 Volt	24 Volt	36 Volt	48 Volt
Bulk Charge Voltage	7.05 - 7.5	9.4 - 10	14.1 - 15	28.2 - 30	42.3 - 45	56.4 - 60
Absorption Charge Voltage	7.05 - 7.5	9.4 - 10	14.1 - 15	28.2 - 30	42.3 - 45	56.4 - 60
Absorption Time	2-4 hours					
Float Voltage	6.51	8.68	13.02	26.04	39.06	52.08
Equalization Voltage	7.5 - 7.8	10.0 - 10.4	15.0 - 15.6	30.0 - 31.2	45.0 - 46.8	60.0 - 62.4
Equalization Time	2-4 hours					
Equalization Frequency	At least once a month; Every two weeks if cycled daily.					

*** Battery pack voltage may be lower than the set-points shown at the start of charging. Most automatic chargers require a pack voltage of at least 1 volt per cell for the charger to initiate charging. If pack voltage is less than 1 vpc, a separate manual charger may be needed to bring battery voltages up to the required voltage for charging.**

- **AGM CHARGING RECOMMENDATIONS**

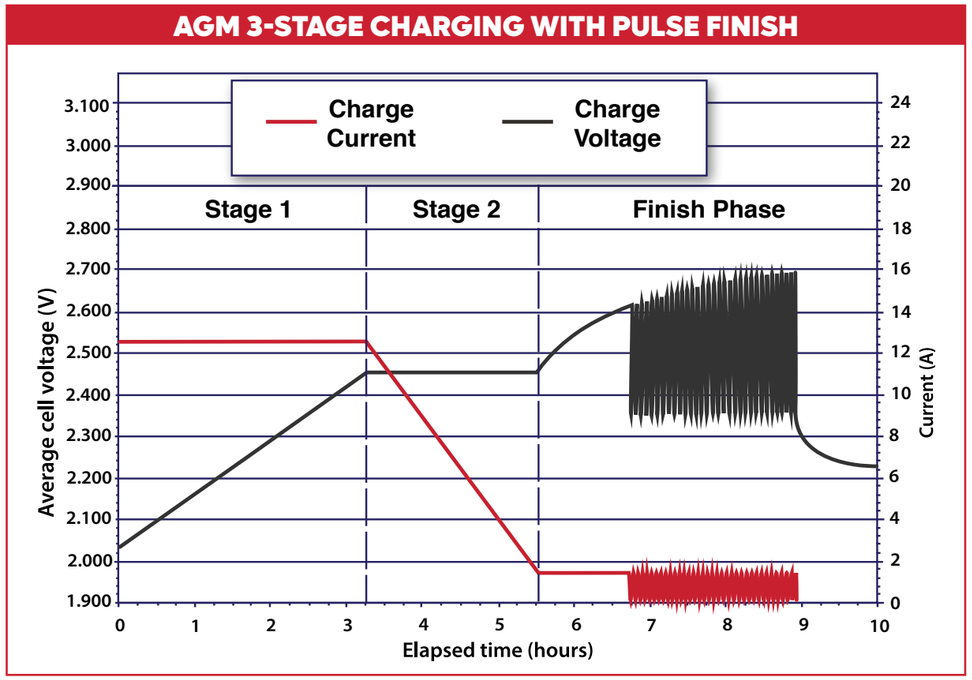
Three-Stage Charger (Constant Current-Constant Voltage-Constant/Pulse Current)*

Following is the chargeing recommendations and charging profile using 3 stage* chargers for US AGM deep cycle products.
**Equalization and float charge modes are not considered to be one of the stages in a charge profile.*

1. Bulk Charge	Constant current @ maximum bulk charge 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 minimum absorption charge then hold for 2-3 hours and terminate charge.
3. Finish Charge	Constant curent 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) Pulse finish: Periodic short current pulses at ~2% of C/20. Voltage rises to 2.7vpc, current turns off, voltage drops to 2.35vpc, current turns on and repeats. Termination is determined by % overcharge or max time.
• (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 2.40 volts per cell.
Finish charge time is typically 2-4 hours.
Float time is unlimited at 2.23 volts per cell.

DIAGRAM 7



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

Following is the chargeing recommendations and charging profile using 2 stage* chargers for US AGM deep cycle products.

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

1. Bulk Charge — Constant current @ maximum bulk charge 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 minimum absorption charge then hold for 2-3 hours and terminate charge.

- (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.
Finish charge time is typically 2-4 hours.
Float time is unlimited at 2.23 volts per cell.

