CYCLON® APPLICATION MANUAL

THIRD EDITION

CYCLON®

Hawker Energy Products Inc.

MISSION STATEMENT

Always high performance.
Always high-reliability battery products.
Always.

Third Edition

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Chapter 1: Introducing Cyclon®

1.1 Introduction

The purpose of this manual is to describe the characteristics of the Cyclon® sealed–lead family of rechargeable batteries from Hawker Energy Products Inc. 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 and High Temperature Performance

The exceptional low temperature performance of the Cyclon® products has been made possible due to the use of plates that provide a high surface area, coupled with a separator system that minimizes diffusion and resistance effects. This results in good utilization of active material and excellent voltage regulation over a wide temperature range.

Cyclon® Single Cells also offer outstanding high temperature performance. They are capable of operating normally at temperatures as high as +80°C. Note, however, that for every 7° to 10°C rise in ambient temperature the life of the battery is cut in half.

1.4 High Rate Charge & Discharge Capabilities

The thin plate construction of Cyclon® products contributes to high utilization 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.

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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® 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 fifteen (15) years' float life.

1.6 Structural Resistance

The rugged outer metal case of the single cell design enhances 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

In addition to the fact that Cyclon® 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. Thus, much total space can be saved. 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® products have very high power density, particularly at high rates of discharge. Please refer to Appendix A for appropriate graphs and charts that detail these capabilities.

1.9 Transportation Classification

Effective September 30, 1995, Cyclon single cells and monoblocs were classified as "non-spillable batteries", and are excepted from the Department of Transportation's comprehensive packaging requirements if the following conditions are satisfied: (1) The battery is protected against short circuits and is securely packaged and (2) The battery and outer packaging must be plainly and durably marked "NONSPILLABLE" or "NONSPILLABLE BATTERY". Cyclon shipments from Hawker Energy Products Inc. Warrensburg location, will be properly labeled in accordance with applicable regulations. **Packaging changes performed at other locations may require additional labeling, since in addition to the battery itself containing the required marking, the outer**

packaging of the battery must also contain the required marking: "NONSPILLABLE" or "NONSPILLABLE BATTERY".

Cyclon single cells and monoblocs have been tested and determined to be in compliance with the vibration and pressure differential tests contained in 49 CFR § 173.159(d).

Because Cyclon single cells and monoblocs are classified as "Nonspillable" and meet the conditions above, [from § 173.159(d)] they do not have an assigned UN number nor do they require additional DOT hazard labeling.

The regulation change effective September, 1995, was to clarify and distinguish to shippers and transporters, all batteries that have been tested and determined to be in compliance with the DOT Hazardous Material Regulations, the International Civil Aeronautics Organization (ICAO), and the International Air Transport Association (IATA) Packaging Instruction 806 and Special Provision A67, and therefore excepted from all other requirements of these regulations and classified as a "nonspillable battery".

1.10 UL Component Recognition

All Cyclon® products are recognized as components per UL 1989.

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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® 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.

Sulfuric acid is then added by a unique vacuum fill process 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.

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Chapter 3: Cyclon® Benefits

3.1 Introduction

This chapter is devoted to describing specific performance characteristics of the Cyclon® product lines 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® 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 proximity of the plates to each other resulting from the use of thin plates in a spirally wound construction.

Typical maximum current capabilities of single cells and monoblocs are shown in Table I 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.*

Higher currents than those indicated in the table below 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 I

Cyclon® Type	Max. Amps to 1.50 vpc
D single cell (2.5Ah)	65
D monobloc (2.5Ah)	50
DT single cell (4.5Ah)	65
X single cell (5.0Ah)	65
X monobloc (5.0Ah)	50
E single cell (8.0Ah)	65
E monobloc (8.0Ah)	50
J single cell (12.0Ah)	100
BC single cell (25.0Ah)	250

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3.3 Low Temperature Operation

Exceptional low temperature characteristics are maintained through the use of a separator system that minimizes resistance and diffusion effects. This feature, combined with a large plate surface area, results in efficient utilization 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. Specific temperature capabilities of single cells and monoblocs may be found in the ***Cyclon® Selection Guide.***

3.4 Position Flexibility

With the starved electrolyte system, the sulfuric 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 Hawker Cyclon® 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 the Cyclon® product, 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 the Cyclon® product. 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 electrolyzes 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.

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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:

$$2Pb + O_2 \rightarrow 2PbO_2 \qquad \text{(Eqn. 1)}$$

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 Eqn. 1 above. The acidic conditions prevailing inside the cell is very conducive to the reaction between lead oxide and the sulfuric acid to form lead sulfate in accordance with Equation 2 below:

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

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

$$2PbSO_4 + 2H_2 \rightarrow 2Pb + 2H_2SO_4 \qquad \text{(Eqn. 3)}$$

Adding the three equations and cancelling out like terms on either side of the equations, we obtain Equation 4:

$$2H_2 + O_2 \rightarrow 2H_2O \qquad \text{(Eqn. 4)}$$

The four equations given above illustrate the reactions that are the heart of the principle of recombination that is employed by the Cyclon® product line. By properly designing the cell, recombination efficiencies in excess of 99% are achieved in the Cyclon® product.

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3.6 Shock & Vibration Characteristics

The spirally wound plate element is compressed within a polypropylene liner or case, minimizing 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.

Cyclon® Shock and Vibration Test

A total of eighteen Cyclon® single cells were tested for compliance with the shock and vibration requirements of the National Aeronautics and Space Administration (NASA). The cells were configured into three 12V battery packs, designated A, B and C, with six cells per pack.

Batteries A and B were tested for vibration compliance; pack A was tested fully charged while B was tested fully discharged. The following table was used for the discharge/recharge profile on A and B. The batteries were recharged for 16 hours at 14.7V per pack.

	Dischge.	**Rechg.**	**Vibrate**	**Rechg.**	**Dischge.**	**Rechg.**
Pack A	X	X	X		X	X
Pack B	X		X	X	X	X

Battery C was tested for compliance with the shock requirements of NASA. The following table was used for the discharge/recharge profile on the shock testing of pack C. The battery was recharged at 14.7V for 16 hours.

	Dischge.	**Shock**	**Rechg.**
Pack C	X	X	X

Vibration test

Batteries A and B were subjected to the following test. The second column of Table II, power spectral density (PSD), represents the power distribution as a function of frequency. The total duration of the test was three minutes.

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Table II

Frequency	PSD/g^2/Hz
20	0.026
50	0.160
800	0.160
2000	0.260

Pre- and post-test voltage readings on battery A are given in Table III while Table IV gives pre- and post-test voltage readings on battery B.

Table III: Battery A voltages

	Pre-test voltage	Post-test voltage
X-axis	13.152V	13.151V
Y-axis	13.133V	13.131V
Z-axis	13.124V	13.122V

Table IV: Battery B voltages

	Pre-test voltage	Post-test voltage
X-axis	12.254V	12.254V
Y-axis	12.255V	12.256V
Z-axis	12.256V	12.257V

Shock test

Battery C was subjected to a shock test in accordance with MIL-STD-810E, Method 516.4, Procedure I. The battery was subjected to three 20g, 11 ms terminal peak sawtooth pulses in each direction of the three orthogonal axes for a total of 18 shocks. Pre- and post-test voltages are recorded in Table V.

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Table V: Battery C voltages

	Pre-test voltage	Post-test voltage
Shock #1–3	13.153V	13.149V
Shock #4–6	13.150V	13.146V
Shock #7–9	13.148V	13.144V
Shock #10–12	13.145V	13.143V
Shock #13–15	13.145V	13.144V
Shock #16–18	13.147V	13.143V

Conclusions

Based on the minimal differences between pre-test and post-test voltages, all samples were able to withstand the vibration and shock tests.

3.7 Float Life Characteristics

As noted previously, life expectancy of Cyclon® products 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.

3.8 Cycle Life Characteristics

The life of the cell in a cyclic 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 2,000. 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 maximize life.

[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.*

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3.10 Storage Characteristics

The Cyclon® 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 we recommend conducting an OCV audit every six (6) months and recharging when OCV readings approach 2.00 volts per cell (vpc). Should storage temperatures be significantly higher than 25°C, even for short durations, the frequency of OCV audits must be increased.

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Chapter 4: Discharging Cyclon®

4.1 Introduction

The standard discharge tables and curves for the Cyclon® family 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

Figure 1 (a) and 1 (b) show the room temperature (25°C) voltage profile of Cyclon® cells when subjected to four loads — $C_{10}/10$, $C_{10}/5$, $1C_{10}$ and $2.2C_{10}$.

In all four 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 $2.2C_{10}$).

