# Cyclon®

Purebred Technology for 35 years

35

Cyclon™

1973 TO 2008



ISO 9000™

EnerSys®
Power/Full Solutions

# Cyclon®

## Wherever the world needs stored energy, EnerSys® is there.

Powered by more than 100 years of expertise, EnerSys® is the world's largest industrial battery manufacturer, operating 21 facilities worldwide. Along with manufacturing and distributing a wide range of reserve power and motive power batteries, chargers, power equipment, and battery accessories, EnerSys provides unmatched aftermarket and customer support to its customers in over 100 countries worldwide.

# A rugged, reliable alternative to conventional lead alloy batteries.

At first glance, a conventional lead battery may seem like a better reserve-power deal than the rechargeable, sealed-lead CYCLON® battery. But a closer look reveals the real bottom line: for long-term cost of ownership, there's simply no comparison. By housing a sealed, pure-lead, thin-plate design within an extremely rugged steel casing, CYCLON batteries outperform lead alloy batteries in a number of ways:

- **Per unit weight, CYCLON® batteries deliver the greatest high-rate power density for your energy dollar.**

- **CYCLON® batteries can be recharged to 95% capacity in under an hour, and boast a design life of ten years for single cell products and up to eight years for monobloc products.**

- **CYCLON® batteries perform remarkably well in extreme applications and temperatures (up to twice the capacity at -20°C) - and are safe enough for installations in offices or hospitals.**

Add it all up and the real value of CYCLON batteries becomes clear. Their power and extended service life means more efficient operation with fewer replacements, while their reliability means fewer system failures. From general purpose to extremely demanding applications CYCLON batteries simply offer better performance and lower long-term cost of ownership.
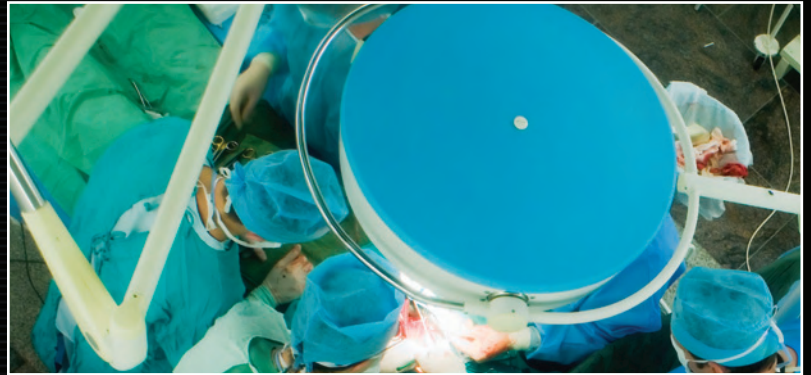
# Rugged construction and reliable performance in extreme temperatures make Cyclon® batteries ideal for a range of applications:

- Telecommunications
- Defence installations
- Aerospace
- Global positioning systems
- Uninterrupted Power Supply (UPS) Equipment
- Emergency lighting
- Medical equipment
- Computer back-up
- Electric vehicles
- Solar power equipment
- General electronics
- Lawn and garden equipment

# Cyclon®

# Powerful design:

# A CYCLON® Single Cell

## Resealable safety valve

A 50-PSI vent lets gases escape, then automatically reseals, so there's no risk of excessive gas accumulation within the battery, or "dry out" failure from repeated recharges.

## Pure lead plates

Made from 99.99% pure lead, CYCLON® battery plates are extremely thin, so they offer more surface area than conventional batteries - and far more power.

## AGM plate separator

High-purity acid is absorbed right into the Absorbed Glass Mat (AGM) plate separators, so the CYCLON battery provides leak-proof operation in any position.

## Steel can enclosure

The CYCLON battery's metal outer jacket offers extreme shock, vibration, temperature, and flammability protection.
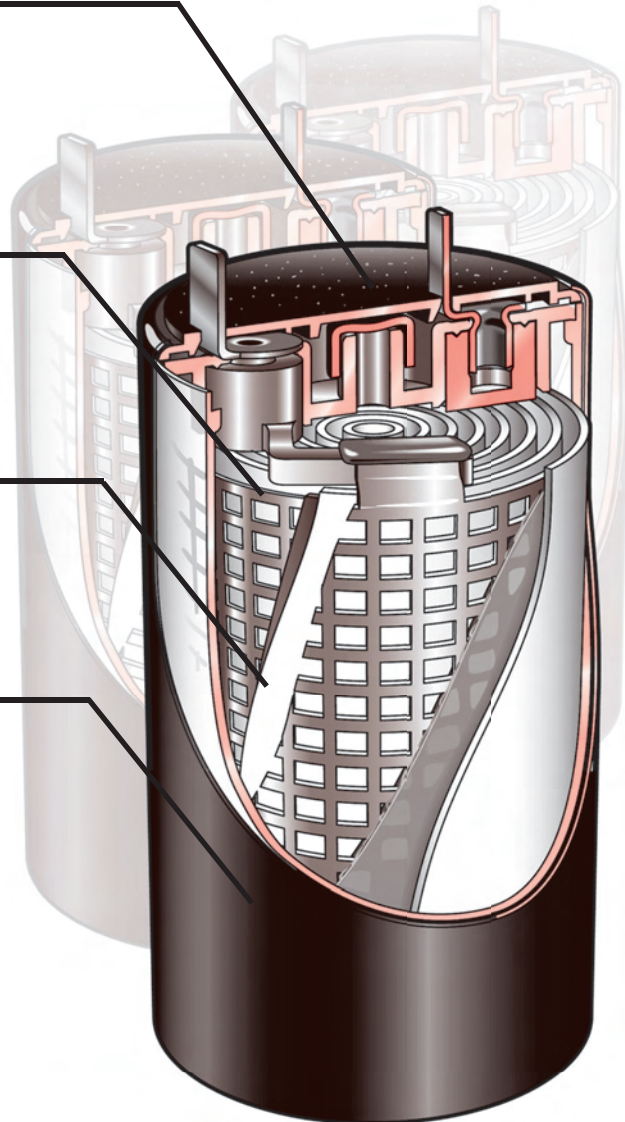
## Table of Contents

## Chapter 1:
## Introducing CYCLON® Batteries

### 1.1 Introduction

The purpose of this guide is to describe the characteristics of the sealed-lead family of rechargeable CYCLON® cells and batteries from EnerSys® in its many different applications. The unique cylindrical design overcomes many limitations of competitive lead-acid systems without sacrificing cost effectiveness, reliability, ruggedness and long life which have always been assets of the lead-acid battery. Some of the features are described below.

### 1.2 Sealed Design

Individual cells and monobloc batteries are sealed to prevent electrolyte leakage. Since the cell operates during its normal life without loss of water, even during continuous overcharge, no water or electrolyte checks are required. Because of the sealed design, the cell, monobloc or battery assembly can be oriented in any position for ease of installation. In addition, the combination of a sealed design and a mechanically operated resealable Bunsen valve allows the cell to be operated even in a vacuum.

### 1.3 Low Temperature Performance

The exceptional low temperature performance of CYCLON batteries have been made possible by the use of plates that provide a high surface area, coupled with a separator system that minimises diffusion and resistance effects. This results in good utilisation of active material and excellent voltage regulation over a wide temperature range.

### 1.4 High Rate Charge & Discharge Capabilities

The thin plate construction of CYCLON batteries contribute to high utilisation of the active plate materials and very low internal impedance. This means that the cells can be discharged at high rates, allowing the use of smaller batteries for short duration, high rate discharges. Another advantage of the very low internal resistance is the fast recharge capability. Depending on the depth of discharge and charge current available, the CYCLON battery cell can be fully charged in a few hours.

### 1.5 Long Life in Float Applications

The high purity of the lead-tin grid (the purity of the lead is in excess of 99.99%) used in CYCLON battery cells results in long life on float charge. Depending on the ambient temperature and the specific product (single cell or monobloc) selected, one can get up to ten (10) years float life at 25°C and 15 years float life at 20°C.

### 1.6 Structural Resistance

The rugged outer metal case of the single cell design increases its resistance to shock, crushing or damage due to dropping, while allowing a very high vent pressure of 50 pounds per square inch (psi) or about 3.4 atmospheres (atm). The cylindrical shape of the monobloc case also allows the highest plastic case vent pressure of 8 psi (0.54 atm), as well as providing resistance to case distortion due to heat.

### 1.7 Packing Flexibility

All CYCLON battery single cells can be used in parallel for additional capacity. The individual cell construction allows the battery to be laid out inside a battery cavity in an almost infinite variety of patterns, maximising space utilisation. Heat sealed combinations of the monoblocs add to the flexibility of mounting configurations as well as contributing to savings in space requirements.

### 1.8 High Power Density

CYCLON batteries have very high power density, particularly at high rates of discharge. Please refer to Appendix A for several graphs and charts that detail these capabilities.

### 1.9 Transportation Classification

The Department of Transportation (DOT) has classified all CYCLON batteries as "**nonspillable wet electric storage batteries.**" Having been tested and found in compliance with section 173.159 (d) of the 49 CFR, subchapter 173.159, CYCLON batteries are exempt and unregulated regarding shipping requirements of DOT 173.159. As a result, **CYCLON® batteries do not have an assigned UN number, nor do they require additional DOT hazard-communication labeling or placarding. CYCLON® batteries may be shipped by air or ground transportation without restriction.**

CYCLON batteries and their outside shipping container must be labeled "nonspillable" or "**nonspillable battery.**" This labeling requirement is to clarify and distinguish to shippers and transporters that all batteries have been tested and determined to be in compliance with DOT HMR 49 Non-Hazardous Materials, and International Civil Aeronautics Organisation (ICAO) and International Air Transport (IATA) Packaging Instruction 806 and Special Provision A67 Vibration and Pressure Differential Tests, and are therefore unregulated and classified as "**nonspillable wet electric storage battery.**"

All CYCLON® cells and batteries are packaged, marked, labeled, and documented according to the appropriate transportation regulations when shipped from an EnerSys® facility. A shipper that fails to follow these same requirements may be subject to substantial civil and/or criminal penalties and may cause a safety hazard.

All CYCLON battery packages must be capable of passing International Safe Transit Association (ISTA) Procedure 1A testing.

Packages weighing no more than 20 lbs. must be packaged in a minimum 200 lb. burst strength or 32 ECT certified carton.

Packages weighing over than 20 lbs. must be packaged in a minimum 275 lb. burst strength or 44 ECT certified carton.

No individual package can exceed a total gross weight of 70 lbs.

It is the responsibility of the shipper to ensure each employee who directly affects hazardous material/dangerous goods transportation safety is appropriately trained in accordance with the selected mode of transportation.

The terminals of CYCLON battery cells can cause shorts if they are not insulated during shipping. Protective caps or other durable inert material must be used to insulate each terminal of each cell unless cells are shipping in the original packaging from EnerSys in full box quantities. Protective caps are available for all cell sizes by contacting EnerSys Customer Service at 1-800-964-2837. International customers should call 1-660-429-6437.

Assembled batteries must have short circuit protection during shipping. Exposed terminals, connectors, or lead wires must be insulated with a durable inert material to prevent exposure during shipping.

**FAILURE TO COMPLY WITH THESE REQUIREMENTS CAN CAUSE A FIRE DURING SHIPPING AND HANDLING!**

**1.10 UL Component Recognition**
All CYCLON batteries are recognised as UL components.

## Chapter 2: Physical Features

**2.1 Single Cell Construction**

Both the positive and negative plates are made of pure lead-tin and are extremely thin. The plates are pasted with lead oxides, separated by an absorbing glass mat separator and spirally wound to form the basic element. Lead busbars are then welded to the exposed positive and negative plate tabs.

The external spade terminals on CYCLON battery single cells are inserted through the polypropylene inner top and are effectively sealed by expansion into the lead busbars. The element is then stuffed into the jar liner and the inner top and liner are bonded together. At this state of construction, the cell is sealed except for the open vent hole.

A unique vacuum fill process then adds sulphuric acid and the Bunsen relief valve is placed over the vent hole. In the manufacture of a single cell, the sealed element is then inserted into the metal can, an outer plastic top added and crimping completes the assembly. The metal case is for mechanical strength and is the principal factor contributing to the high pressure rating of the resealable vent. The cell is now charged for the first time (electrochemically formed).