DIAGRAM 8

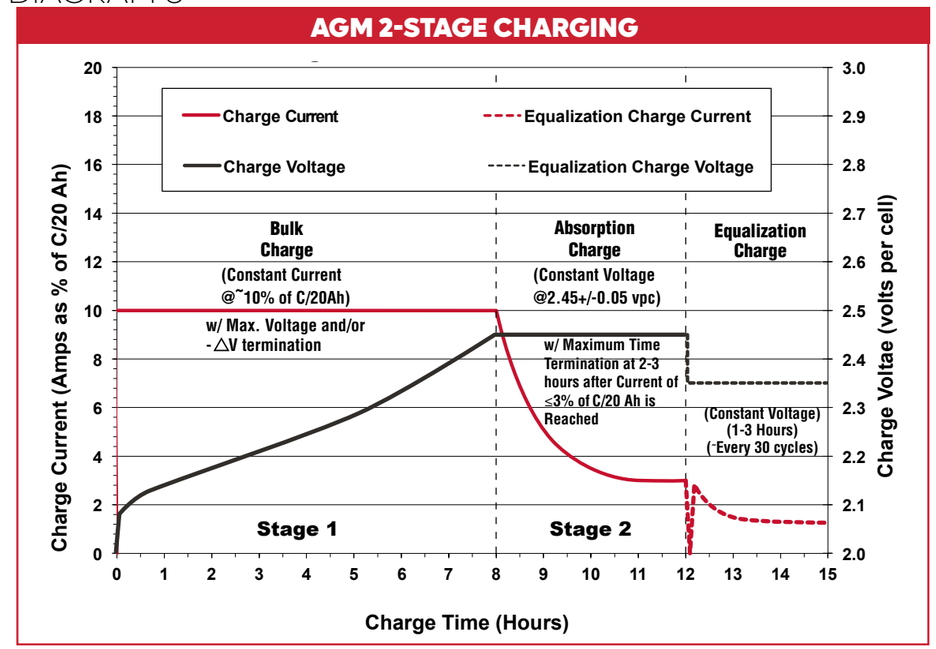


TABLE 5

Example of voltage settings for deep-cycle AGM lead acid batteries using a 2-stage charger

2-Stage Charger Settings for Deep-Cycle AGM Batteries						
System Voltage*	6 Volt	8 Volt	12 Volt	24 Volt	36 Volt	48 Volt
Bulk Charge Voltage	7.2 - 7.35	9.6 - 9.8	14.4 - 14.7	28.8 - 29.4	43.2 - 44.1	57.6 - 58.8
Absorption Charge Voltage	7.2 - 7.35	9.6 - 9.8	14.4 - 14.7	28.8 - 29.4	43.2 - 44.1	57.6 - 58.8
Absorption Time	2-3 hours					
Float Voltage	6.7	9	13.5	27	40.5	54
Equalization Voltage	7.35	9.8	14.7	29.4	44.1	58.8
Equalization Time	5-6 hours					
Equalization Frequency	At least once a month; Every two weeks if cycled daily.					

*** Battery pack voltage may be lower than the set-points shown at the start of charging. Most automatic chargers require a pack voltage of at least 1 volt per cell for the charger to initiate charging. If pack voltage is less than 1 vpc, a separate manual charger may be needed to bring battery voltages up to the required voltage for charging.**

4.3 EQUALIZATION CHARGING RECOMMENDATIONS

As deep cycle battery packs are discharged and recharged over multiple cycles, the individual cells within the batteries can become imbalanced due to small differences among the cells. This can result in differences in specific gravity between cells over time. If left uncorrected, the lower cells can become progressively undercharged resulting in capacity loss, sulfation and premature battery failure. To correct for this effect, equalization charging should be used to rebalance the cells. Equalization charging is a fixed overcharge performed after the charger has completed a normal full charge. Equalization charging also assures that all the cells are gassing enough to fully mix the electrolyte to prevent electrolyte stratification. US Battery recommends an equalization charge of 2-4 hours every 30 days or 30 cycles or whenever a specific gravity difference of over 15 points is noted among all the cells of the battery.

Some chargers have an equalization charge programmed into their charge algorithm but manual equalization can be initiated as follows:

- **Fully charge batteries.**
- **Unplug charger until it completely turns off.**
- **Plug the charger back in.** The charger should perform a shortened charge cycle and go through the initial charge stages very quickly. It should then remain in the last charge stage until the charge termination criteria are met. This normally takes 2-4 hours and results in an extended overcharge that balances the cells. This should be confirmed by checking specific gravities.

- **Measure the specific gravity.** If the specific gravity is <1.265 or there is >0.015 points of variance between the cells, then repeat the equalization steps until those two conditions are met.

4.4 FLOAT CHARGE

- **A float charge** is given to the batteries in order to overcome the self-discharge rate. This should be applied to the batteries when stored and after given a full charge. The float voltage for flooded lead acid US Batteries is 2.17 volts per cell and 2.23 volts per cell for US AGM Batteries.

4.5 RENEWABLE ENERGY LINE

Deep cycle batteries used in Renewable Energy applications are subjected to a different kind of service compared to deep cycle batteries used in vehicular applications. Renewable Energy applications are considered 'stationary' applications and do not have the movement that occurs in vehicles. As a result, renewable energy batteries experience failure modes that are not prevalent in vehicular applications. To offset these effects, US Battery has designed Renewable Energy batteries with specific design features to address failure modes such as mossing and sulfation. US Battery uses 'moss shields' to prevent moss shorts that can form when positive active material dislodges from the positive plates and collects under the plate connectors. US Battery also uses an 'Outside Positive Plate' design that minimizes the effects of 'Partial State of Charge' or PSOC operation often found in renewable energy applications using solar and wind as the source for charging that often results in incomplete charging.