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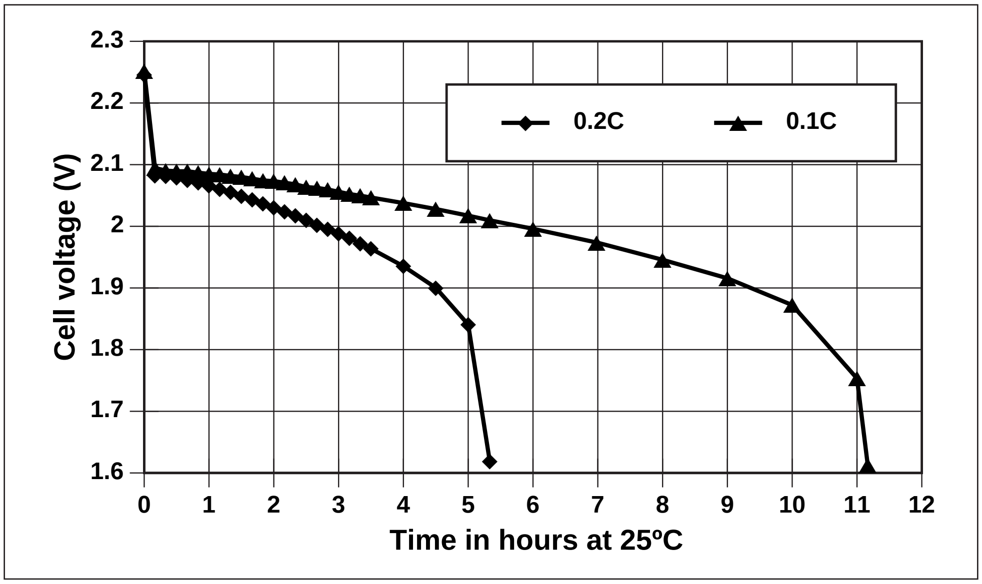

Figure 1(a): Cyclon® Medium Rate Discharge Voltage Profile

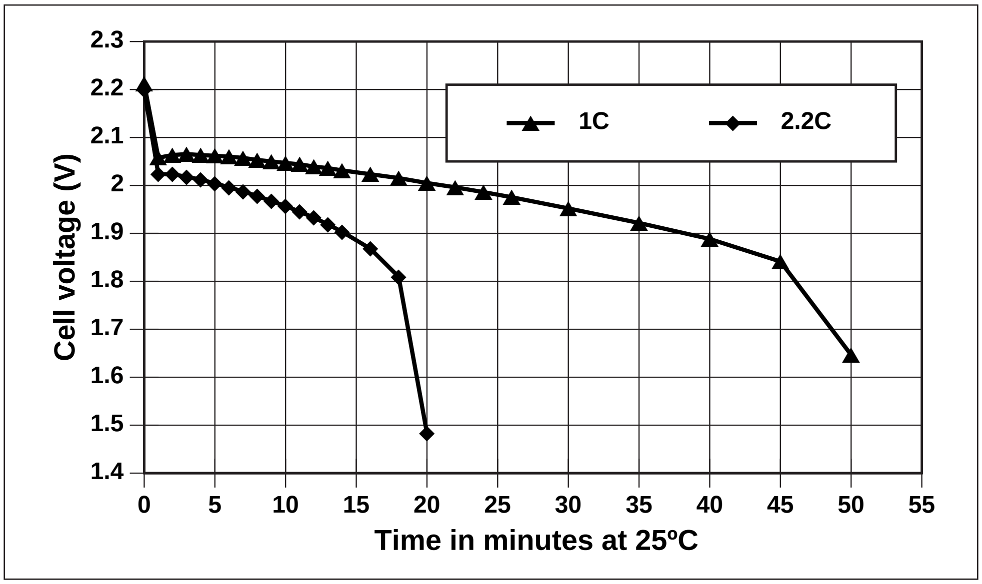

Figure 1(b): Cyclon® High Rate Discharge Voltage Profile

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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 VI below:

Table VI

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

Discharging the Cyclon® 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 sulfuric acid electrolyte can be depleted of the sulfate ion and become essentially water, which can create several problems. A lack of sulfate 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 may resume.

Disconnecting the battery from the load will totally eliminate the possibility of an overdischarge, provided of course 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.

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Chapter 5: Cyclon® Storage

5.1 Introduction

Another area where the Cyclon® 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® cells and monoblocs.

5.2 State of Charge

The state of charge (SOC) of the Cyclon® cell can be approximated by using the curve given in Figure 2.

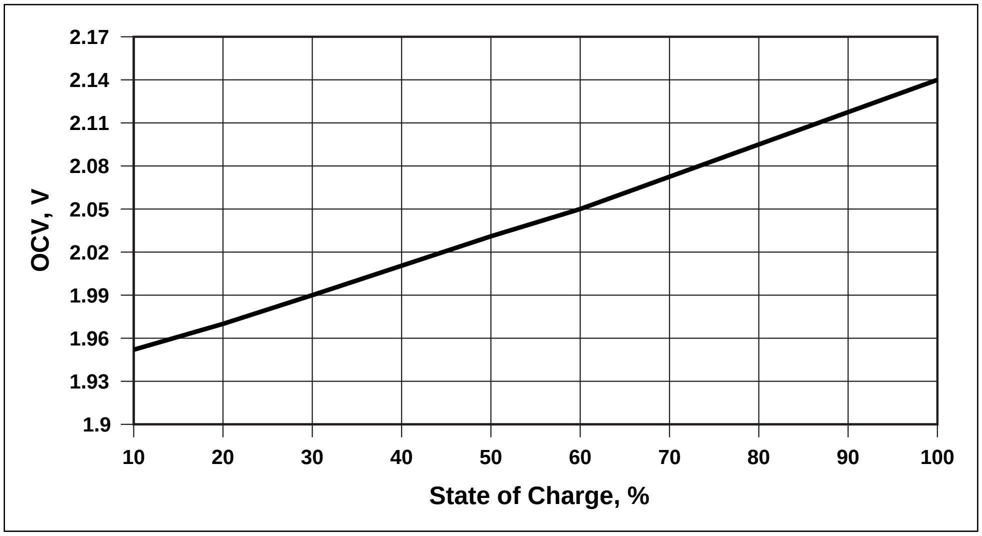

Figure 2: Cyclon® Open Circuit Voltage Vs. State of Charge

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.

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.

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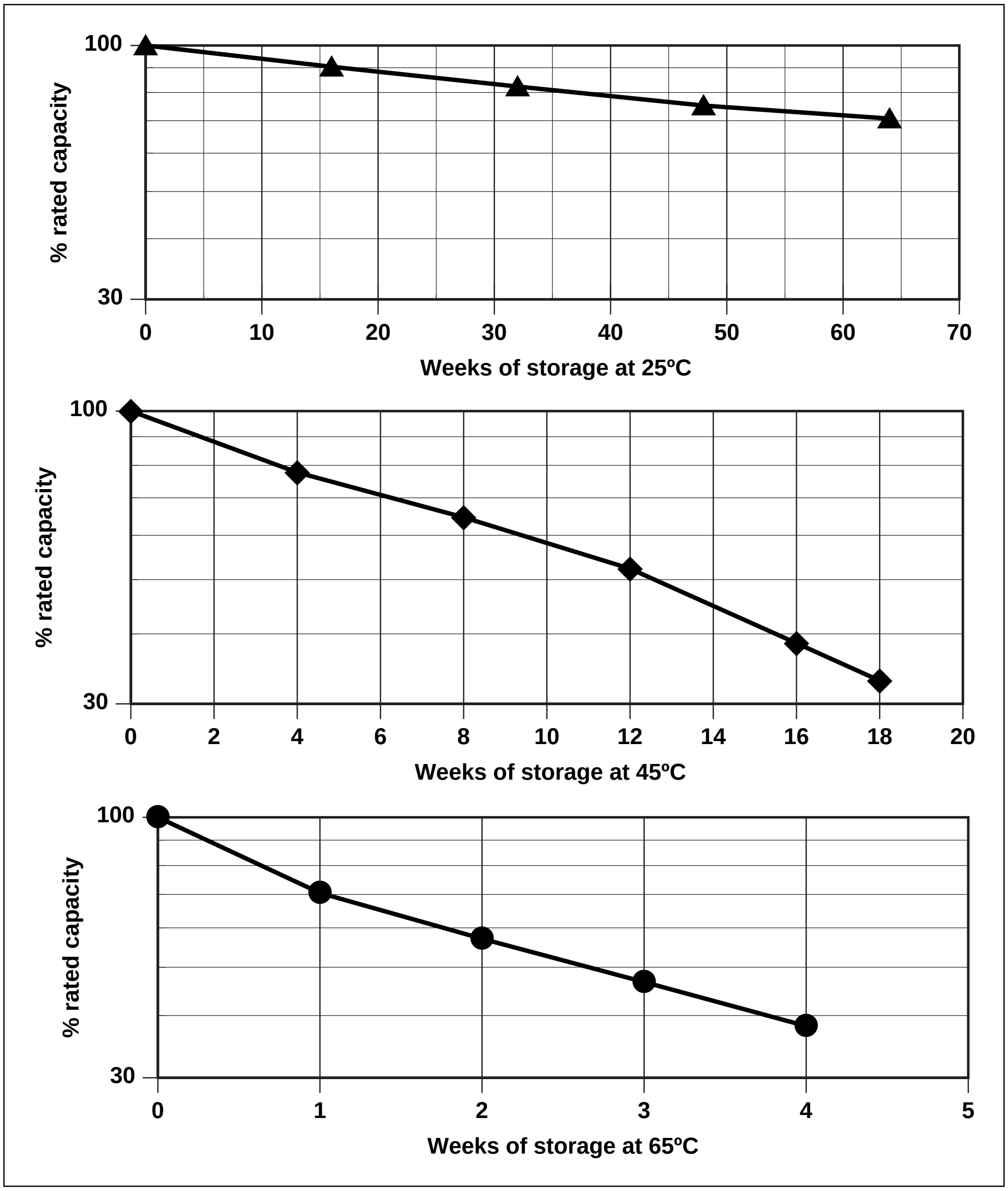

Figure 3: Cyclon® Storage Capacity at Various Temperatures

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All Cyclon® products offer a shelf life superior to that offered by conventional lead acid batteries. As shown in the top graph of Figure 3, at the end of 64 weeks (1.23 years) of storage at room temperature (25°C/77°F) the cells still had 71% of rated capacity.

It is important to recognize that the self–discharge rate of the Cyclon® products 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.

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Chapter 6: Charging Cyclon®

6.1 Introduction

The superior charging characteristics of the Cyclon® product make them the power source of choice in demanding applications that require extremely 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 somewhat inefficient, it is necessary to return more than 100% of the energy removed during the discharge.

The Cyclon® cell incorporates the gas recombination principle which 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 insure 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® cells. However, *constant current* (CC), taper current and variations thereof can also be used.