**2.2 Monobloc Construction**

The monobloc construction differs from single cell construction as it is essentially a battery consisting of multiple cells, each cell element inserted in a single plastic container. Spade terminals are inserted into the molded openings connecting internally to the plate tab lead busbars. Intercell plate tabs are connected by through-the-wall welds. Acid is added using the vacuum fill process, the cover is heat sealed in place and a Bunsen relief valve installed.
The battery is now formation charged.

## Chapter 3: CYCLON® Battery Benefits

**3.1 Introduction**

This chapter is devoted to describing specific performance characteristics of CYCLON batteries that make them a superior battery choice, particularly for demanding applications such as temperature extremes typically encountered in outdoor environments.

**3.2 High Discharge Current**

CYCLON battery cells can be discharged at very high currents while maintaining a reasonably flat voltage profile. This characteristic is achieved because of the high plate surface area and closeness of the plates to each other due to the use of thin plates in a spirally wound construction.

Typical maximum current capabilities of single cells and monoblocs are shown in Table 3-1 below. In all cases, the duration of discharge is one (1) minute to 1.50 volts per cell at an ambient temperature of 25°C (77°F).

Higher currents than those shown in the table may be maintained for durations shorter than one minute. The ability of the cell or monobloc to maintain higher currents is dependent on the magnitude of the current, its duration, the frequency of its application and, most importantly, on the ability of the terminal connection to act as a heat sink and dissipate the heat generated. For high rate applications we strongly recommend testing under actual or simulated application conditions.

**Table 3-1**

| CYCLON® Battery Type | Max. amps to 1.50 VPC |
|---|---|
| D single cell (2.5Ah) | 65 |
| Tall D single cell (4.5Ah) | 65 |
| D monobloc (2.5Ah) | 50 |
| X single cell (5.0Ah) | 65 |
| E single cell (8.0Ah) | 65 |
| X monobloc (5.0Ah) | 50 |
| E monobloc (8.0Ah) | 50 |
| J single cell (12.0Ah) | 100 |
| BC single cell (25.0Ah) | 250 |

## 3.3 Low Temperature Operation

Exceptional low temperature characteristics are maintained through the use of a separator system that minimises resistance and diffusion effects. This feature, combined with a large plate surface area, results in efficient utilisation of active materials and excellent voltage regulation.

Because the cell operates as a "starved" electrolyte system, there is only enough electrolyte to maintain the rated capacity of the cell. The capacity available at low temperatures is a function of both temperature and discharge current.

Figure 3-1 shows another reason why CYCLON® battery cells have good discharge performance at low temperatures.

**Figure 3-1: Internal Resistance Vs. Temperature**
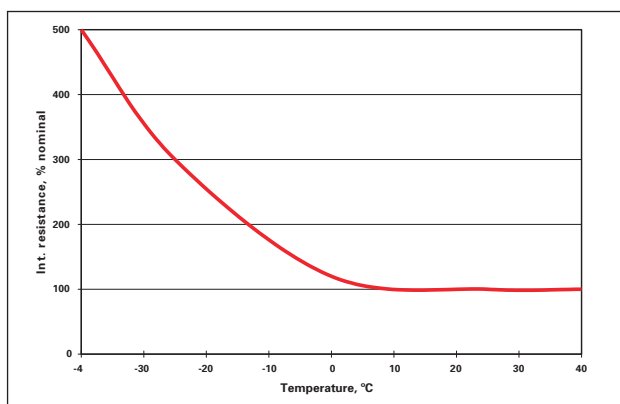


As the temperature drops, the increase in internal resistance is relatively gradual down to a little under 0°C (32°F). This also explains why CYCLON battery cells have excellent low temperature performance.

## 3.4 Position Flexibility

With the starved electrolyte system, the sulphuric acid is absorbed within the cell plates and the glass mat separator. The cell is virtually dry with no free electrolyte, allowing it to be charged, discharged or stored in any position without electrolyte leakage.

## 3.5 Recombinant VRLA Design

One of the most important features of the CYCLON battery design is its **recombinant valve regulated lead-acid (VRLA) design**. This mode of operation is possible because the cell is able to use the oxygen cycle during overcharge. The oxygen, evolved at the positive electrode when the cell is overcharged, is recombined at the negative electrode. A self-resealing valve is provided as a safety vent in case of misapplication or other abuse of the cell that would cause the internal cell pressure to increase.

In CYCLON batteries, water loss is greatly reduced due to two design features. First, because water tends to decompose around impurities in the lead, the rate of such decomposition is reduced due to the high purity of the lead used in CYCLON batteries. Second, the use of high pressure seals contains the gases within the cell, promoting more efficient recombination.

In a conventional lead-acid cell, the charge current electrolyses the water to produce hydrogen from the negative electrode and oxygen from the positive electrode. Thus water is lost from the cell, and it must be replenished by means of frequent topping up with water.

The evolution of the two gases does not occur at the same time due to the fact that the recharge efficiency of the positive electrode is less than that of the negative electrode. This means that oxygen is evolved from the positive plate before the negative plate can generate hydrogen.

As oxygen is evolved from the positive plate, a significant quantity of highly active spongy lead exists on the negative electrode before the negative plate can generate hydrogen. If the oxygen that is generated by the positive plate can be transported to the negative plate, the spongy lead will react rapidly with the oxygen to form lead oxide as shown by the following reaction:

$$2Pb + O_2 \rightarrow 2PbO \, \text{(Eqn. 1)}$$

The movement of oxygen from the positive electrode to the negative electrode is facilitated by the use of highly porous separators that allow the oxygen to diffuse within the cell and cause the reaction defined by Equation 1. The acidic conditions prevailing inside the cell is very conducive to the reaction between lead oxide and the sulphuric acid to form lead sulphate in accordance with Equation 2 below:

$$2PbO + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O \quad \text{(Eqn. 2)}$$

As the lead sulphate is deposited on a surface that generates hydrogen, it (lead sulphate) is reduced to lead and sulphuric acid as indicated by Equation 3:

$$2PbSO_4 + 2H_2 \rightarrow 2Pb + 2H_2SO_4 \quad \text{(Eqn. 3)}$$
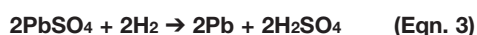
Adding the three equations and cancelling out like terms on either side of the equations, we obtain Equation 4:

$$2H_2 + O_2 \rightarrow 2H_2O \quad \text{(Eqn. 4)}$$
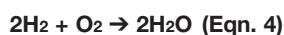
These four equations show the reactions that form the principle of recombination that is employed by the CYCLON® battery product line. By properly designing the cell, recombination efficiencies in excess of 99% are achieved in the CYCLON batteries.

### 3.6 Shock & Vibration Characteristics

The spirally wound plate element is compressed within a polypropylene liner or case, minimising plate movement in high shock or vibration applications. Movement in a vertical direction is also limited by the polypropylene lid design. Overall, the cell has excellent shock and vibration characteristics.

### 3.7 Float Life Characteristics

As noted previously, life expectancy of CYCLON batteries is not limited by loss of electrolyte due to the sealed design. Instead, life expectancy is determined by long-term corrosion of the positive current collecting grid. The corrosion effect on cell capacity is minimal until the cell approaches end-of-life, which is defined as the inability of the cell to provide at least 80% of its rated capacity compared to that of 50% from a standard AGM.

### 3.8 Cycle Life Characteristics

The cycle life of the cell in an application will be a function of the depth of discharge (DOD), temperature and charging rate. Depending on the DOD, the cycle life available can vary from 300 to more than 20,000. However, to get these cycle numbers, the battery must be recharged effectively.

### 3.9 Fast Charging Characteristics

Efficient fast charging can be accomplished using a constant voltage charger. With an initial charge current capability in the $2C_{10}$[1] range the cell can be recharged to better than 95% state of charge in less than one hour. Applications using fast charging must allow for periodic extended charging to maximise life.

### 3.10 Storage Characteristics

The CYCLON battery cell and monobloc may be stored for up to two years at room temperature (25°C or 77°F) and recharged with no loss in cell reliability or performance capabilities. The recharge may be accomplished without resorting to special charging techniques.

When batteries are stored at or near 25°C (77°F) we recommend conducting an OCV audit every 12 months and recharging when OCV readings approach 2.00 volts per cell (VPC). If storage temperatures are significantly higher than 25°C (77°F), even for short durations, the frequency of OCV audits must be increased.

### Chapter 4: Discharging CYCLON® Batteries

#### 4.1 Introduction

Discharge tables and curves for CYCLON batteries are shown in Appendix A. The capacity available from a cell is a complex function of the state of charge, temperature, the rate of discharge and the end of discharge voltage (EODV). The tables provide the discharge performance of these cells to various EODVs. The graphs provide the same information but only to three EODVs.

#### 4.2 Discharge Voltage Profile

Figures 4-1 and 4-2 show the room temperature (25°C/77°F) voltage profile of CYCLON battery cells when subjected to four loads - $C_{10}/10$, $C_{10}/5$, $1C_{10}$ and $2.2C_{10}$.

In all cases, the low internal resistance of the cells allows very stable voltage profiles, regardless of whether the discharge is moderate ($C_{10}/5$ to $C_{10}/10$) or at a high rate ($1C_{10}$ to $2.2C_{10}$).

---

[1] The $C_{10}$ rate of a battery is defined as the charge or discharge current in amperes that is numerically equal to the rated capacity of a cell in ampere-hours at the 10 hr rate of discharge. Thus the $2C_{10}$ rate for a 5Ah cell would be 10 amps.

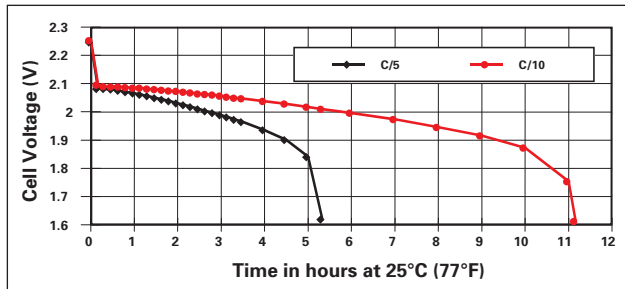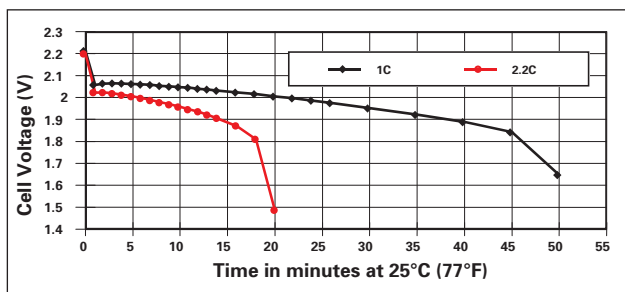**Figure 4-1: CYCLON® Battery Medium Rate Discharge Voltage Profile**



**Figure 4-2: CYCLON® Battery High Rate Voltage Profile**



## 4.3 Discharge Level

The voltage point at which 100% of the usable capacity has been depleted is a function of the discharge rate. For optimum cell life, it is recommended that the battery be disconnected from the load at this end voltage point. The recommended end of discharge voltage (EODV) is a function of the rate of discharge, and these numbers are given in Table 4-1 below:

**Table 4-1**

| Discharge rate in amps | Suggested minimum EODV per cell |
|---|---|
| $0.05C_{10}$ ($C_{10}/20$) | 1.75V |
| $0.10C_{10}$ ($C_{10}/10$) | 1.70V |
| $0.20C_{10}$ ($C_{10}/5$) | 1.67V |
| $0.40C_{10}$ ($C_{10}/2.5$) | 1.65V |
| $1.00C_{10}$ | 1.60V |
| $2.00C_{10}$ | 1.55V |
| $>5.00C_{10}$ | 1.50V |

**NOTE: Discharging a CYCLON® battery cell below these voltage levels or leaving the cell connected to a load in a discharged state may impair the ability of the cell to accept a charge.**

In "overdischarge" conditions, the sulphuric acid electrolyte can be depleted of the sulphate ion and essentially become water, which can create several problems. A lack of sulphate ions as charge conductors will cause the cell impedance to appear high and little charge current to flow. Longer charge time or alteration of charge voltage may be required before normal charging can resume.