Since many of the charge controllers for solar applications are two stage chargers the best way to ensure your batteries get a full charge is to increase the absorption stage in 30 minute increments until a full charge is verified with specific gravity readings.

4.6 TEMPERATURE COMPENSATION

Temperature compensation is critical for charging and maintaining batteries in environments with ambient temperatures significantly higher or lower than 80ºF (27ºC) where overcharging or undercharging may occur. **Temperature compensation allows the use of higher charge currents; 20% of the 20 hour rating compared to 10% when charging FLA batteries. AGMs can accept 25% of the 20 hour rating compared to 15%.** Also, temperature compensation is required for warranty claims with AGMs due to their sensitivity to overcharging. Many chargers today come with temperature probes making temperature compensation easy.

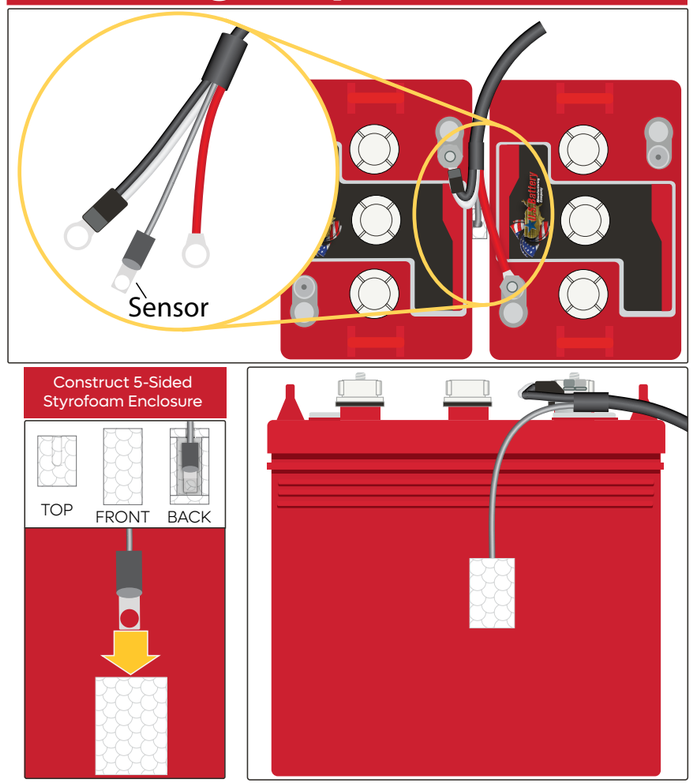
- **The temperature compensation formula is as follows:**
  - Fahrenheit
    - Subtract 0.0028 volts per cell per degrees F above 80ºF
    - Add 0.0028 volts per cell per degrees F below 80ºF
  - Celsius
    - Subtract 0.005 volts per cell per degrees C above 27ºC
    - Add 0.005 volts per cell per degrees C below 27ºC
  - Example
    - Two 6Vs wired in series for 12Vs. 100ºF sunny day in California.
    - Typically the bulk charge voltage would be ~ 14.1V at 80ºF.
    - At 100ºF, subtract (0.0028 * 6 cells * 20ºF) 0.336v from all voltages.
    - The bulk charge voltage would then be ~13.8V.

Temperature sensors

Most chargers that utilize temperature compensation in their charge algorithms provide a temperature sensor to measure battery temperature at a battery. These temperature sensors are usually designed to be attached to a battery terminal and utilize an internal program to correlate battery terminal temperature to actual internal battery temperature. One common method is to attach the temperature sensor to the negative battery terminal along with the negative lead. However, it is important to follow the charger manufacturer's instructions for installation of the temperature sensor since various charger manufacturers use different methods. For example, another method is to attach the temperature sensor to the side of a battery in the pack. It is usually recommended to attach the temperature sensor to the middle of the long side of a battery in the center of the battery pack. It may also be necessary to insulate the sensor following the charger manufacturer's instructions.

DIAGRAM 8

Mounting Temperature Sensor



4.7 DELTA-Q CHARGING ALGORITHMS

The following link will take you to a US Battery Technical Service Bulletin regarding the appropriate Delta-Q charging algorithms for each battery: Delta-Q Charging Algorithms

The following tips will help ensure that your batteries remain in good condition during storage:

- **Fully charge batteries** before placing in storage.
- **Store in a cool, dry location**, protected from the elements.
- **Disconnect from equipment** to eliminate potential parasitic loads that may discharge the battery.
- **Batteries gradually self-discharge** during storage. Monitor the specific gravity or voltage every 4-6 weeks. Stored batteries should be given a boost charge when they are at 80% state of charge (SOC) or less. Refer to Diagrams 9 and 10 for specific gravity and voltage measurements for flooded/wet and AGM batteries respectively.
- **When batteries are taken out of storage**, recharge before use.
- **If put on float voltage** there is no need for periodic boost.

DIAGRAM 9

U.S. BATTERY FLOODED-LEAD ACID BATTERY SELF-DISCHARGE RATE AT 20°F TO 120°F