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6.3 Constant Voltage (CV) Charging

Constant voltage (CV) charging is the most efficient method of charging Cyclon® sealed–lead products.

Tables VII and VIII in the next section on fast charging show the recharge times as a function of charge voltage and inrush current at 25°C. 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® cell under constant voltage charge.

A very important note to keep in mind is that for cyclic applications, it is imperative that the charge voltage be in the 2.45 to 2.50 volts per cell (vpc) range. Lowering the voltage to anything under 2.45 vpc in such an application will lead to a rapid loss in capacity, regardless of the magnitude of the inrush current.

6.4 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® products, 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® 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 utilized alloyed lead is not evident with the Cyclon® system, as the extremely high purity of lead minimizes 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® 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 VII and VIII 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® cell were discharged to 100% DOD.

Table VII (1.5C_{10} inrush)

Charge time at 2.45 vpc	Capacity returned
17 min.	50%
27 min.	80%
31 min.	90%
60 min.	100%

Table VIII (2.5C_{10} inrush)

Charge time at 2.45 vpc	Capacity returned
12 min.	50%
19 min.	80%
24 min.	90%
40 min.	100%

These tables clearly demonstrate the superior fast charge capabilities of the Cyclon® line of sealed lead batteries. The numbers in Table VII were generated using an initial current in the 1.5C_{10} range while those in Table VIII 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.

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Although Cyclon® 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.

Recognizing this broad fact, Table IX shows cyclic charging tests which were conducted using a CV charger that had only a 1A (C_{10}/2.5 on a 2.5Ah cell) current limit. The charge voltage, however, was set at 2.45 vpc. As a final note on the information provided by Table IX, the last column reflects the number of cycles one may expect for specific DOD numbers.

Table IX

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

6.5 Float Charging

When Cyclon® products are to be used in a purely float application at an ambient temperature of 25°C (room temperature), the recommended charge voltage setting is 2.27 to 2.35 volts per cell (vpc) at 25°C. We also recommend that this charge voltage be temperature compensated as outlined in the next section.

6.6 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 maximize life, a negative charging temperature coefficient of approximately 3mV per cell per °C variation from 25°C is used at temperatures significantly different from 25°C. Please refer to

[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)*

the ***Cyclon® Selection Guide*** for float voltage values at 25°C. Note that this coefficient is negative— as the ambient temperature increases the charge voltage must be reduced, and vice versa.

It is important to note here that even if the charge voltage is perfectly compensated for high ambient temperatures, 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 exert 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.

6.7 Constant Current (CC) Charging

Constant current (CC) charging is another efficient method of charging Cyclon® single cells and monoblocs. Constant current 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. Constant current charging charges all cells or batteries equally because it is independent of the charging voltage of each cell in the battery.

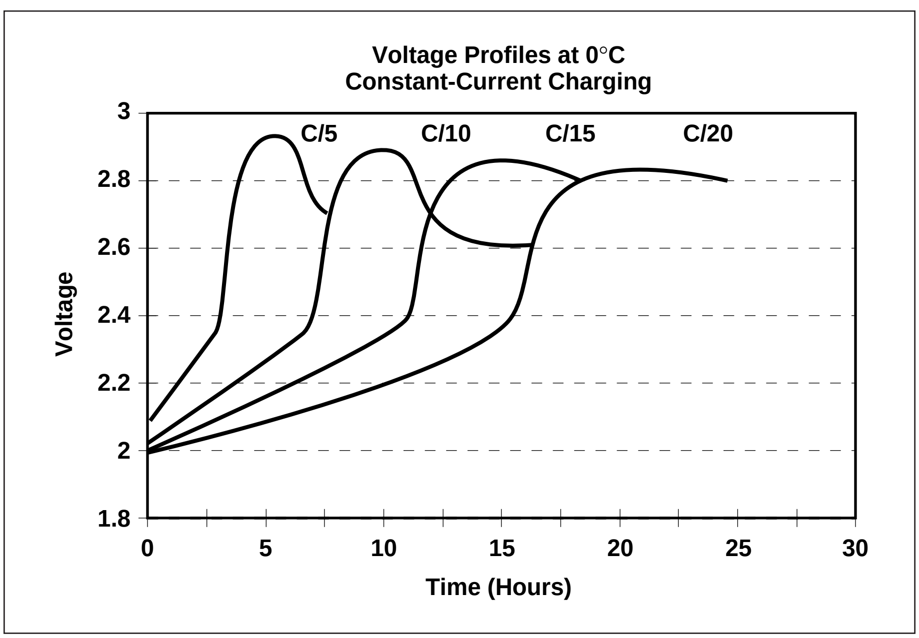

Figure 4(a): Constant current charging at 0°C

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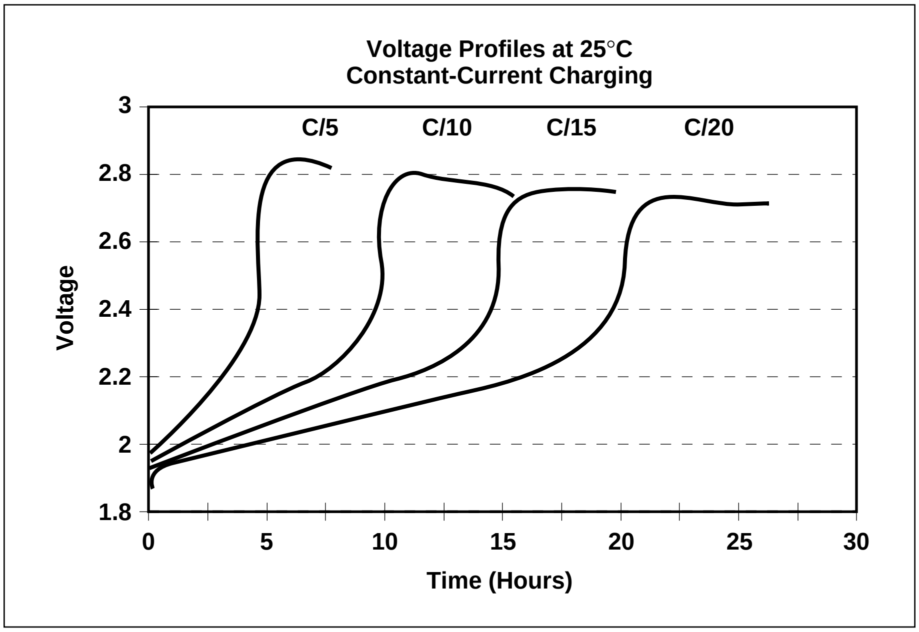

Figure 4(b): Constant current charging at 25°C

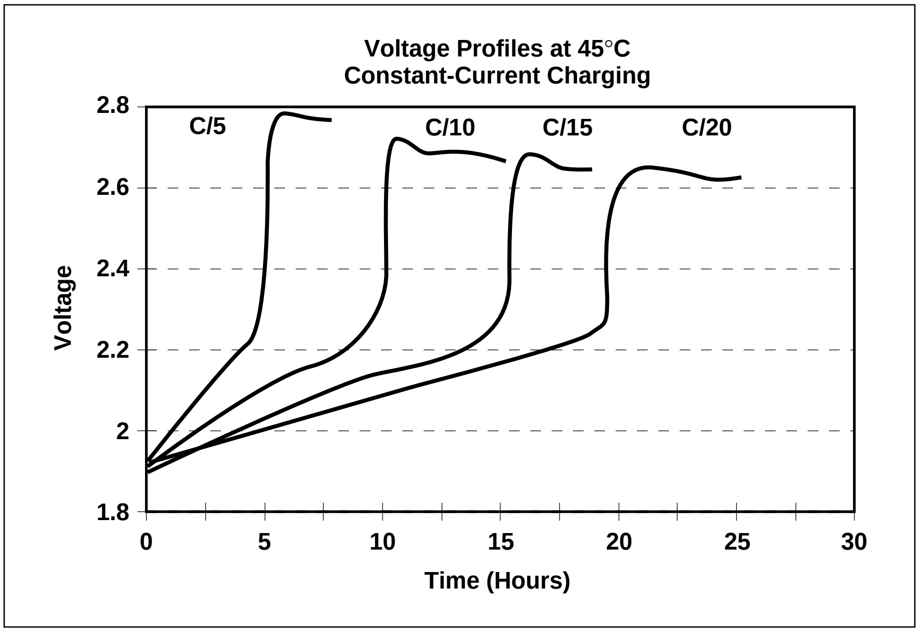

Figure 4(c): Constant current charging at 45°C

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Figure 4(a) is a family of curves depicting cell voltage vs. percent of capacity of previous discharge returned at different CC charging rates at an ambient temperature of 0°C. Figures 4(b) and 4(c) show the same curves but at two different temperatures — 25°C and 45°C, respectively. Table X summarizes the key points conveyed by these three graphs.

Table X

Parameter	Temperature	$C_{10}/5$	$C_{10}/10$	C_{10}	$C_{10}/20$
Peak voltage, volts per cell	0°C	2.91	2.87	2.84	2.82
	25°C	2.83	2.79	2.76	2.73
	45°C	2.78	2.71	2.67	2.64
Time to reach peak voltage, hours	0°C	4.71	9.61	15.00	20.00
	25°C	5.88	10.95	17.87	22.28
	45°C	5.80	11.05	16.62	22.10

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 sulfate 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 4(a), (b) and (c) are somewhat 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.

The Cyclon® cell is capable of recombining the oxygen produced on overcharge up to the $C_{10}/3$ rate of CC charge. At higher rates, the recombination reaction is unable to continue at the same rate as the gas generation.

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 of 10 years at room temperature (25°C).

Finally, 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 constant current charger.

6.8 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® products 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 a.c. input into a d.c. 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 a.c. (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.

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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:

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

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.