Disconnecting the battery from the load will totally eliminate the possibility of an overdischarge, provided that it is put back on recharge immediately after the discharge. Doing so will allow each cell to provide its full cycle life and charge capabilities.

It is important to note that when the load is removed from the battery, its terminal voltage will increase - up to approximately 2 volts per cell. Because of this phenomenon, some hysteresis must be designed into the battery disconnect circuit so that the load is not continuously reapplied to the battery as the battery voltage recovers.

## 4.4 Overdischarge Recovery

Although overdischarging the battery is not recommended, CYCLON® batteries have an excellent tolerance for this type of abuse. The following protocol may be used to recover cells that have been overdischarged. This procedure should not be attempted if the OCV of the battery pack is 1.0 volt per cell (VPC) or less.

1. Bring the battery to room temperature (77ºF or 25ºC).

2. Measure the OCV. Continue to step 3 if it is at least 1.00 VPC; otherwise terminate the procedure and reject the battery.

3. Charge the battery using a 0.05C constant current for 24 hours. The charger should be able to provide a driving voltage as high as 3.0 VPC. Monitor the battery temperature; *discontinue charging if the battery temperature rises by more than 20ºC.*

4. Allow the charged battery to stand on open circuit for 18 hours.

5. Perform a capacity test on the battery and record the amp-hours delivered. The longer the discharge the more reliable the result. This is Cycle 1.

6. Repeat steps (3) to (5). The capacity returned in step 5 is now Cycle 2. If Cycle 2 capacity is greater than Cycle 1 capacity proceed to step 7; otherwise reject the battery.

7. Repeat steps (3) to (5) to get Cycle 3 capacity. Proceed to step 8 if Cycle 3 capacity is equal to or more than Cycle 2 capacity. Reject the battery if Cycle 3 capacity is less than Cycle 2 capacity.

8. If Cycle 3 capacity equals or exceeds Cycle 2 capacity recharge the battery and put it back in service.

## Chapter 5:
## CYCLON® Battery Storage

### 5.1 Introduction

Another area where the CYCLON® battery product has a significant advantage over conventional sealed-lead batteries is storage. This chapter devotes itself to offering the reader useful information on properly exploiting the long storage (shelf) life of CYCLON battery cells and monoblocs.

### 5.2 State of Charge

The state of charge (SOC) of the CYCLON battery cell can be approximated by using the curve given in Figure 5-1. This curve is accurate to within 20% of the true SOC of the cell under consideration, if it has not been charged or discharged within the past 24 hours. The curve is accurate to within 5% if the cell has not seen any activity, charge or discharge, for the past 5 days.

**Figure 5-1: CYCLON® Battery Open Circuit Voltage Vs. State of Charge**
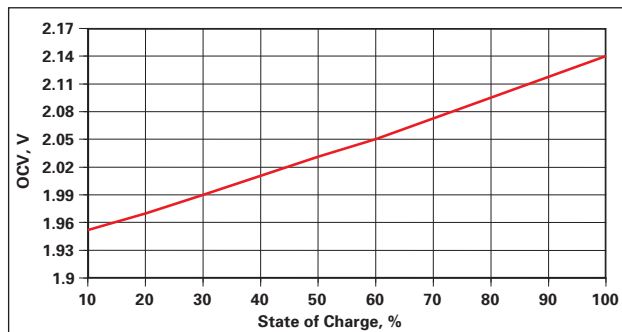


### 5.3 Storage

Most batteries lose their stored energy when allowed to stand on open circuit due to the fact that the active materials are in a thermodynamically unstable state. The rate of self-discharge is dependent both on the chemistry of the system as well as on the temperature at which the battery is stored.

All CYCLON batteries are capable of long storage without damage. Figure 5-2 is a plot of maximum storage time as a function of storage temperature. This curve shows the maximum number of days at any given temperature, from 10°C (50°F) to 65°C (149°F), for the cell to discharge from a fully charged state (about 2.14 volts per cell) down to zero state of charge (1.93 volts per cell). The cell should not be allowed to discharge below 1.93 volts because of the danger of damaging the performance characteristics of the cell permanently.

**Figure 5-2: CYCLON® Battery Storage Time Vs. Temperature**
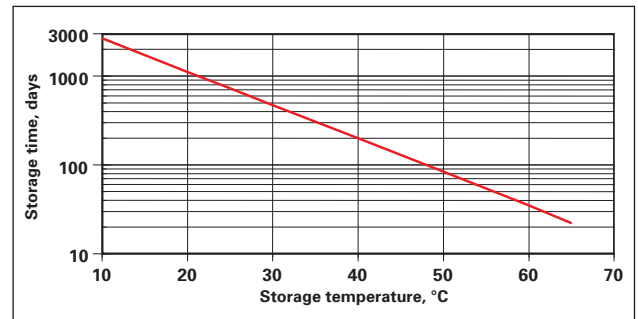


It is important to recognise that the self-discharge rate of CYCLON batteries is non-linear. Thus, the rate of self-discharge changes as the SOC of the cell changes. In other words, the time taken for a cell to discharge from a 100% SOC to 90% SOC is very different from the time it takes to self-discharge from a 20% SOC to a 10% SOC.

## Chapter 6:
## Charging CYCLON® Batteries

### 6.1 Introduction

The superior charging characteristics of CYCLON batteries makes them the power source of choice in demanding applications that require rapid charging. Conventional sealed-lead batteries are not suited for this type of charging where charge currents can be of the order of $2C_{10}$ or higher.

### 6.2 General

Charging CYCLON sealed-lead acid products, like charging other rechargeable batteries, is a matter of replacing the energy depleted during the discharge. Because this process is not 100% efficient, it is necessary to return more than 100% of the energy removed during the discharge.

The CYCLON battery cell uses the gas recombination principle that allows up to 100% of the oxygen generated at up to the $C_{10}/3$ overcharge rate to be recombined to form water at the negative plate, eliminating oxygen outgassing. Hydrogen gas generation has been substantially reduced by the use of pure lead-tin grid material, which has high hydrogen overvoltage. The corrosion of the positive current collecting grid has been reduced by the use of pure lead-tin.

The amount of energy necessary for a complete recharge depends upon how deeply the cell has been discharged, the method of recharge, the recharge time and the temperature. Typically, between 105% and 110% of the discharged ampere-hours must be returned for a full recharge. Thus, for every ampere-hour discharged, one must put back between 1.05 and 1.10 ampere-hours to ensure a full recharge.

If watt-hours rather than ampere-hours are measured, the required overcharge factor will be higher. It is important to note that although the battery can deliver at or near its full capacity prior to receiving the required overcharge, in order to obtain long cycle life, the battery must periodically receive the required overcharge.

Charging can be accomplished by various methods. The objective is to drive current through the cell in the direction opposite that of discharge. Constant voltage (CV) charging is the conventional method for charging lead-acid cells, and is acceptable for CYCLON® battery cells. However, constant current (CC), taper current and variations thereof can also be used.

### 6.3 Series-parallel CYCLON® Battery Systems

While there are no theoretical limits on the number of parallel strings in a CYCLON battery pack, in practical situations that limitation is imposed by (a) whether the application is floating or cyclic in nature and (b) the charger design.

To avoid charge imbalance in a cyclic application, there should be no more than five (5) parallel strings. Further, the minimum inrush current that the charger should be able to provide, assuming single step constant voltage charger is 5C for a five-string system. If a more sophisticated charge algorithm such as the adaptive IUI charge profile is used, the minimum inrush can be reduced to 2C for the five-string battery pack, allowing 0.4C charge current per string.

These minimum current values are critical in a cyclic environment as the battery is on charge for only limited periods of time, creating a potential for significant undercharge. Undercharging batteries in cyclic applications leads to premature capacity loss and early end of life.

Batteries in a float application spend most of their time on float charge. This allows all strings in a series-parallel system to be charged adequately, eliminating the need to restrict the number of parallel strings. However, it is still good practice to have no more than five parallel strings, regardless of the nature of the application.

### 6.4 Constant Voltage (CV) Charging

Constant voltage (CV) charging is the most efficient method of charging CYCLON battery sealed-lead products.

Tables 6-1 and 6-2 in the next section on fast charging show the recharge times as a function of charge voltage and inrush current at 25°C (77°F). The minimum inrush current for single voltage level charging is of the order of $0.4C_{10}$ ($C_{10}/2.5$), and one must allow about sixteen (16) hours for a full charge under repetitive cycling conditions. If the CV charger that is used has an inrush current less than $C_{10}/2.5$, then either the charge time allowed must be increased or special charge algorithms must be evaluated.

Generally speaking, when the initial current is less than $C_{10}/2.5$, the charge times must be lengthened by the hourly rate at which the charger is limited. In other words, if the charger is limited to the $C_{10}/10$ rate, then 10 hours should be added, giving a total charge time of 26 hours. Using the same rule, if the charger is limited to the $C_{10}/5$ rate, then 5 hours should be added and recharge would require about 21 hours instead of 16 hours.

Note that there are no practical limitations on the maximum current imposed by the charging characteristics of the CYCLON battery cell under constant voltage charge.

**NOTE: It is important to keep in mind that for cyclic applications the charge voltage must be in the 2.45 to 2.50 volts per cell (VPC) range. Lowering the voltage to under 2.45 VPC in such an application will lead to a rapid loss in capacity, *regardless of the magnitude of the inrush current.***

### 6.5 Fast Charging or Cyclic Charging

A fast charge is broadly defined as a method of charge that will return the full capacity of a cell in less than four hours. However, many applications require a return to a high state of charge in one hour or less. Prior to the development of CYCLON batteries, commercially available lead-acid batteries required charging times of greater than four hours to be brought up to a high state of charge.

Unlike conventional parallel flat plate lead-acid cells, the CYCLON battery cell uses a starved electrolyte system where the majority of the electrolyte is contained within a highly retentive fibrous glass mat separator, creating the starved environment necessary for homogeneous gas phase transfer.

The gassing problem inherent in flooded electrolyte sealed-lead batteries that utilised alloyed lead is not evident with the CYCLON battery system, as the extremely high purity of lead minimises the oxygen and hydrogen gas generation during overcharge and any oxygen gas generated is able to recombine within the sealed cell. The high plate surface area of the thin plates used in CYCLON battery cells reduces the current density to a level far lower than normally seen in fast charge of conventional lead-acid cells, thereby enhancing the fast charge capabilities.

Tables 6-1 and 6-2 display the relationships between charge rate and percent of previous discharge capacity returned to the cell vs. time at 2.45 volts per cell CV charge. Prior to the recharges, the CYCLON battery cell were discharged to 100% DOD.

### Table 6-1 (1.5C$_{10}$ inrush)

| Charge time at 2.45VPC | Capacity Returned |
|---|---|
| 17 min. | 50% |
| 27 min. | 80% |
| 31 min. | 90% |
| 60 min. | 100% |

### Table 6-2 (2.5C$_{10}$ inrush)

| Charge time at 2.45VPC | Capacity Returned |
|---|---|
| 12 min. | 50% |
| 19 min. | 80% |
| 24 min. | 90% |
| 40 min. | 100% |

These tables demonstrate the superior fast charge capabilities of the CYCLON® line of sealed-lead batteries. The numbers in Table 6-1 were generated using an initial current in the 1.5C$_{10}$ range while those in Table 6-2 were generated using a current limit in the 2.5C$_{10}$ range.

Increasing the magnitude of the inrush current has a dramatic impact on the total time to recharge the cells -only 40 minutes to return 100% of previously discharged capacity at 2.5C$_{10}$ compared with 60 minutes at 1.5C$_{10}$ to reach the same mark. This is a useful result to keep in mind when designing battery systems for applications that require rapid opportunistic charging.

Although CYCLON battery cells do not require a current limit (initial current inrush) when being charged by a CV source, most practical applications have chargers that have limited power handling capabilities, thereby also restricting the current limit.

Cyclic charging tests were conducted using a CV charger that had only a 1A (C$_{10}$/2.5 on a 2.5Ah cell) current limit and the charge times shown in Table 6-3. The charge voltage, however, was set at 2.45 VPC. The last column shows the number of cycles one may expect for specific DOD numbers.

### Table 6-3

| Depth of discharge, %[2] | Charge[3] time, hr. | Number of cycles |
|---|---|---|
| Up to 30 | 5 | 2500 |
| 31 to 50 | 8 | 1700 |
| 51 to 100 | 16 | 300 |

## 6.6 Float Charging

When CYCLON battery products are in a purely float application at an ambient temperature of 25°C (77°F), the recommended charge voltage setting is 2.25 to 2.30 volts per cell (VPC). We also recommend that this charge voltage be temperature compensated, as outlined in the next section.

## 6.7 Temperature Compensation

High temperatures accelerate the rate of the reactions that reduce the life of a cell. At increased temperatures, the voltage necessary for returning full capacity to a cell in a given time is reduced because of the increased reaction rates within the battery.

To maximise life, a negative charging temperature coefficient of approximately ±3mV per cell per °C variation from 25°C (77°F) is used at temperatures significantly different from 25°C (77°F). This coefficient is negative - as the ambient temperature increases the charge voltage must be reduced, and vice versa. Figure 6-1 shows the variation of float voltage with temperature.

It is important to note that even if the charge voltage is perfectly compensated for high ambient temperature, the float life expectancy of the cell would still be reduced. This is due to the fact that while the charge currents are lowered because of lower charge voltages, the high ambient temperature continues to have a negative influence on the life of the battery. Thus, temperature compensation of the charge voltage only partially offsets the impact of high ambient temperature on the float life of the cell.

### Figure 6-1: Variation of Charge Voltage with Temperature



Applied battery charging voltage vs temperature
2.45 VPC@ 25°C for cyclic (fast) charge
2.27 VPC@ 25°C for float (slow) charge

Theoretical cycling (ideal)
$V=0.00004T^2 - 0.006T + 2.5745$

Theoretical float (ideal)
$V=0.00004T^2 - 0.006T + 2.3945$
and 2.20VPC minimum

[2] Discharged at C$_{10}$/5 (460mA) to 1.70 VPC
[3] Constant voltage charge at 2.45 VPC with inrush current limited to 1A (C$_{10}$/2.5 for a 2.5Ah cell)
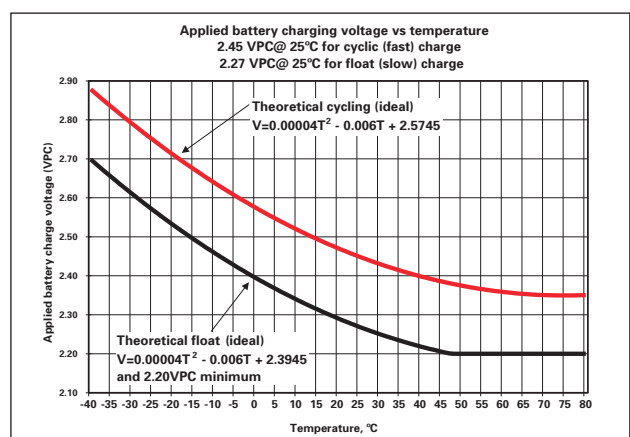
## 6.8 Constant Current (CC) Charging

Constant current (CC) charging is another efficient method of charging CYCLON® battery single cells and monoblocs. CC charging of a cell or battery is accomplished by the application of a nonvarying current source. This charge method is especially effective when several cells are charged in series since it tends to eliminate any charge imbalance in a battery. CC charging charges all cells in the battery.
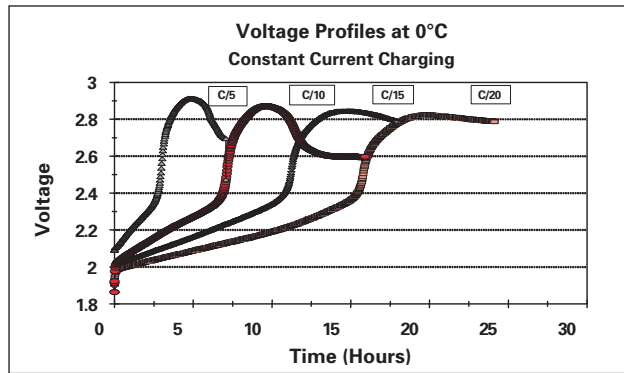
### Figure 6-2: Constant Current Charging at 0°C



Voltage Profiles at 0°C
Constant Current Charging

### Figure 6-3: Constant Current Charging at 25°C



Voltage Profiles at 25°C
Constant Current Charging

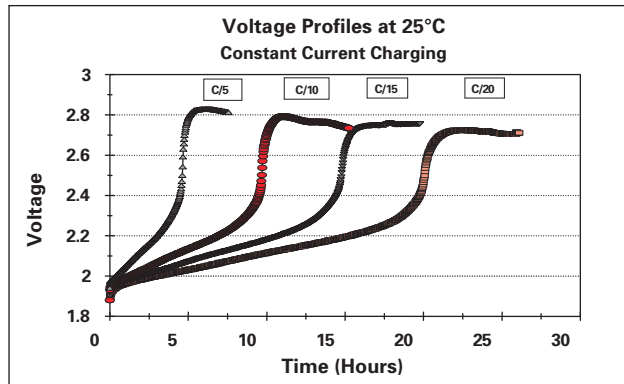### Figure 6-4: Constant Current Charging at 45°C



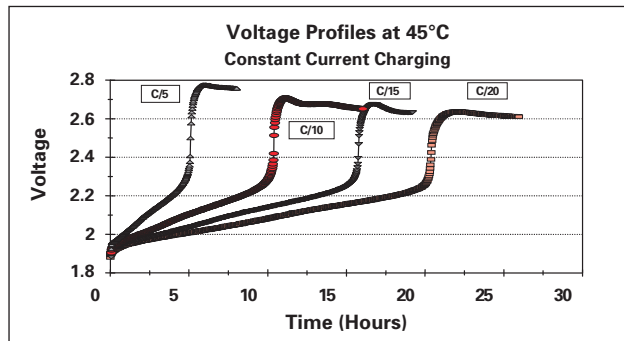Voltage Profiles at 45°C
Constant Current Charging

Figure 6-2 is a family of curves depicting cell voltage vs. time at different CC charging rates at an ambient temperature of 0°C (32°F). Figures 6-3 and 6-4 show the same curves bit at two different temperatures - 25°C (77°F) and 45°C (113°F), respectively. Table 6-4 summarises these three graphs.

**Table 6-4**

| Parameter | Temperature | C/5 | C/10 | C/15 | C/20 |
|---|---|---|---|---|---|
| Peak Voltage, volts per cell | 0°C (32°F) | 2.91 | 2.87 | 2.84 | 2.82 |
| | 25°C (77°F) | 2.83 | 2.79 | 2.76 | 2.73 |
| | 45°C (113°F) | 2.78 | 2.71 | 2.67 | 2.64 |
| Time to reach peak voltage, hours | 0°C (32°F) | 2.91 | 2.87 | 2.84 | 2.82 |
| | 25°C (77°F) | 2.83 | 2.79 | 2.76 | 2.73 |
| | 45°C (113°F) | 2.78 | 2.71 | 2.67 | 2.64 |

As shown by these curves, the voltage of the cell rises sharply as the full charge state is approached. This increase in voltage is caused by the plates going into overcharge when the majority of the active material on the plates has been converted from lead sulphate to spongy lead on the negative plate and lead dioxide on the positive plate.

The voltage increase will occur at lower states of charge when the cell is being charged at higher rates. This is because at the higher CC charge rates, the charging efficiency is reduced. The voltage curves in Figures 6-2 to 6-4 are different from those of a conventional lead-acid cell due to the effect of the recombination of gases on overcharge within the pure lead-tin system.

While CC charging is an efficient method of charging, it requires a greater degree of control to prevent serious overcharge. Continued application at rates above $C_{10}/500$, after the cell is fully charged, will be detrimental to the life of the cell.

At overnight charge rates ($C_{10}/10$ to $C_{10}/20$), the large increase in voltage at the nearly fully-charged state is a useful indicator for terminating or reducing the rates for a CC charger. If the rate is reduced to between $C_{10}/1000$ and $C_{10}/500$, the cell can be left connected continuously and yield a float life up to 8 to 10 years at room temperature (25°C/77°F).

These graphs and charts reflect data obtained from CYCLON cells that had been cycled three times at the $C_{10}/5$ rate. Thus, these numbers should not be treated as specification values but rather as guidelines to follow when developing or using a CC charger.

### 6.9 Taper Current Charging

Although taper current chargers are among the least expensive types of chargers, their lack of voltage regulation can be detrimental to the life of any cell or battery. While CYCLON® batteries have a superior ability to withstand charge voltage variations, some caution in using taper chargers is recommended.

A taper charger contains a transformer for voltage reduction and a half-wave or full-wave rectifier for converting the AC input into a DC output. The output characteristics are such that as the voltage of the battery rises during charge, the charging current decreases. This effect is achieved by using proper wire size and turns ratio.

Basically, the turns ratio from primary to secondary determines the output voltage at no load, and the wire size in the secondary determines the current at a given voltage. The transformer is essentially a constant voltage transformer that depends entirely on the AC (input) line voltage regulation for its output voltage regulation.

Because of the crude method of regulation, any changes in input line voltage directly affect the charger output. Depending on the charger design, the output-to-input voltage change can be more than a direct ratio. For example, a 10% line voltage change can produce a 13% change in the output voltage.

There are several charging parameters that must be met. The parameter of main concern is the recharge time to 100% nominal capacity for cyclic application. This parameter can primarily be defined as the charge rate available to the cell when the cell is at 2.20 volts (representing the charge voltage at which approximately 50% of the charge has been returned at normal charge rates between $C_{10}/10$ and $C_{10}/20$) and 2.50 volts (representing the voltage point at which the cell is in overcharge).

Given the charge rate at 2.20 volts, the recharge time for a taper current charger can be defined by the following equation:

$$\text{Recharge time} = \frac{1.10 \times C_D}{C_{2.2V}}$$

In the equation above for the recharge time using a taper charger, $C_D$ represents the discharged capacity in ampere-hours while $C_{2.2V}$ is the charge current delivered at 2.20 VPC. The 1.10 multiplier represents the 5% to 10% overcharge that is recommended for a complete recharge.

It is recommended that the charge current rate at 2.50 volts be between $C_{10}/50$ maximum and $C_{10}/100$ minimum to insure that the battery will be recharged at normal rates and that the battery will not be severely overcharged if the charger is left connected for extended time periods.

### 7.1 Introduction

All batteries have extremely variable service life, depending upon the type of cycle, environment, and charge to which the cell or battery is subjected during its life. CYCLON batteries are no exception to this rule. There are two basic types of service life: cycle life and float life.

### 7.2 Cycle Life

A cyclic application is basically an application where the discharge and charge times are of about the same order. The cycle life of a battery is defined as the number of cycles[4] a battery delivers before its capacity falls below the acceptable level, usually defined as 80% of rated capacity.

Several factors influence the cycle life available from a battery. The depth of discharge (DOD) is an important variable affecting the cycle life. For the CYCLON battery series, the cycle life expectancy is about 300 full DOD cycles. One can obtain more cycles with lower depths of discharge as Figure 7-1 shows.

**Figure 7-1: Cycle Life and DOD for CYCLON® Battery Cells**
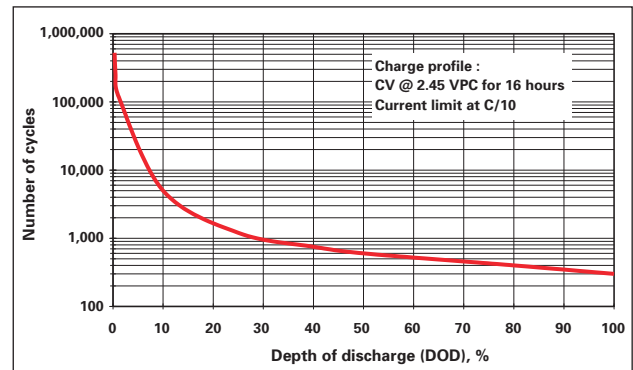


The quality of recharge is a critical determinant of the life of a battery in a given cyclic application. In contrast to float applications where more than adequate time is allowed for a full recharge, in cyclic applications a major concern is whether the batteries are being fully recharged in the time available between discharges. If the recharge time is insufficient, the battery will "cycle down" or lose capacity prematurely.