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Chapter 7: Cyclon® Service Life

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® products are no exception to this rule. There are two basic types of service life: cycle life and calendar 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® series, the cycle life expectancy is about 300 full DOD cycles. One can obtain more cycles with lower depths of discharge.

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.

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 insure 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.*

[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 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® products is ten (10) years at room temperature (25°C) 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. Specifically, high temperatures are used to accelerate the aging process of the battery under test.

The primary failure mode of Cyclon® products 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. As shown in Figure 5, for every 7°C to 10°C increase in ambient temperature the float life is cut approximately in half.

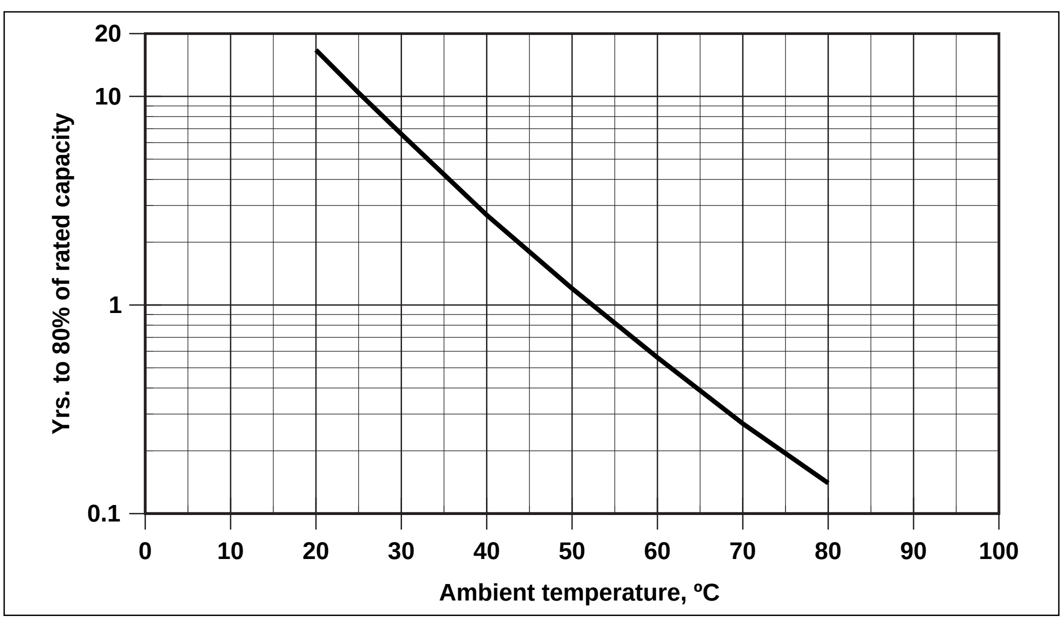

Figure 5: Cyclon® Float Life

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Chapter 8: Safety Issues

8.1 Introduction

There are two main considerations relative to the application of Cyclon® cells and batteries that should be recognized 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 over-charging. 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 sulfuric acid used in the manufacture of the Cyclon® cell all serve to minimize the amount of hydrogen gas produced.

The minute quantities of gases that are released or diffused from the Cyclon® 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.

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® products 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 96% 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® products 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.

Inadvertently placing these 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 jewelry 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.

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Appendix A

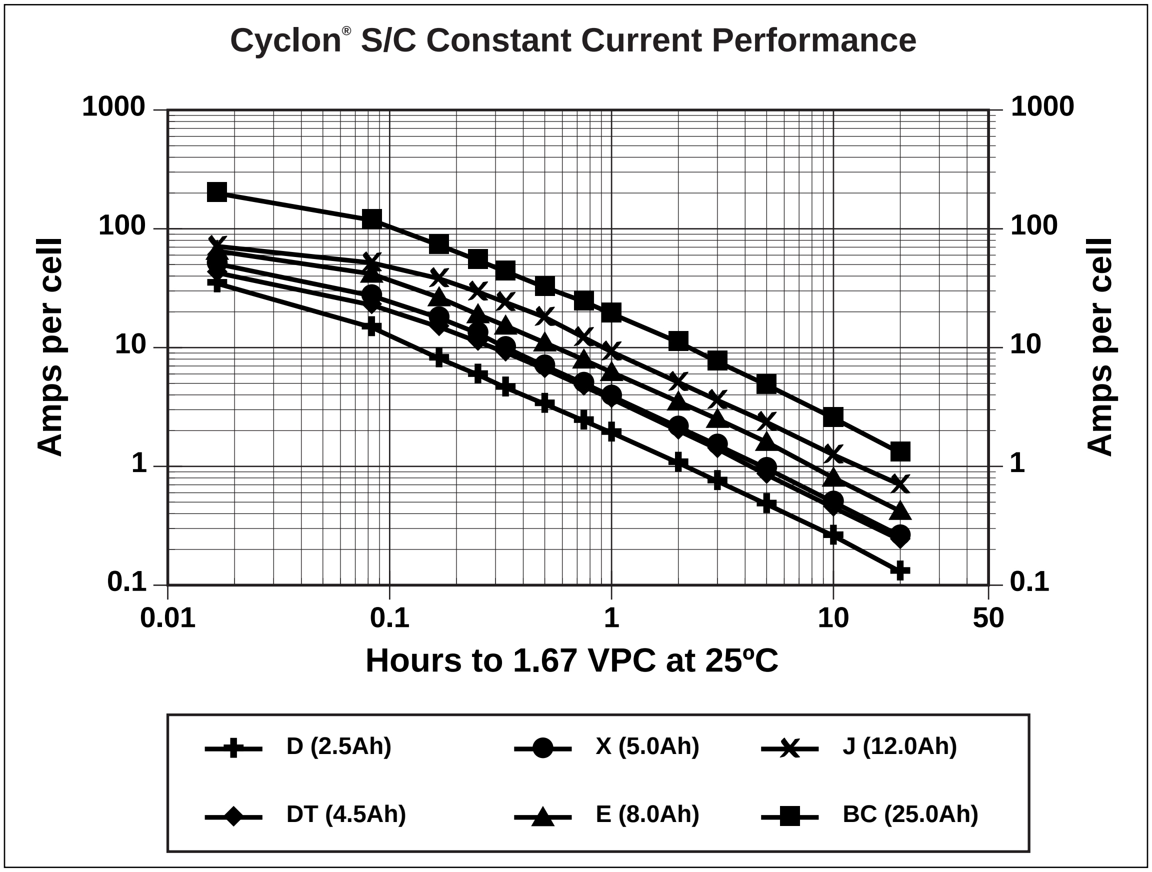

Figure A—1 : Single Cell CC Graphs to 1.67

HAWKER TECHNOLOGY Pb PERFORMANCE BY DESIGN

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Run time	D	DT	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.	6.6	11.2	13.0	20.1	26.0	58.7
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.	2.15	3.7	4.2	6.7	9.3	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.	0.50	0.85	1.0	1.5	2.3	4.8
8 hr.	0.30	0.55	0.60	1.0	1.5	3.1
10 hr.	0.25	0.45	0.50	0.80	1.2	2.5
20 hr.	0.14	0.23	0.30	0.40	0.6	1.4

Table A—1 : Amperes per Single Cell Data to 1.67 VPC

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Performance by design since 1973

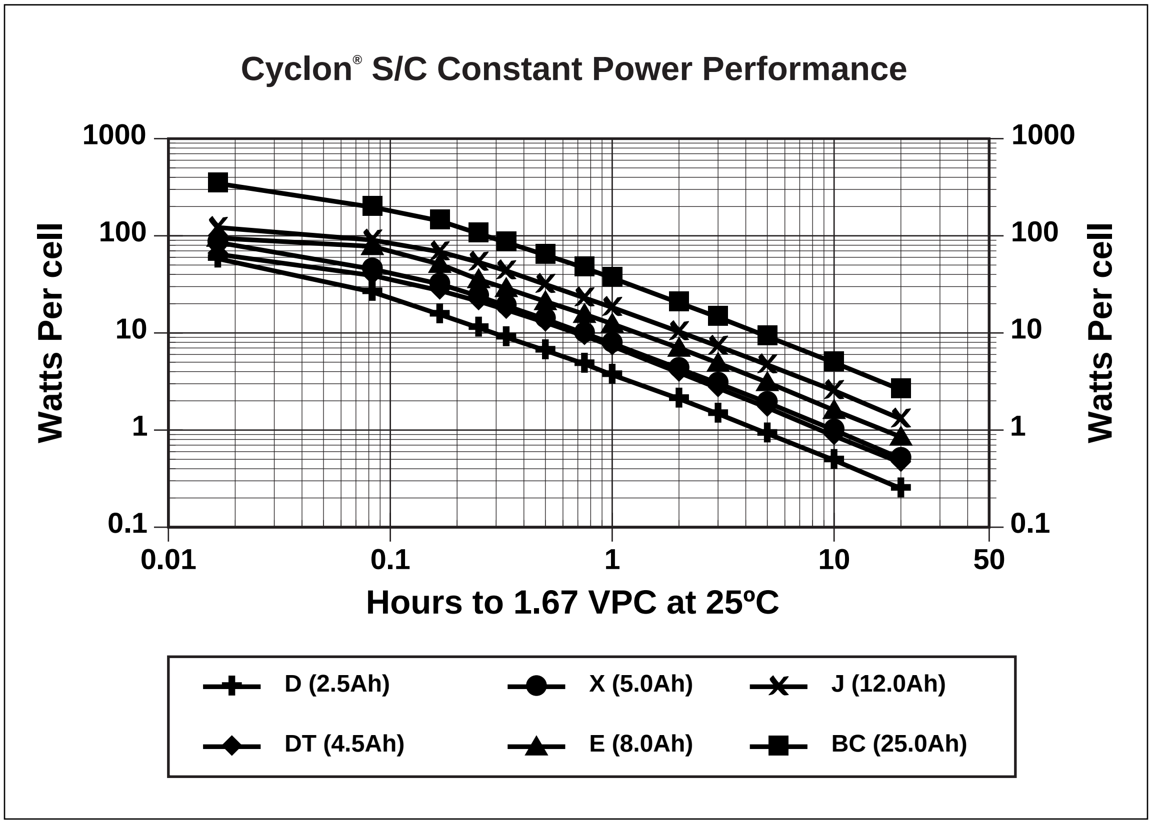

Figure A—2 : Single Cell CP Graphs to 1.67 VPC

Performance by design since 1973

Run time	D	DT	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

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

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Performance by design since 1973