In our experience, undercharging is a leading cause of premature capacity loss in cyclic applications. Although undercharge and overcharge are both detrimental to the life of a battery, the time frame over which the effects of either undercharge or overcharge are felt is very different.

---

[4] A battery is said to have completed a cycle if it starts out from a fully charged condition, completes a discharge and is then fully recharged, regardless of the depth of discharge.

The impact of undercharging is felt much earlier than that of overcharge. Hence, for cyclic applications, where the calendar life is relatively short, it is very important to ensure that the batteries are not undercharged. For cyclic applications, it is preferable to err on the side of overcharge than on the side of undercharge.

The recommended charge voltage for cyclic applications is higher than that for float applications. This is due to the fact that in cyclic applications the time available for a recharge is substantially less than that for float applications. To compensate for the shorter recharge time, the charging voltage, and thereby the charging current, in cyclic applications is raised so that more ampere-hours can be supplied to the battery in a given time.

### 7.3 Float Life

The design float life of CYCLON® batteries is up to eight (8) to ten (10) years at room temperature (25°C/77°F) and under proper charging conditions. This design life has been confirmed by the use of accelerated testing methods that are widely accepted by both manufacturers and users of sealed-lead batteries. High temperatures are used to accelerate the aging process of the battery under test.

The primary failure mode of CYCLON batteries can be defined as positive current collecting grid corrosion and growth. Because this corrosion and growth are the result of chemical reactions within the cell, the rate of corrosion and growth increases with increasing temperature as expressed by the widely-accepted Arrhenius equation, which shows that the float life of a VRLA cell is cut in half for roughly every 8°C (14.4°F) rise in ambient temperature. Figure 7-2 shows this relationship between ambient temperature and float life for CYCLON single cells that have a float life of ten years at 25°C (77°F).

**Figure 7-1: Cycle Life and DOD for CYCLON® Battery Cells**
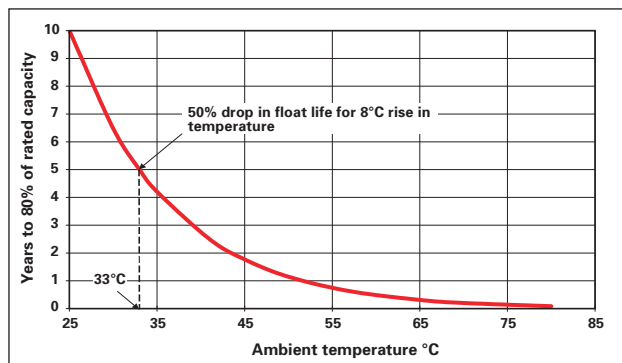


A ten year battery, such as a CYCLON battery single cell pack will last for five years at 33°C (91.4°F) and only 2 1/2 years at 41°C (105.8°F).

## Chapter 8:
## Safety Issues

### 8.1 Introduction

There are two main considerations relative to the application of CYCLON cells and batteries that should be recognised to assure that the usage is safe and proper. These are gassing and shorting.

### 8.2 Gassing

Lead-acid batteries produce hydrogen and oxygen gases internally during charging and overcharging. The gases released or diffused must not be allowed to accumulate. An explosion could occur if a spark were introduced.

During normal charging operation, some hydrogen gas is released (vented) or diffused through the container walls. The pure lead-tin grid construction as well as the extremely high purity of lead oxides and sulphuric acid used in the manufacture of the CYCLON battery cell all serve to minimise the amount of hydrogen gas produced.

The minute quantities of gases that are released or diffused from the CYCLON battery cell with recommended rates of charge and overcharge will normally dissipate rapidly into the atmosphere. Hydrogen gas is difficult to contain in anything but a metal or glass enclosure. It can permeate a plastic container at a relatively rapid rate.

Table 8-1 illustrates how little gas is generated by CYCLON battery cells when they are under charge. The chart also shows how much ventilation is needed to keep hydrogen gas below 1%, 2% and 4% concentration levels.

The use of this table can be understood by an example. Suppose you have a 120V CYCLON pack using ten of the 12V, 25Ah BC cells packs and these batteries are in a float application with the charger set at 2.27 VPC. As a safety measure you want to design a ventilation system that will keep hydrogen gas accumulation to less than 1%.

Looking at the 1% cell under the 2.27 VPC column (shaded and boldfaced), each 12V BC pack will require 0.0032 cubic feet of airflow per hour to limit the concentration of hydrogen to 1%. Since there are ten 12V packs, the ventilation system should be designed for an airflow of 0.032 cubic feet per hour. This is a very small amount of airflow.

Because of the characteristics of gases and the relative difficulty in containing them, most applications will allow for their release into the atmosphere. If any CYCLON batteries are being designed into a gas-tight container, precautions must be taken so that the gases produced during charge can be released into the atmosphere. If hydrogen is allowed to accumulate and mix with the atmosphere at a concentration ranging from 4% to 75% by volume, an explosive mixture is formed that would be ignited in the presence of a flame or spark.

Another consideration is the potential failure of the charger. If the charger malfunctions, causing higher-than-recommended charge rates, substantial volumes of hydrogen and oxygen will be vented from the cell. This mixture is explosive and should not be allowed to accumulate. Therefore, despite its significant advantages over other lead-acid batteries, the CYCLON® cells/batteries SHOULD NEVER BE CHARGED IN A GAS-TIGHT CONTAINER.

### 8.3 Shorting

CYCLON batteries have very low internal impedance and thus are capable of delivering high currents if externally short circuited. The resultant heat can cause severe burns and is a potential fire hazard. Particular caution should be used when the person working near the open terminals of cells or batteries is wearing metal rings or watchbands.

Accidentally placing metal articles across the terminals could result in severe skin burns. It is a good practice to remove all metallic items such as watches, bracelets and personal jewellery when working on or around battery terminals.

As a further precaution, when installing batteries or working on them, insulating gloves should be worn and only insulated tools should be used to prevent accidental short circuits.

**Table 8-1**

| 12V Battery | Hydrogen gas evolved per battery, cc/sec. | | Cu. ft/hr. of airflow to keep hydrogen accumulation below: | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **2.27 VPC** | **2.45 VPC** | **2.27 VPC** | | | **2.45VPC** | | |
| | | | **1%** | **2%** | **4%** | **1%** | **2%** | **4%** |
| 2.5Ah (D) | 0.00003 | 0.0003 | 0.0004 | 0.0002 | 0.0001 | 0.0038 | 0.0019 | 0.0010 |
| 4.5Ah (DT) | 0.00005 | 0.0005 | 0.00064 | 0.00032 | 0.00016 | 0.00636 | 0.00318 | 0.00159 |
| 5Ah (X) | 0.000052 | 0.00052 | 0.00066 | 0.00033 | 0.00017 | 0.00661 | 0.00331 | 0.00165 |
| 8Ah (E) | 0.00008 | 0.0008 | 0.0010 | 0.0005 | 0.0003 | 0.0102 | 0.0051 | 0.0025 |
| 12Ah (J) | 0.0012 | 0.00012 | 0.0015 | 0.0008 | 0.0004 | 0.0153 | 0.0076 | 0.0038 |
| 25Ah (BC) | 0.00025 | 0.0025 | 0.0032 | 0.0016 | 0.0008 | 0.0318 | 0.0159 | 0.0079 |

## Appendix A

### Figure A-1: Single Cell CC Graphs to 1.67 VPC



**Hours to 1.67 VPC at 25°C/77°F**

Legend: D, TD, X, E, J, BC
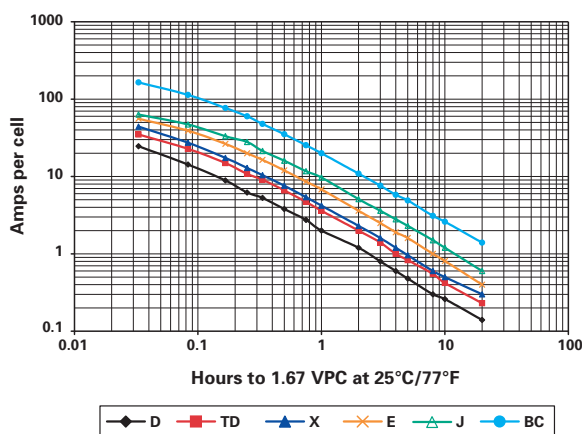
### Table A-1: Amperes per Single Cell Data to 1.67 VPC

| Run Time | D | Tall D | X | E | J | BC |
|---|---|---|---|---|---|---|
| 2 min. | 24.6 | 34.9 | 44.1 | 55.9 | 63.3 | 164.7 |
| 5 min. | 14.3 | 22.8 | 27.3 | 39.0 | 47.1 | 113.6 |
| 10 min. | 8.9 | 14.9 | 17.4 | 26.4 | 33.2 | 76.7 |
| 15 min. | 5.9 | 10.8 | 12.9 | 20.0 | 27.9 | 60.0 |
| 20 min. | 5.3 | 9.1 | 10.4 | 16.4 | 21.4 | 47.8 |
| 30 min. | 3.8 | 6.6 | 7.6 | 12.0 | 16.0 | 35.2 |
| 45 min. | 2.75 | 4.7 | 5.4 | 8.6 | 11.7 | 25.4 |
| 1 hr. | 1.9 | 3.6 | 4.2 | 6.8 | 9.7 | 20.0 |
| 2 hr. | 1.2 | 2.0 | 2.3 | 3.6 | 5.1 | 10.9 |
| 3 hr. | 0.80 | 1.4 | 1.6 | 2.5 | 3.6 | 7.6 |
| 4 hr. | 0.60 | 1.0 | 1.2 | 1.9 | 2.8 | 5.8 |
| 5 hr. | 0.48 | 0.83 | 0.96 | 1.6 | 2.3 | 4.9 |
| 8 hr. | 0.30 | 0.55 | 0.60 | 1.0 | 1.5 | 3.1 |
| 10 hr. | 0.26 | 0.42 | 0.50 | 0.81 | 1.2 | 2.6 |
| 20 hr. | 0.14 | 0.23 | 0.30 | 0.40 | 0.60 | 1.4 |

## Table A-2: Watts per Single Cell Data to 1.67 VPC

| Run Time | D | Tall D | X | E | J | BC |
|----------|------|--------|------|------|------|-------|
| 2 min. | 42.2 | 52.9 | 62.4 | 85.3 | 95.2 | 269.3 |
| 5 min. | 25.5 | 39.0 | 44.2 | 64.4 | 79.7 | 197.6 |
| 10 min. | 16.3 | 27.3 | 30.5 | 45.8 | 60.1 | 138.7 |
| 15 min. | 12.3 | 21.2 | 23.6 | 36.0 | 48.4 | 108.2 |
| 20 min. | 10.0 | 17.3 | 19.4 | 29.8 | 40.7 | 89.3 |
| 30 min. | 7.3 | 12.8 | 14.4 | 22.3 | 31.0 | 66.7 |
| 45 min. | 5.3 | 9.3 | 10.4 | 16.3 | 23.0 | 48.9 |
| 1 hr. | 4.2 | 7.3 | 8.2 | 12.9 | 18.3 | 38.7 |
| 2 hr. | 2.3 | 3.9 | 4.5 | 7.1 | 10.2 | 21.5 |
| 3 hr. | 1.6 | 2.7 | 3.1 | 4.9 | 7.1 | 15.0 |
| 4 hr. | 1.2 | 2.1 | 2.4 | 3.8 | 5.5 | 11.6 |
| 5 hr. | 1.0 | 1.7 | 1.9 | 3.1 | 4.5 | 9.5 |
| 8 hr. | 0.70 | 1.1 | 1.2 | 2.0 | 2.9 | 6.2 |
| 10 hr. | 0.50 | 0.90 | 1.0 | 1.6 | 2.3 | 5.1 |
| 20 hr. | 0.30 | 0.46 | 0.50 | 0.80 | 1.2 | 2.7 |

Figure A-2: Single Cell CP Graphs to 1.67 VPC

Watts per cell vs. Hours to 1.67 VPC at 25°C/77°F

D (2.5Ah)  X (5.0Ah)  J (12.0Ah)
TD (4.5Ah)  E (8.0Ah)  BC (25.0Ah)
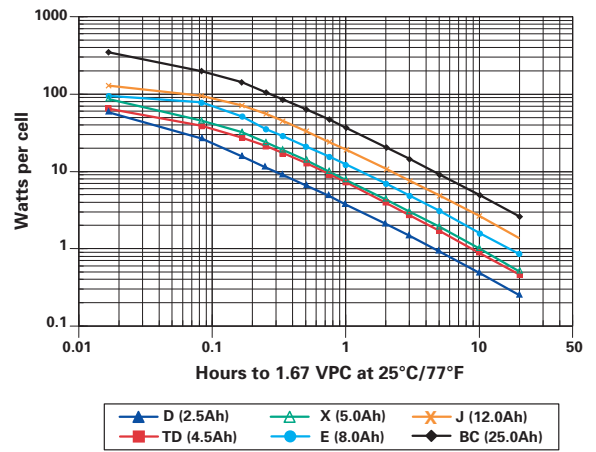
## Table A-3: Monobloc Amperes per Cell Data to 1.67 VPC

| Run Time | D Monobloc | X Monobloc | E Monobloc |
|----------|-----------|------------|------------|
| 2 min. | 24.6 | 44.1 | 55.9 |
| 5 min. | 14.3 | 27.3 | 39.0 |
| 10 min. | 8.9 | 17.4 | 26.4 |
| 15 min. | 6.1 | 13.0 | 19.0 |
| 20 min. | 5.3 | 10.4 | 16.4 |
| 30 min. | 3.8 | 7.6 | 12.0 |
| 45 min. | 2.75 | 5.4 | 8.6 |
| 1 hr. | 2.0 | 4.2 | 6.3 |
| 2 hr. | 1.2 | 2.3 | 3.6 |
| 3 hr. | 0.80 | 1.6 | 2.5 |
| 4 hr. | 0.60 | 1.2 | 1.9 |
| 5 hr. | 0.50 | 1.0 | 1.5 |
| 8 hr. | 0.30 | 0.60 | 1.0 |
| 10 hr. | 0.26 | 0.50 | 0.80 |
| 20 hr. | 0.14 | 0.30 | 0.40 |

Figure A-3: Monobloc CC Graphs to 1.67 VPC

Amps per cell vs. Hours to 1.67 VPC at 25°C/77°F

D monobloc  X monobloc  E monobloc
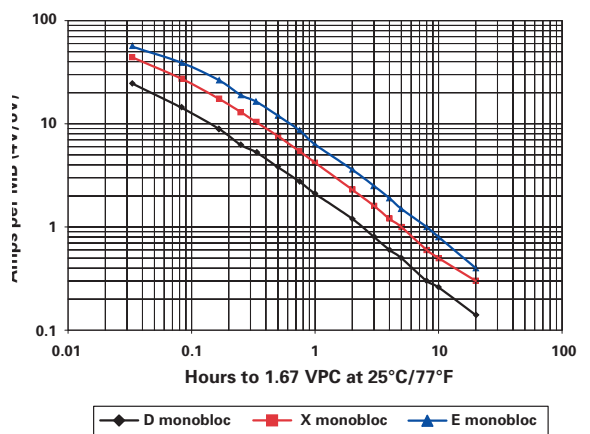
## Table A-4: Monobloc Watts per Cell Data to 1.67 VPC

| Run Time | D Monobloc | X Monobloc | E Monobloc |
|----------|-----------|------------|------------|
| 2 min. | 42.2 | 62.4 | 85.3 |
| 5 min. | 25.5 | 44.2 | 64.4 |
| 10 min. | 16.3 | 30.5 | 45.8 |
| 15 min. | 12.3 | 23.6 | 36.0 |
| 20 min. | 10.0 | 19.4 | 29.8 |
| 30 min. | 7.3 | 14.4 | 22.3 |
| 45 min. | 5.3 | 10.4 | 16.3 |
| 1 hr. | 4.2 | 8.2 | 12.9 |
| 2 hr. | 2.3 | 4.5 | 7.1 |
| 3 hr. | 1.6 | 3.1 | 4.9 |
| 4 hr. | 1.2 | 2.4 | 3.8 |
| 5 hr. | 1.0 | 1.9 | 3.1 |
| 8 hr. | 0.70 | 1.2 | 2.0 |
| 10 hr. | 0.50 | 1.0 | 1.6 |
| 20 hr. | 0.30 | 0.50 | 0.80 |

Figure A-4: Monobloc CP Graphs to 1.67 VPC

Watts per cell vs. Hours to 1.67 VPC at 25°C/77°F

D monobloc  X monobloc  E monobloc

## Figure A-5: 2.5Ah Single Cell Discharge to 1.75 VPC
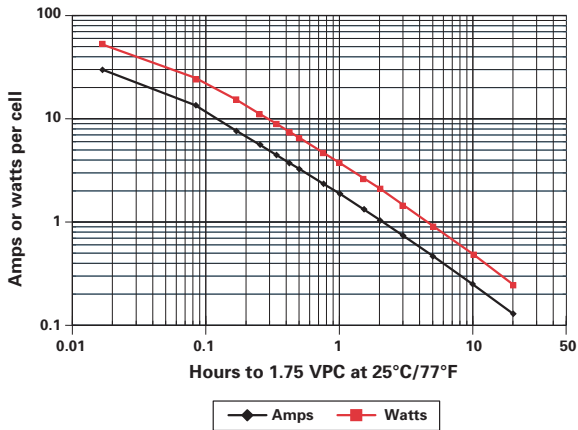


**Table A-5: 2.5Ah Single Cell Data to 1.75 VPC**

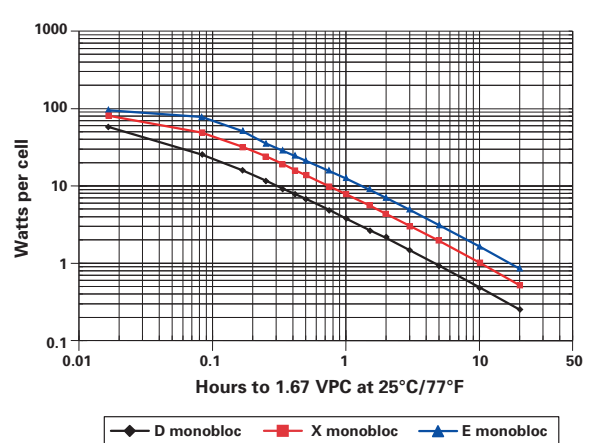| Run Time at 25°C | Amperes per 2.5Ah Cell | Watts per 2.5Ah Cell |
|---|---|---|
| 2 min. | 21.2 | 37.7 |
| 5 min. | 13.1 | 23.9 |
| 10 min. | 8.4 | 15.7 |
| 15 min. | 6.3 | 11.9 |
| 20 min. | 5.1 | 9.7 |
| 30 min. | 3.7 | 7.1 |
| 45 min. | 2.7 | 5.2 |
| 1 hr. | 2.1 | 4.1 |
| 2 hr. | 1.15 | 2.3 |
| 3 hr. | 0.80 | 1.6 |
| 4 hr. | 0.60 | 1.2 |
| 5 hr. | 0.50 | 1.0 |
| 8 hr. | 0.32 | 0.65 |
| 10 hr. | 0.25 | 0.50 |
| 20 hr. | 0.14 | 0.30 |

## Figure A-6: 2.5Ah Single Cell Discharge to 1.85 VPC
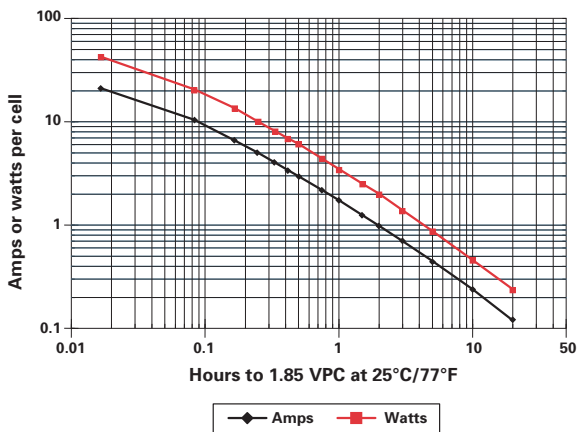


**Table A-6: 2.5Ah Single Cell Data to 1.85 VPC**

| Run Time at 25°C | Amperes per 2.5Ah Cell | Watts per 2.5Ah Cell |
|---|---|---|
| 2 min. | 17.0 | 31.0 |
| 5 min. | 11.3 | 21.0 |
| 10 min. | 7.6 | 14.0 |
| 15 min. | 5.8 | 11.2 |
| 20 min. | 4.7 | 9.2 |
| 30 min. | 3.5 | 6.9 |
| 45 min. | 2.5 | 5.0 |
| 1 hr. | 2.0 | 4.0 |
| 2 hr. | 1.1 | 2.2 |
| 3 hr. | 0.80 | 1.5 |
| 4 hr. | 0.60 | 1.2 |
| 5 hr. | 0.50 | 1.0 |
| 8 hr. | 0.30 | 0.60 |
| 10 hr. | 0.25 | 0.50 |
| 20 hr. | 0.13 | 0.27 |

## Figure A-7: 4.5Ah Single Cell Discharge to 1.75 VPC
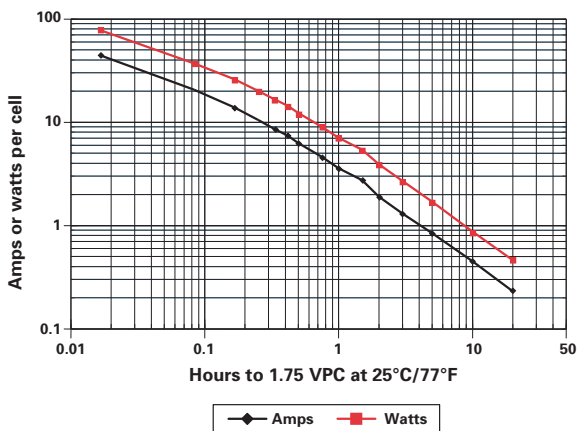


**Table A-7: 4.5Ah Single Cell Data to 1.75 VPC**

| Run Time at 25°C | Amperes per 4.5Ah Cell | Watts per 4.5Ah Cell |
|---|---|---|
| 2 min. | 30.0 | 50.3 |
| 5 min. | 20.6 | 37.1 |
| 10 min. | 13.9 | 26.0 |
| 15 min. | 10.6 | 20.2 |
| 20 min. | 8.6 | 16.6 |
| 30 min. | 6.3 | 12.3 |
| 45 min. | 4.6 | 9.0 |
| 1 hr. | 3.6 | 7.1 |
| 2 hr. | 1.9 | 3.9 |
| 3 hr. | 1.3 | 2.7 |
| 4 hr. | 1.0 | 2.0 |
| 5 hr. | 0.84 | 1.7 |
| 8 hr. | 0.54 | 1.1 |
| 10 hr. | 0.44 | 0.87 |
| 20 hr. | 0.23 | 0.45 |

## Table A-8: 4.5Ah Single Cell Data to 1.85 VPC

| Run Time at 25°C | Amperes per 4.5Ah Cell | Watts per 4.5Ah Cell |
|---|---|---|
| 2 min. | 24.4 | 47.1 |
| 5 min. | 17.7 | 33.7 |
| 10 min. | 12.4 | 23.6 |
| 15 min. | 9.7 | 18.4 |
| 20 min. | 8.0 | 15.3 |
| 30 min. | 5.9 | 11.5 |
| 45 min. | 4.3 | 8.5 |
| 1 hr. | 3.4 | 6.7 |
| 2 hr. | 1.9 | 3.8 |
| 3 hr. | 1.3 | 2.6 |
| 4 hr. | 1.0 | 2.0 |
| 5 hr. | 0.82 | 1.7 |
| 8 hr. | 0.53 | 1.1 |
| 10 hr. | 0.43 | 0.86 |
| 20 hr. | 0.22 | 0.45 |