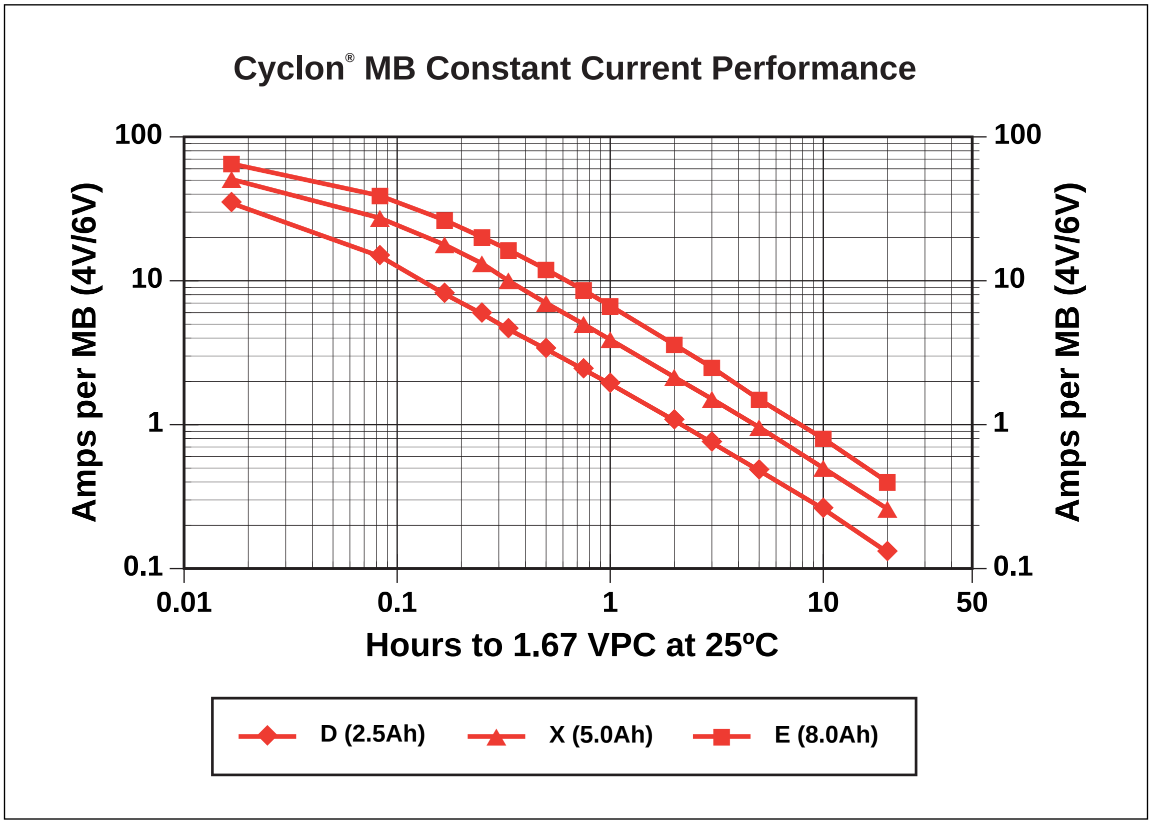

Figure A—3 : Monobloc CC Graphs to 1.67 VPC

Performance by design since 1973

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.	6.6	13.0	20.1
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.	2.15	4.2	6.7
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.	0.25	0.50	0.80
20 hr.	0.14	0.30	0.40

Table A—3 : Monobloc Amperes per Cell Data to 1.67 VPC

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Performance by design since 1973

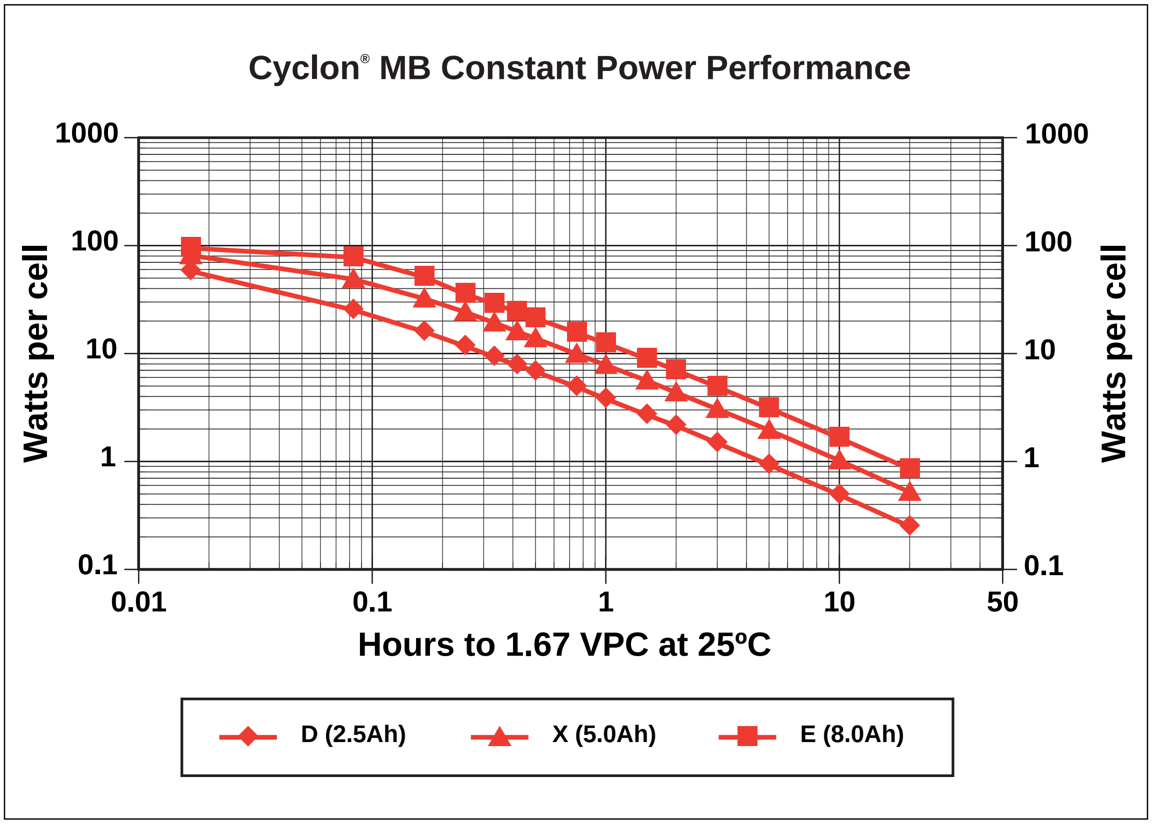

Figure A—4 : Monobloc CP Graphs to 1.67 VPC

Performance by design since 1973

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

Table A—4 : Monobloc Watts per Cell Data to 1.67 VPC

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Performance by design since 1973

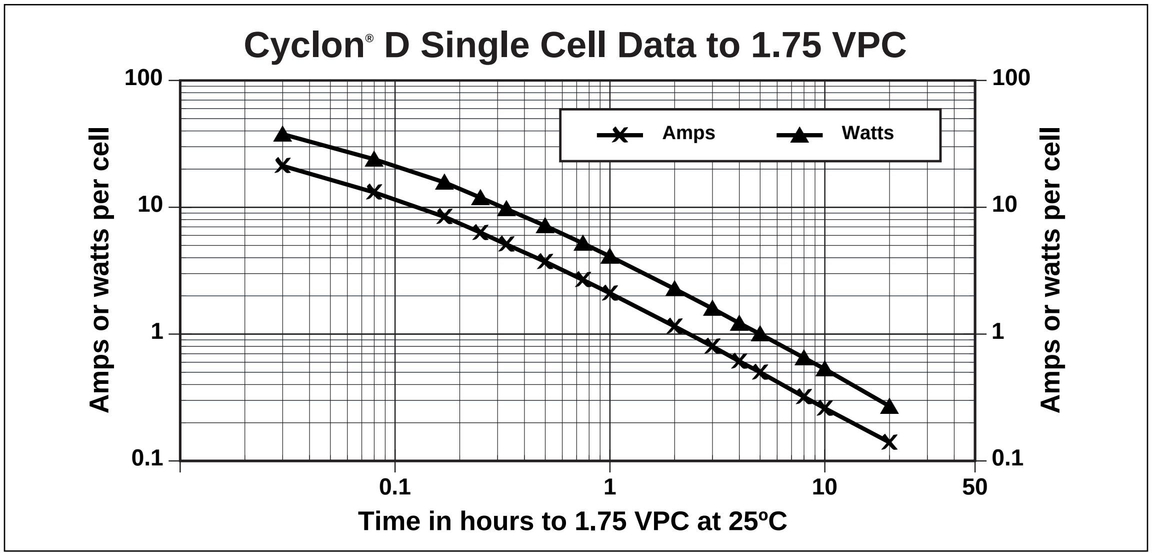

Figure A—5 : 2.5Ah Single Cell Performance Graphs to 1.75 VPC

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

Table A—5 : 2.5Ah Single Cell Performance Data to 1.75 VPC

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Performance by design since 1973