Figure A-8: 4.5Ah Single Cell Discharge to 1.85 VPC
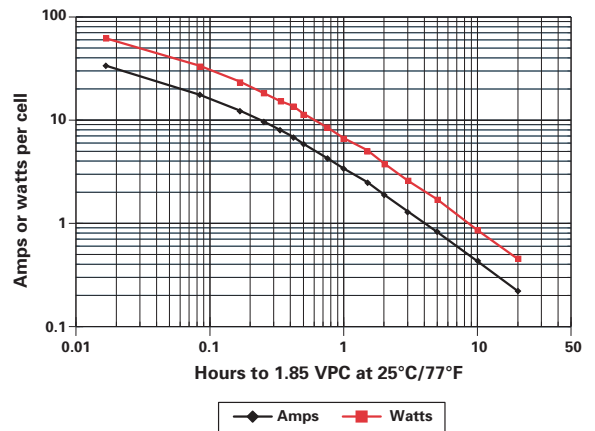
## Table A-9: 5.0Ah Single Cell Data to 1.75 VPC

| Run Time at 25°C | Amperes per 5.0Ah Cell | Watts per 5.0Ah Cell |
|---|---|---|
| 2 min. | 37.2 | 58.6 |
| 5 min. | 24.3 | 41.9 |
| 10 min. | 16.1 | 29.1 |
| 15 min. | 12.2 | 22.7 |
| 20 min. | 9.9 | 18.7 |
| 30 min. | 7.2 | 13.9 |
| 45 min. | 5.2 | 10.1 |
| 1 hr. | 4.1 | 8.0 |
| 2 hr. | 2.2 | 4.4 |
| 3 hr. | 1.5 | 3.0 |
| 4 hr. | 1.2 | 2.3 |
| 5 hr. | 1.0 | 1.9 |
| 8 hr. | 0.60 | 1.2 |
| 10 hr. | 0.50 | 1.0 |
| 20 hr. | 0.30 | 0.50 |



Figure A-9: 5.0Ah Single Cell Discharge to 1.75 VPC
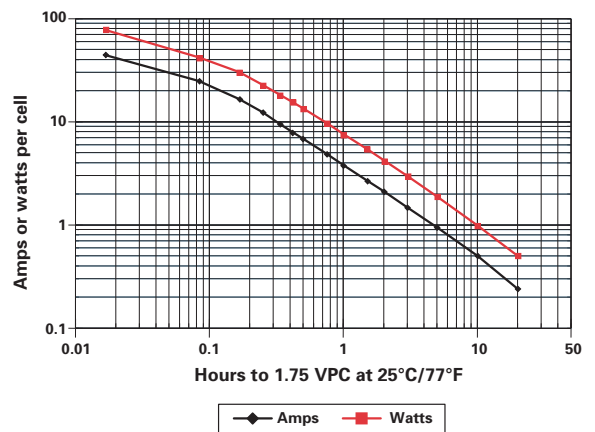
## Table A-10: 5.0Ah Single Cell Data to 1.85 VPC

| Run Time at 25°C | Amperes per 5.0Ah Cell | Watts per 5.0Ah Cell |
|---|---|---|
| 2 min. | 29.1 | 53.5 |
| 5 min. | 20.3 | 38.1 |
| 10 min. | 14.0 | 26.7 |
| 15 min. | 10.9 | 20.9 |
| 20 min. | 9.0 | 17.3 |
| 30 min. | 6.7 | 13.0 |
| 45 min. | 4.9 | 9.6 |
| 1 hr. | 3.9 | 7.7 |
| 2 hr. | 2.2 | 4.3 |
| 3 hr. | 1.5 | 3.0 |
| 4 hr. | 1.2 | 2.3 |
| 5 hr. | 0.90 | 1.9 |
| 8 hr. | 0.60 | 1.2 |
| 10 hr. | 0.50 | 1.0 |
| 20 hr. | 0.20 | 0.50 |



Figure A-10: 5.0Ah Single Cell Discharge to 1.85 VPC

## Figure A-11: 8.0Ah Single Cell Discharge to 1.75 VPC



### Table A-11: 8.0Ah Single Cell Data to 1.75 VPC

| Run Time at 25°C | Amperes per 8.0Ah Cell | Watts per 8.0Ah Cell |
|---|---|---|
| 2 min. | 46.9 | 76.7 |
| 5 min. | 34.4 | 59.5 |
| 10 min. | 24.0 | 43.1 |
| 15 min. | 18.7 | 34.2 |
| 20 min. | 15.3 | 28.5 |
| 30 min. | 11.4 | 21.5 |
| 45 min. | 8.3 | 15.8 |
| 1 hr. | 6.5 | 12.6 |
| 2 hr. | 3.5 | 7.0 |
| 3 hr. | 2.4 | 4.9 |
| 4 hr. | 1.9 | 3.7 |
| 5 hr. | 1.5 | 3.0 |
| 8 hr. | 1.0 | 1.9 |
| 10 hr. | 0.80 | 1.6 |
| 20 hr. | 0.40 | 0.80 |

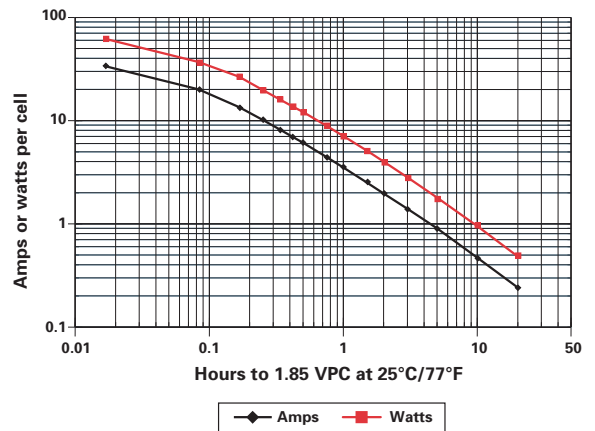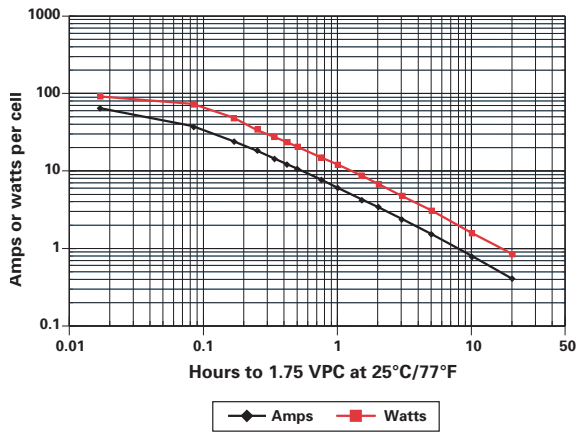## Figure A-12: 8.0Ah Single Cell Discharge to 1.85 VPC
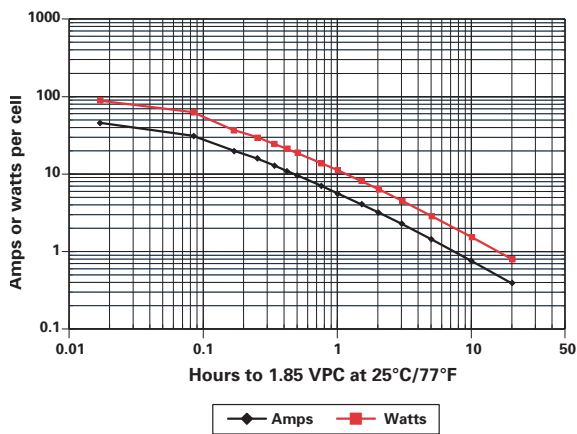


### Table A-12: 8.0Ah Single Cell Data to 1.85 VPC

| Run Time at 25°C | Amperes per 8.0Ah Cell | Watts per 8.0Ah Cell |
|---|---|---|
| 2 min. | 35.8 | 64.0 |
| 5 min. | 28.3 | 52.0 |
| 10 min. | 20.7 | 38.9 |
| 15 min. | 16.5 | 31.3 |
| 20 min. | 13.8 | 26.3 |
| 30 min. | 10.4 | 20.2 |
| 45 min. | 7.7 | 15.0 |
| 1 hr. | 6.1 | 12.0 |
| 2 hr. | 3.4 | 6.8 |
| 3 hr. | 2.4 | 4.7 |
| 4 hr. | 1.8 | 3.6 |
| 5 hr. | 1.5 | 3.0 |
| 8 hr. | 0.90 | 1.9 |
| 10 hr. | 0.80 | 1.5 |
| 20 hr. | 0.40 | 0.80 |

## Figure A-13: 12.0Ah Single Cell Discharge to 1.75 VPC
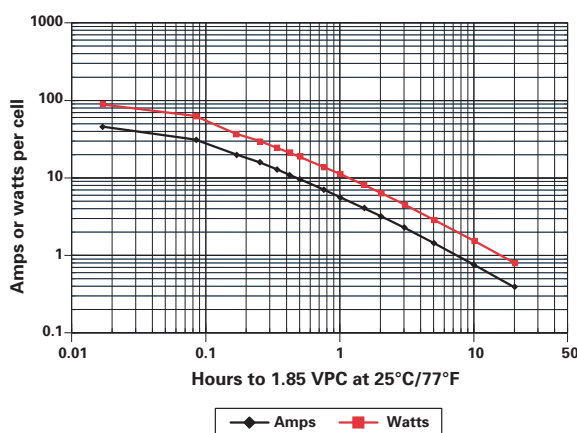


### Table A-13: 12.0Ah Single Cell Data to 1.75 VPC

| Run Time at 25°C | Amperes per 12.0Ah Cell | Watts per 12.0Ah Cell |
|---|---|---|
| 2 min. | 49.6 | 81.9 |
| 5 min. | 40.6 | 72.1 |
| 10 min. | 30.1 | 55.8 |
| 15 min. | 24.1 | 45.5 |
| 20 min. | 20.1 | 38.5 |
| 30 min. | 15.3 | 29.6 |
| 45 min. | 11.3 | 22.1 |
| 1 hr. | 9.0 | 17.7 |
| 2 hr. | 5.0 | 10.0 |
| 3 hr. | 3.5 | 7.0 |
| 4 hr. | 2.7 | 5.4 |
| 5 hr. | 2.2 | 4.4 |
| 8 hr. | 1.4 | 2.9 |
| 10 hr. | 1.2 | 2.3 |
| 20 hr. | 0.60 | 1.2 |

**Table A-14: 12.0Ah Single Cell Data to 1.85 VPC**

| Run Time at 25°C | Amperes per 12.0Ah Cell | Watts per 12.0Ah Cell |
|---|---|---|
| 2 min. | 33.5 | 64.1 |
| 5 min. | 32.2 | 60.3 |
| 10 min. | 25.9 | 48.5 |
| 15 min. | 21.4 | 40.3 |
| 20 min. | 18.3 | 34.5 |
| 30 min. | 14.2 | 27.0 |
| 45 min. | 10.7 | 20.4 |
| 1 hr. | 8.6 | 16.5 |
| 2 hr. | 4.8 | 9.5 |
| 3 hr. | 3.4 | 6.7 |
| 4 hr. | 2.6 | 5.2 |
| 5 hr. | 2.1 | 4.3 |
| 8 hr. | 1.4 | 2.8 |
| 10 hr. | 1.1 | 2.3 |
| 20 hr. | 0.60 | 1.2 |



Figure A-14: 25.0Ah Single Cell Discharge to 1.75 VPC
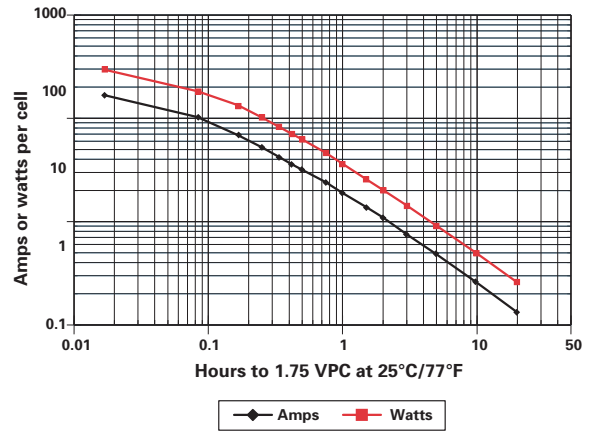
**Table A-15: 25.0Ah Single Cell Data to 1.75 VPC**

| Run Time at 25°C | Amperes per 25.0Ah Cell | Watts per 25.0Ah Cell |
|---|---|---|
| 2 min. | 136.9 | 235.0 |
| 5 min. | 99.8 | 179.1 |
| 10 min. | 69.7 | 128.7 |
| 15 min. | 54.3 | 101.7 |
| 20 min. | 44.7 | 84.6 |
| 30 min. | 33.4 | 63.9 |
| 45 min. | 24.4 | 47.2 |
| 1 hr. | 19.3 | 37.6 |
| 2 hr. | 10.7 | 21.1 |
| 3 hr. | 7.5 | 14.8 |
| 4 hr. | 5.8 | 11.5 |
| 5 hr. | 4.7 | 9.4 |
| 8 hr. | 3.1 | 6.1 |
| 10 hr. | 2.5 | 5.0 |
| 20 hr. | 1.3 | 2.7 |