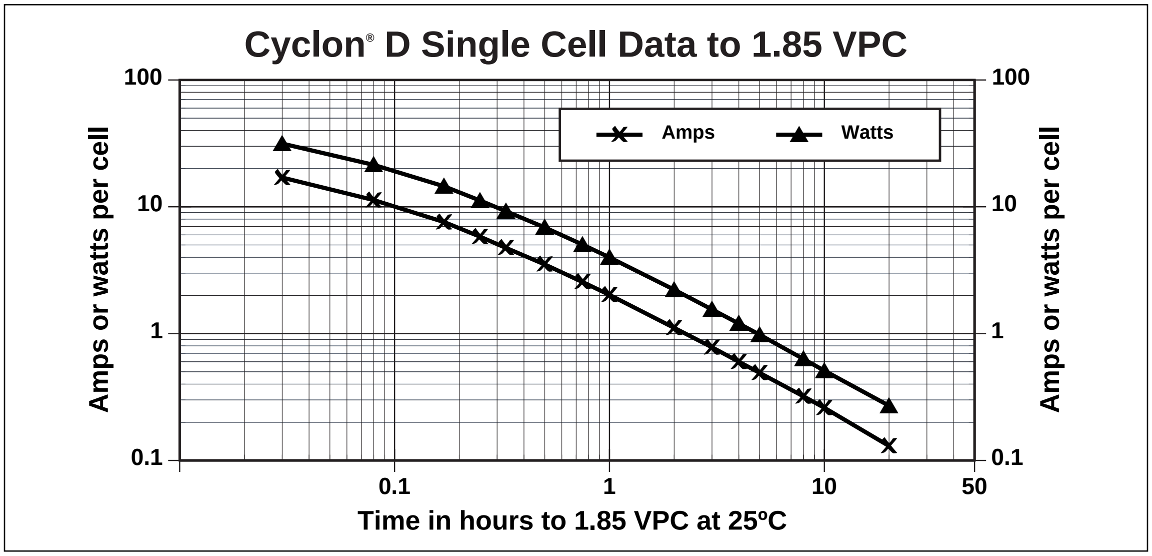

Figure A—6 : 2.5Ah Single Cell Performance Graphs to 1.85 VPC

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

Table A—6 : 2.5Ah Single Cell Performance Data to 1.85 VPC

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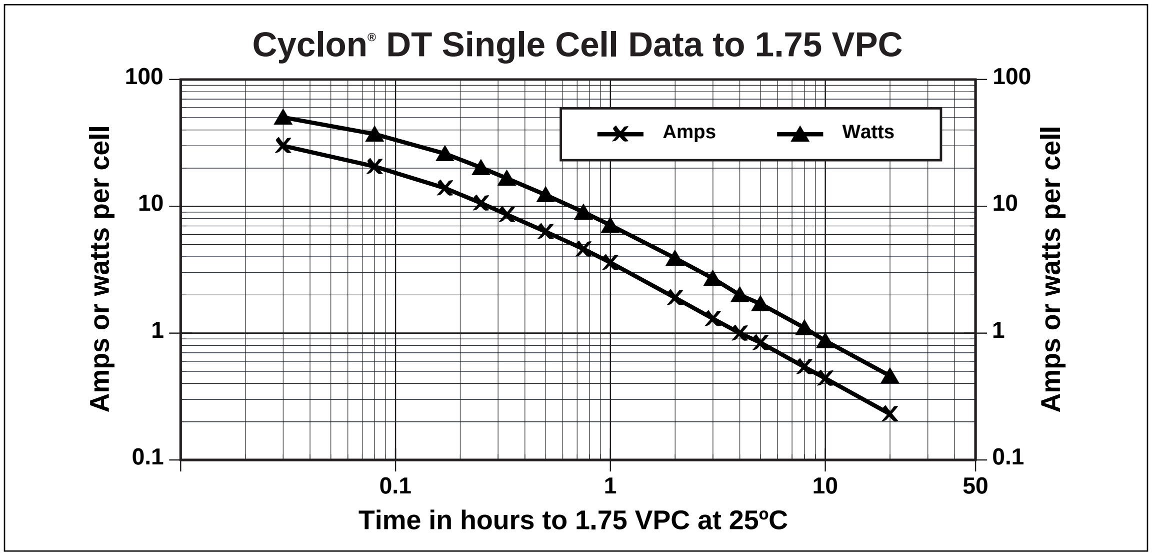

Figure A—7 : 4.5Ah Single Cell Performance Graphs to 1.75 VPC

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—7 : 4.5Ah Single Cell Performance Data to 1.75 VPC

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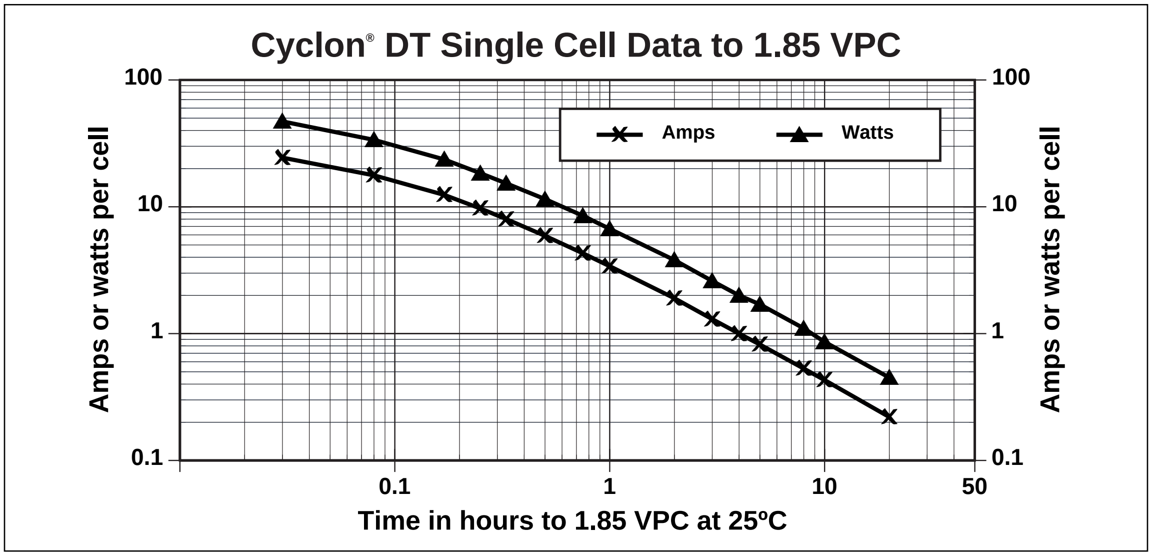

Figure A—8 : 4.5Ah Single Cell Performance Graphs to 1.85 VPC

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

Table A—8 : 4.5Ah Single Cell Performance Data to 1.85 VPC

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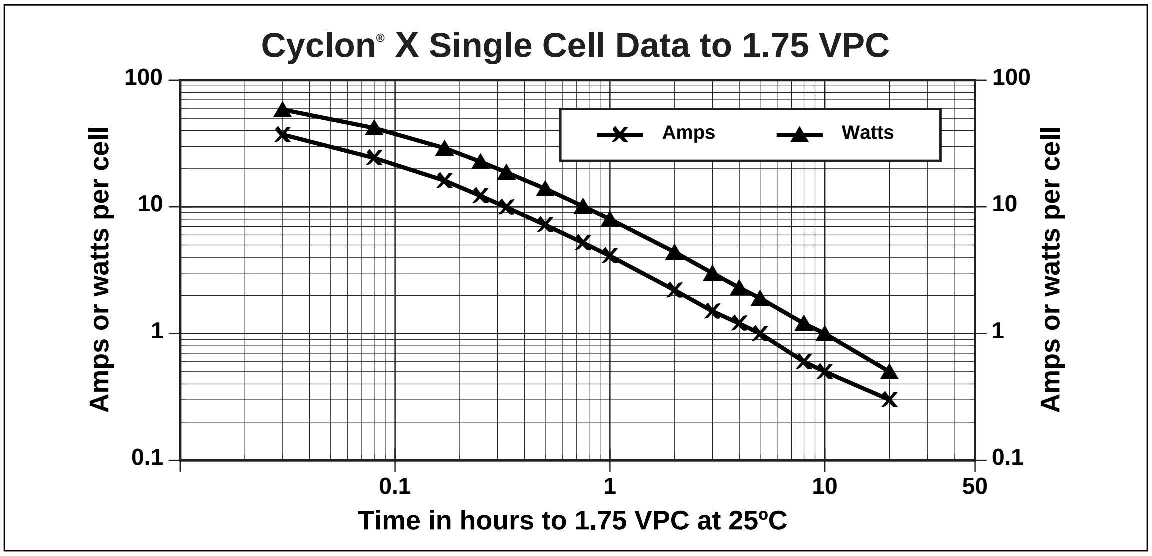

Figure A—9: 5.0Ah Single Cell Performance Graphs to 1.75 VPC

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

Table A—9 : 5.0Ah Single Cell Performance Data to 1.75 VPC

Performance by design since 1973

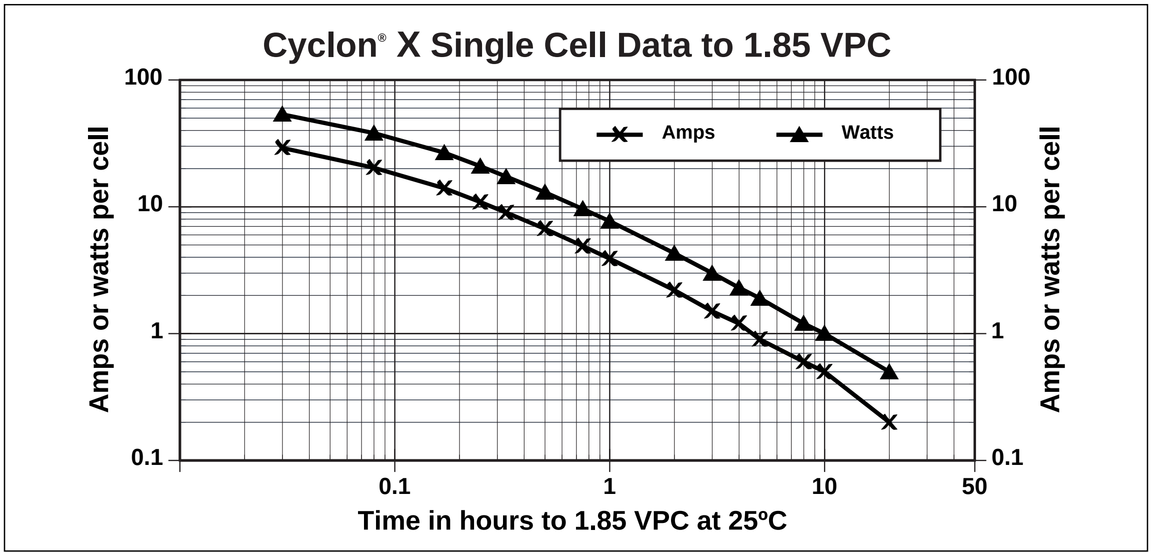

Figure A—10 : 5.0Ah Single Cell Performance Graphs to 1.85 VPC

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

Table A—10 : 5.0Ah Single Cell Performance Data to 1.85 VPC

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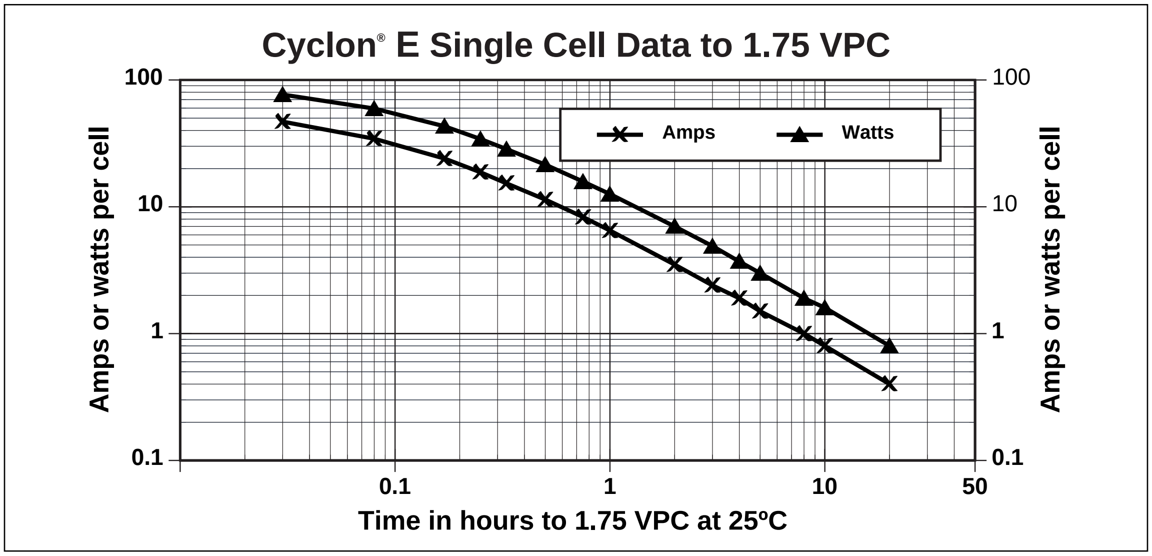


Figure A—11 : 8.0Ah Single Cell Performance Data to 1.75 VPC

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

Table A—11 : 8.0Ah Single Cell Performance Data to 1.75 VPC

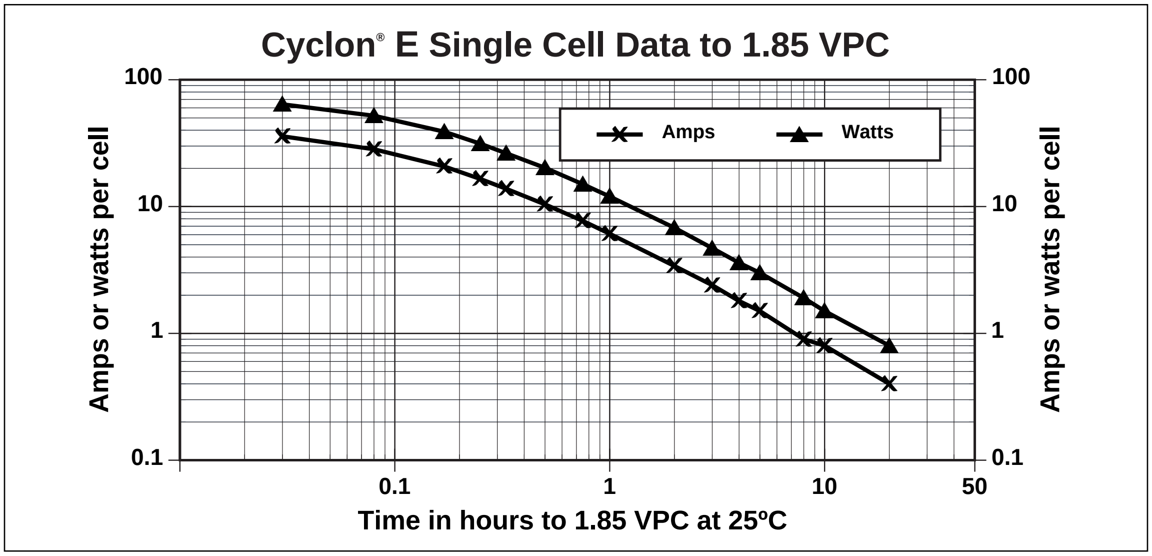


Figure A—12 : 8.0Ah Single Cell Performance Graphs to 1.85 VPC

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

Table A—12 : 8.0Ah Single Cell Performance Data to 1.85 VPC

HAWKER ENERGY

Performance by design since 1973

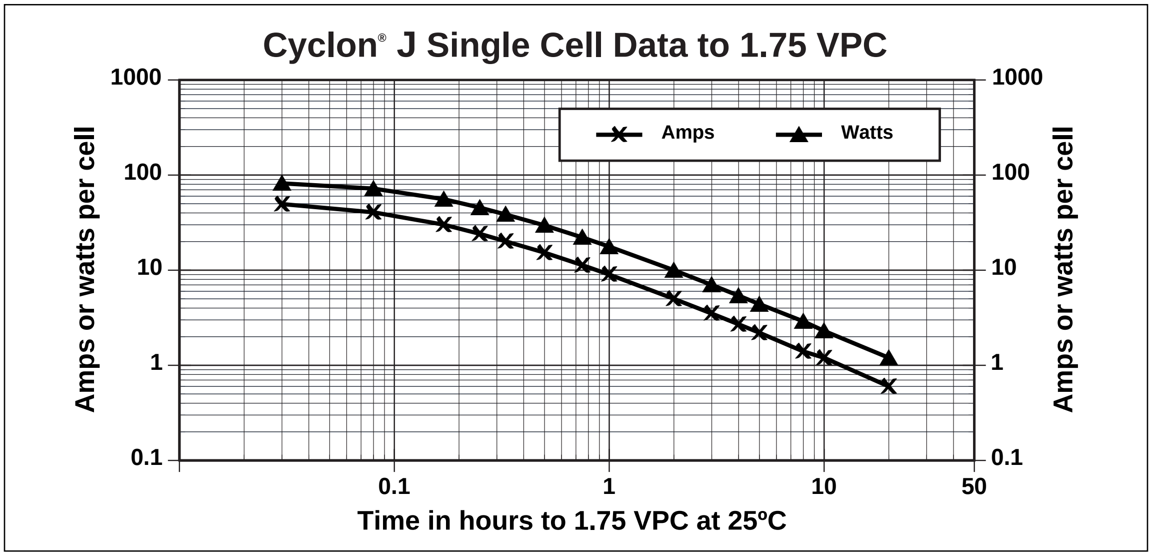


Figure A—13 : 12.0Ah Single Cell Performance Graphs to 1.75 VPC

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—13 : 12.0Ah Single Cell Performance Data to 1.75 VPC

Performance by design since 1973

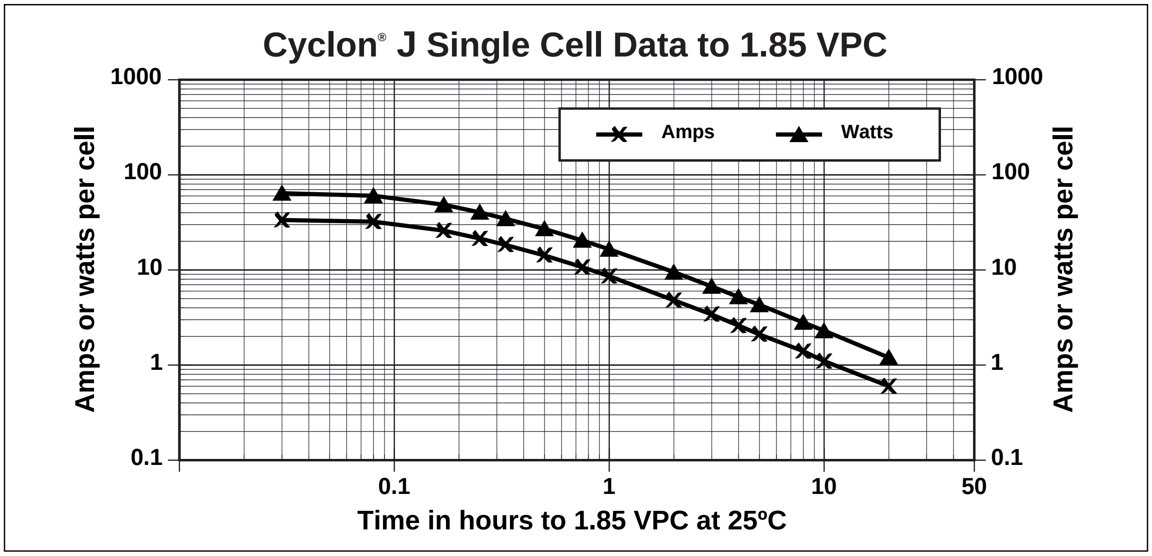


Figure A—14 : 12.0Ah Single Cell Performance Graphs to 1.85 VPC

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

Table A—14 : 12.0Ah Single Cell Performance Data to 1.85 VPC

HAWKER ENERGY

Performance by design since 1973

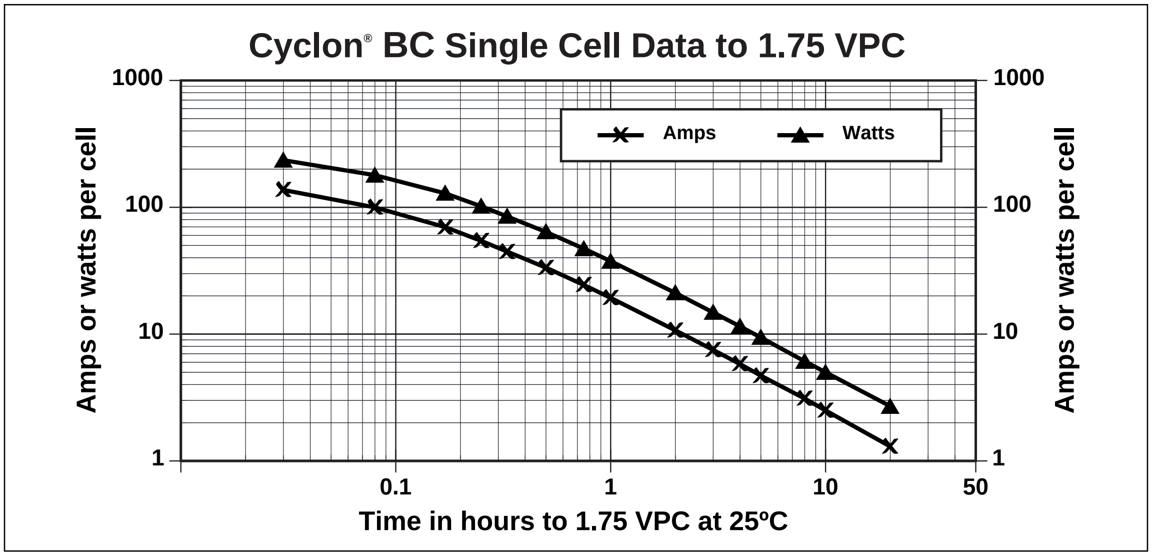


Figure A—15 : 25.0Ah Single Cell Performance Graphs to 1.75 VPC

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

Table A—15 : 25.0Ah Single Cell Performance Data to 1.75 VPC

Performance by design since 1973

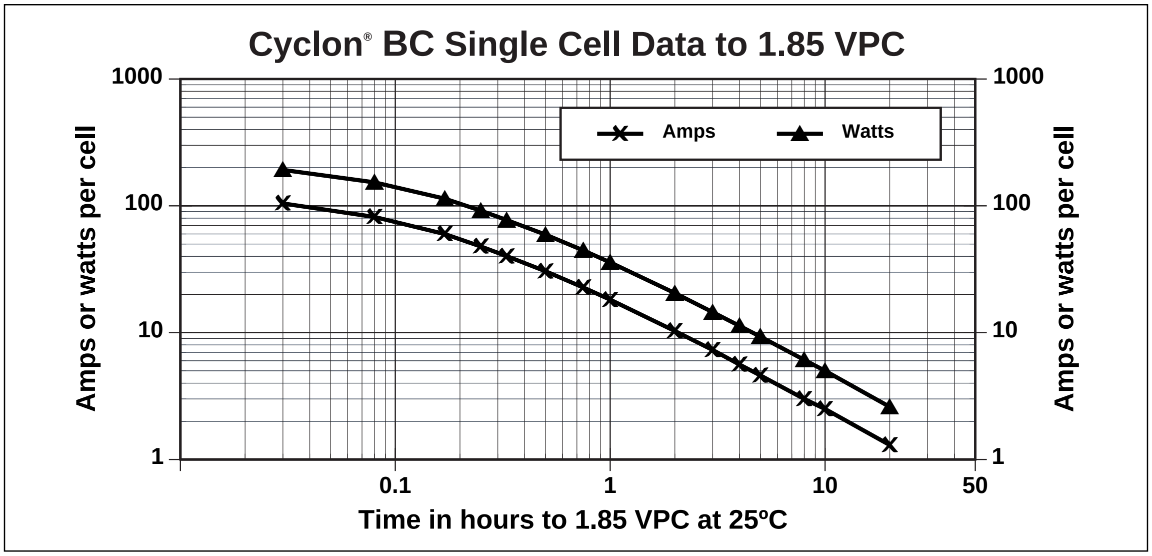


Figure A—16 : 25.0Ah Single Cell Performance Data to 1.85 VPC

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

Table A—16 : 25.0Ah Single Cell Performance Data to 1.85 VPC

HAWKER ENERGY

Performance by design since 1973

Appendix B

Run time	1.50	VPC	1.60	VPC
	Amps per cell	Watts per cell	Amps per cell	Watts per 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—1: Cyclon® D Single Cell and MB Performance Chart

Performance by design since 1973

Run time	1.50	VPC	1.60	VPC
	Amps per cell	Watts per cell	Amps per cell	Watts per 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—2: Cyclon® DT Single Cell Performance Chart

HAWKER ENERGY

Performance by design since 1973

Run time	1.50	VPC	1.60	VPC
	Amps per cell	Watts per cell	Amps per cell	Watts per 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—3: Cyclon® X Single Cell and MB Performance Chart

Performance by design since 1973

Run time	1.50	VPC	1.60	VPC
	Amps per cell	Watts per cell	Amps per cell	Watts per 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—4: Cyclon® E Single Cell and MB Performance Chart

HAWKER ENERGY

Performance by design since 1973

HAWKER TECHNOLOGY Pb PERFORMANCE BY DESIGN

Run time	1.50	VPC	1.60	VPC
	Amps per cell	Watts per cell	Amps per cell	Watts per 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—5 : Cyclon® J Single Cell Performance Chart

Performance by design since 1973

Run time	1.50	VPC	1.60	VPC
	Amps per cell	Watts per cell	Amps per cell	Watts per 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

Table B—6 : Cyclon® BC Single Cell Performance Chart

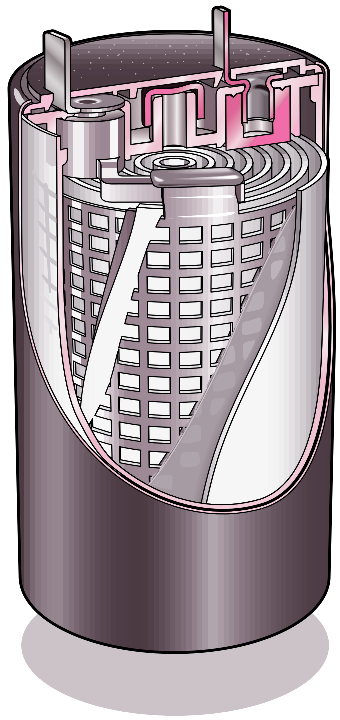
HAWKER ENERGY

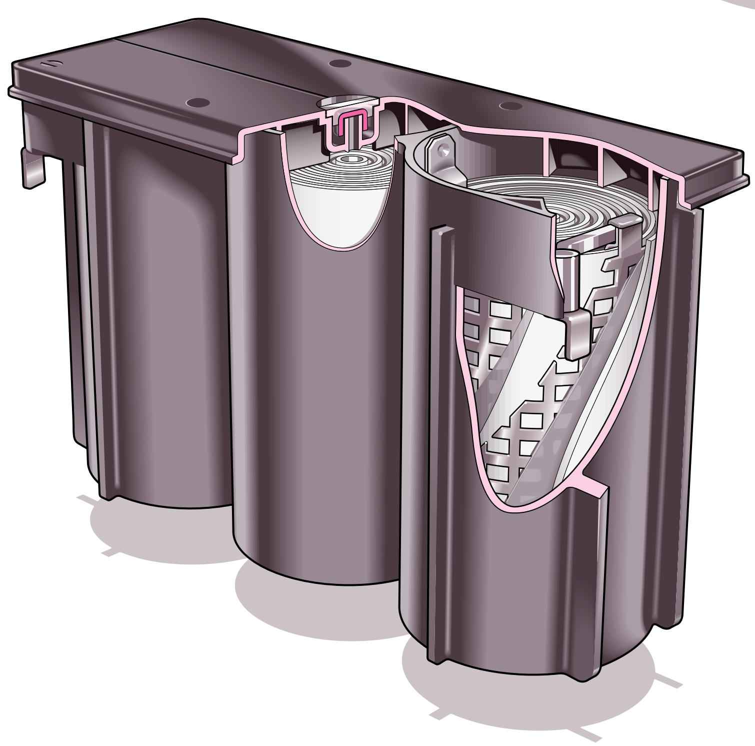
Performance by design since 1973

HAWKER TECHNOLOGY Pb PERFORMANCE BY DESIGN

Cyclon® Application Manual

Cyclon® 2V Single Cell





Cyclon® 6V Monobloc

CYCLON®

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