Figure A-15: 25.0Ah Single Cell Discharge to 1.75 VPC
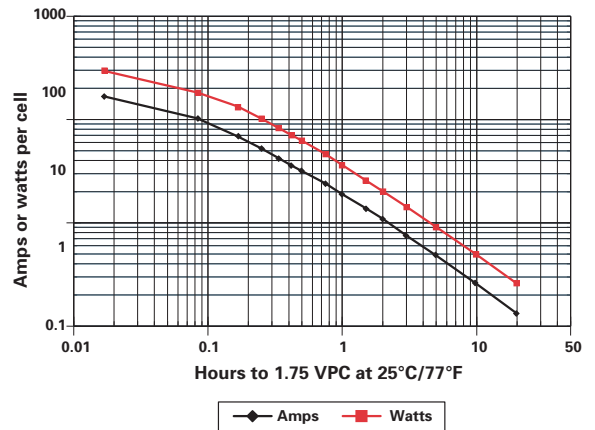
**Table A-16: 25.0Ah Single Cell Data to 1.85 VPC**

| Run Time at 25°C | Amperes per 25.0Ah Cell | Watts per 25.0Ah Cell |
|---|---|---|
| 2 min. | 104.4 | 192.0 |
| 5 min. | 81.7 | 153.1 |
| 10 min. | 59.9 | 113.8 |
| 15 min. | 47.8 | 91.6 |
| 20 min. | 40.1 | 77.2 |
| 30 min. | 30.5 | 59.3 |
| 45 min. | 22.7 | 44.5 |
| 1 hr. | 18.2 | 35.8 |
| 2 hr. | 10.3 | 20.5 |
| 3 hr. | 7.3 | 14.5 |
| 4 hr. | 5.6 | 11.3 |
| 5 hr. | 4.6 | 9.3 |
| 8 hr. | 3.0 | 6.1 |
| 10 hr. | 2.5 | 5.0 |
| 20 hr. | 1.3 | 2.6 |



Figure A-16: 25.0Ah Single Cell Discharge to 1.85 VPC
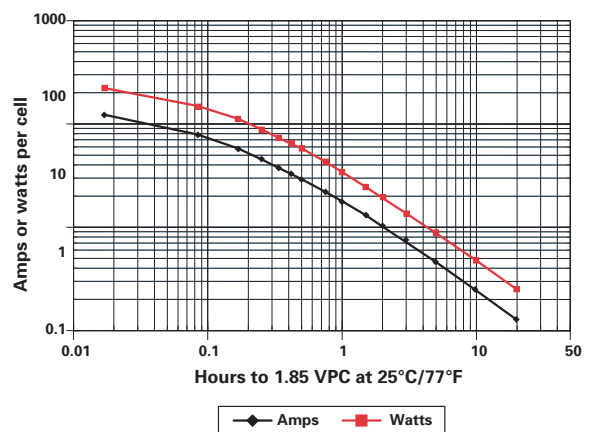
## Appendix B

### Table B-1: CYCLON® D Single Cell and MB Performance

| Run Time | 1.50 VPC | | 1.60 VPC | |
|---|---|---|---|---|
| | Amps | Watts/cell | Amps | Watts/cell |
| 2 min. | 30.4 | 48.0 | 27.3 | 45.4 |
| 5 min. | 15.7 | 26.9 | 15.1 | 26.5 |
| 10 min. | 9.3 | 16.7 | 9.2 | 16.7 |
| 15 min. | 6.8 | 12.5 | 6.8 | 12.5 |
| 20 min. | 5.4 | 10.1 | 5.4 | 10.1 |
| 30 min. | 3.9 | 7.4 | 3.9 | 7.4 |
| 45 min. | 2.8 | 5.35 | 2.8 | 5.3 |
| 1 hr. | 2.2 | 4.2 | 2.2 | 4.2 |
| 2 hr. | 1.2 | 2.35 | 1.2 | 2.3 |
| 3 hr. | 0.80 | 1.65 | 0.80 | 1.6 |
| 4 hr. | 0.65 | 1.3 | 0.60 | 1.3 |
| 5 hr. | 0.50 | 1.0 | 0.50 | 1.0 |
| 8 hr. | 0.30 | 0.70 | 0.30 | 0.70 |
| 10 hr. | 0.28 | 0.54 | 0.27 | 0.54 |
| 20 hr. | 0.14 | 0.28 | 0.14 | 0.28 |

### Table B-2: CYCLON® Tall D Single Cell Performance

| Run Time | 1.50 VPC | | 1.60 VPC | |
|---|---|---|---|---|
| | Amps | Watts/cell | Amps | Watts/cell |
| 2 min. | 45.4 | 56.7 | 39.3 | 54.8 |
| 5 min. | 26.2 | 39.9 | 24.5 | 39.9 |
| 10 min. | 16.1 | 27.6 | 15.6 | 27.6 |
| 15 min. | 11.9 | 21.4 | 11.6 | 21.6 |
| 20 min. | 9.5 | 17.6 | 9.3 | 17.6 |
| 30 min. | 6.8 | 13.1 | 6.7 | 13.1 |
| 45 min. | 4.8 | 9.5 | 4.8 | 9.4 |
| 1 hr. | 3.8 | 7.4 | 3.7 | 7.4 |
| 2 hr. | 2.0 | 4.0 | 2.0 | 4.0 |
| 3 hr. | 1.4 | 2.8 | 1.4 | 2.7 |
| 4 hr. | 1.1 | 2.1 | 1.1 | 2.1 |
| 5 hr. | 0.90 | 1.7 | 0.90 | 1.7 |
| 8 hr. | 0.60 | 1.1 | 0.55 | 1.1 |
| 10 hr. | 0.50 | 0.90 | 0.45 | 0.90 |
| 20 hr. | 0.24 | 0.46 | 0.24 | 0.46 |

### Table B-3: CYCLON® X Single Cell and MB Performance

| Run Time | 1.50 VPC | | 1.60 VPC | |
|---|---|---|---|---|
| | Amps | Watts/cell | Amps | Watts/cell |
| 2 min. | 57.5 | 67.4 | 50.1 | 65.2 |
| 5 min. | 30.9 | 44.6 | 29.3 | 45.0 |
| 10 min. | 18.5 | 30.4 | 18.2 | 31.0 |
| 15 min. | 13.5 | 23.5 | 13.4 | 23.5 |
| 20 min. | 10.8 | 19.4 | 10.7 | 19.6 |
| 30 min. | 7.7 | 14.5 | 7.7 | 14.6 |
| 45 min. | 5.5 | 10.6 | 5.5 | 10.6 |
| 1 hr. | 4.3 | 8.4 | 4.3 | 8.3 |
| 2 hr. | 2.3 | 4.6 | 2.3 | 4.5 |
| 3 hr. | 1.6 | 3.2 | 1.6 | 3.1 |
| 4 hr. | 1.2 | 2.4 | 1.2 | 2.4 |
| 5 hr. | 1.0 | 2.0 | 1.0 | 1.9 |
| 8 hr. | 0.60 | 1.3 | 0.60 | 1.2 |
| 10 hr. | 0.50 | 1.0 | 0.50 | 1.0 |
| 20 hr. | 0.30 | 0.50 | 0.30 | 0.50 |

### Table B-4: CYCLON® E Single Cell and MB Performance

| Run Time | 1.50 VPC | | 1.60 VPC | |
|---|---|---|---|---|
| | Amps | Watts/cell | Amps | Watts/cell |
| 2 min. | 70.6 | 92.6 | 63.1 | 90.5 |
| 5 min. | 45.3 | 68.1 | 42.3 | 67.2 |
| 10 min. | 29.2 | 47.9 | 28.0 | 47.4 |
| 15 min. | 21.8 | 37.4 | 21.1 | 37.0 |
| 20 min. | 17.5 | 30.8 | 17.1 | 30.6 |
| 30 min. | 12.6 | 23.0 | 12.4 | 22.8 |
| 45 min. | 8.9 | 16.7 | 8.8 | 16.6 |
| 1 hr. | 6.9 | 13.2 | 6.9 | 13.1 |
| 2 hr. | 3.7 | 7.2 | 3.7 | 7.2 |
| 3 hr. | 2.5 | 5.0 | 2.5 | 5.0 |
| 4 hr. | 1.9 | 3.8 | 1.9 | 3.8 |
| 5 hr. | 1.6 | 3.1 | 1.6 | 3.1 |
| 8 hr. | 1.0 | 2.0 | 1.0 | 2.0 |
| 10 hr. | 0.80 | 1.6 | 0.80 | 1.6 |
| 20 hr. | 0.40 | 0.80 | 0.40 | 0.80 |

### Table B-5: CYCLON® J Single Cell Performance

| Run Time | 1.50 VPC | | 1.60 VPC | |
|---|---|---|---|---|
| | Amps | Watts/cell | Amps | Watts/cell |
| 2 min. | 82.9 | 106.9 | 74.0 | 103.8 |
| 5 min. | 55.8 | 84.4 | 51.8 | 83.8 |
| 10 min. | 37.2 | 61.9 | 35.4 | 62.2 |
| 15 min. | 28.4 | 49.2 | 27.3 | 49.7 |
| 20 min. | 23.1 | 41.1 | 22.3 | 41.6 |
| 30 min. | 17.0 | 31.0 | 16.5 | 31.5 |
| 45 min. | 12.3 | 22.9 | 12.0 | 23.3 |
| 1 hr. | 9.6 | 18.2 | 9.5 | 18.5 |
| 2 hr. | 5.3 | 10.1 | 5.2 | 10.3 |
| 3 hr. | 3.7 | 7.0 | 3.6 | 7.1 |
| 4 hr. | 2.8 | 5.4 | 2.8 | 5.4 |
| 5 hr. | 2.3 | 4.4 | 2.3 | 4.4 |
| 8 hr. | 1.5 | 2.8 | 1.5 | 2.9 |
| 10 hr. | 1.2 | 2.3 | 1.2 | 2.3 |
| 20 hr. | 0.60 | 1.2 | 0.60 | 1.2 |

### Table B-6: CYCLON® BC Single Cell Performance

| Run Time | 1.50 VPC | | 1.60 VPC | |
|---|---|---|---|---|
| | Amps | Watts/cell | Amps | Watts/cell |
| 2 min. | 216.7 | 324.7 | 188.4 | 296.4 |
| 5 min. | 133.8 | 219.9 | 124.0 | 210.4 |
| 10 min. | 85.2 | 148.2 | 81.5 | 144.9 |
| 15 min. | 63.5 | 113.7 | 61.6 | 112.1 |
| 20 min. | 51.0 | 92.9 | 49.8 | 92.0 |
| 30 min. | 36.9 | 68.8 | 36.3 | 68.3 |
| 45 min. | 26.3 | 50.0 | 26.1 | 49.8 |
| 1 hr. | 20.6 | 39.5 | 20.4 | 39.3 |
| 2 hr. | 11.2 | 21.8 | 11.1 | 21.7 |
| 3 hr. | 7.7 | 15.3 | 7.7 | 15.2 |
| 4 hr. | 5.9 | 11.8 | 5.9 | 11.7 |
| 5 hr. | 4.9 | 9.6 | 4.8 | 9.6 |
| 8 hr. | 3.2 | 6.3 | 3.1 | 6.2 |
| 10 hr. | 2.6 | 5.2 | 2.6 | 5.1 |
| 20 hr. | 1.4 | 2.8 | 1.4 | 2.8 |

Distributed by: