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THE LITHIUM–SULFUR DIOXIDE PRIMARY BATTERY — ITS CHARACTERISTICS, PERFORMANCE AND APPLICATIONS

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Summary

The lithium–sulfur dioxide battery is a new primary battery system with many advantages over conventional batteries. It has an energy density up to 330 W h/kg (150 W h/lb.), two to four times greater than zinc batteries, and can perform to temperatures as low as —54 °C (-–65 °F). The battery can withstand high temperature storage 71 °C (160 °F) for long periods of time and its shelf life is projected to be 5 - 10 years at 21 °C (70 °F). The chemistry, construction and detailed performance characteristics of the battery are presented. The Li/SO_2 system provides an all-purpose, all-climate primary battery that is capable of filling a wide variety of military, industrial and consumer applications. A number of these applications are discussed. With increasing production and cost reduction, the Li/SO_2 battery will be cost-competitive and will receive wide acceptability and use.

Introduction

The lithium–sulphur dioxide (Li/SO_2) battery is a new, lightweight, high energy primary battery system capable of performance over a wide temperature range (—54 to 71 °C, —65 to 160 °F) and delivering more than two to four times the service life of conventional batteries [1]. It is the most advanced of all of the lithium primary cells. The Li/SO_2 cell offers, at a reasonable cost, the capability of reducing the size and weight of battery-operated equipment, and meeting performance characteristics and requirements heretofore not attainable with primary battery systems.

The major advantages of the Li/SO_2 battery are:

(a) High cell voltage. The nominal cell voltage of the Li/SO_2 cell is 3.0 V compared with 1.5 V for most conventional primary cells.

(b) High energy density. The Li/SO_2 cell has an energy density up to 330 W h/kg (150 W h/lb.) and 525 W h/dm^3 (8.5 W h/cu.in.). This is from two to four times better than the performance of conventional zinc and magnesium batteries.

(c) High power density. The Li/SO_2 cell is capable of delivering its energy at high current or power levels, well beyond the capability of conventional primary batteries.

(d) Good low temperature performance. The Li/SO_2 cell is capable of performance to temperatures as low as —54 °C (—65 °F) compared with other primary batteries which provide little service below —18 °C (0 °F).

(e) Flat discharge characteristic. The Li/SO_2 cell maintains a relatively constant output voltage until its capacity is almost fully utilized.

(f) Superior shelf life. The storage or shelf life of the Li/SO_2 cell is projected to be 5 - 10 years at 21 °C (70 °F); storage of five years at room temperature and one year at 71 °C (160 °F) have been demonstrated.

(g) Leakproof design. The Li/SO_2 cell is encased in a leakproof hermetically sealed container. No leakage or gassing should occur during storage or use of the battery.

A comparison of the performance of a typical Li/SO_2 battery with other primary battery systems on a weight basis is shown in Fig. 1. At 21 °C (70 °F), the performance of the Li/SO_2 cell is from two to four times better than the performance of the conventional zinc and magnesium batteries. This advantage becomes more pronounced at lower temperatures; *e.g.*, the conventional primary batteries fail to operate below —18 °C (0 °F) while the lithium battery still delivers about 50% of its room temperature service at —40 °C (—40 °F). The advantage of the lithium cell on a volumetric basis is shown in Fig. 2. Typical discharge curves of several primary "D" size cells are compared with the lithium cell. The lithium cell has more than a 2:1 energy advantage over most of the conventional batteries. Only the zinc–mercuric oxide cell, which is noted for its high volumetric energy density, approaches the capability of the lithium system at 21 °C (70 °F), but the per-

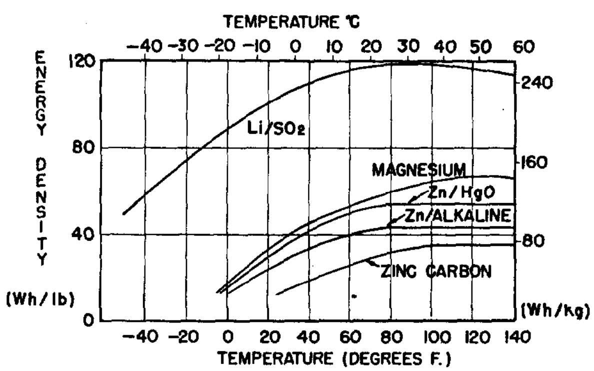

Fig. 1. Comparative performance of primary battery systems.

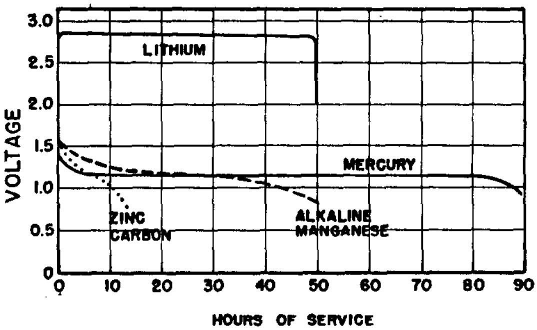

Fig. 2. Typical discharge on 'D' size cell at 200 mA avg. drain. 70 °F.

formance of the zinc–mercuric oxide cell drops off rapidly as the temperature is reduced.

Chemistry

The Li/SO_2 cell uses lithium as the anode and a porous carbon cathode electrode with sulphur dioxide as the active cathode material. The cell reaction mechanism is:

$$2\,Li + 2\,SO_2 \longrightarrow Li_2S_2O_4 \quad \text{(lithium dithionite).}$$

Lithium is a most attractive anode material because of its light weight, high electrochemical equivalence, good conductivity, high anode voltage and high energy density. As lithium reacts readily with water, a non-aqueous electrolyte is used. This consists of sulphur dioxide and an organic solvent, acetonitrile, containing dissolved lithium bromide. The specific conductivity of this electrolyte is high and decreases only moderately with decreasing temperatures (Fig. 3), thus providing a basis for good, high rate and low temperature performance [2].

Sulphur dioxide is contained in the electrolyte and constitutes about 70% of the weight of the electrolyte/depolarizer. The internal cell pressure, in an undischarged cell, due to the vapor pressure of the liquid SO_2 is 3 - 4 atm at 21 °C (70 °F). The internal pressure at various temperatures is shown in Fig. 4. The mechanical features of the cell are designed safely to contain this pressure without leaking.

During discharge, the SO_2 is depleted and the cell pressure is reduced. The discharge is generally terminated by the full use of the available lithium (in designs where the lithium is the stoichiometrically limiting electrode) or by the deactivation of the carbon electrode due to blocking of the active area by the precipitation of the discharge product (when the cathode is the limiting electrode).

The good shelf life of the Li/SO_2 cell results from the formation of a protective dithionite film on the anode, formed by the initial reaction of lithium and SO_2, which prevents further reaction or loss of capacity on stand.

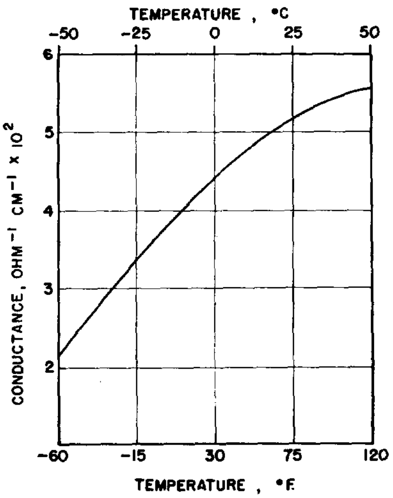

Fig. 3. Conductance of acetonitrile–lithium bromide–sulphur dioxide electrolyte.

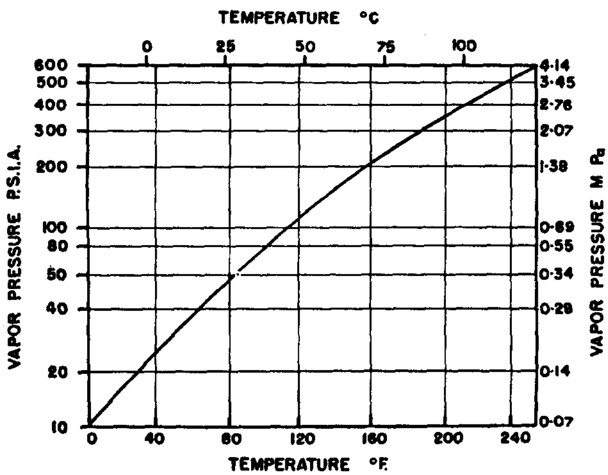

Fig. 4. Internal cell pressure.

The problem of anode corrosion, as occurs in conventional aqueous batteries, and the generation of H_2 gas is eliminated.

Construction

The Li/SO_2 cell is typically fabricated in a cylindrical structure (Fig. 5). A "jelly-roll" construction is used, made by spirally winding rectangular strips of lithium foil, a micro-porous polypropylene separator, the cathode electrode (a Teflon–carbon black mix, pressed on a supporting expanded

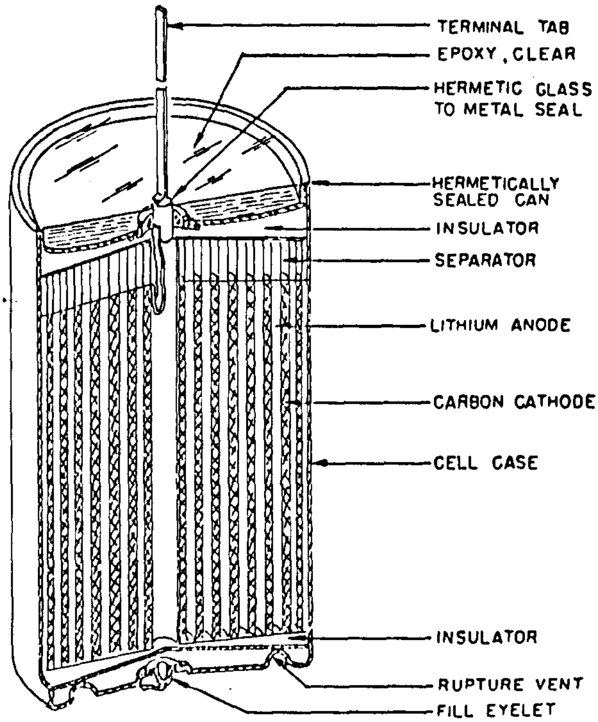

Fig. 5. Lithium–sulphur dioxide cell.

aluminum screen), and a second separator layer. This design provides the high surface area and low cell resistance to obtain the high current and low temperature performance. The roll is inserted in a nickel-plated-steel can which is electrically connected to the lithium anode. The cathode is welded to the center of the tantalum post of a glass-to-metal seal. The top is then hermetically sealed in place by welding the periphery to the can. The electrolyte/depolarizer is added through a temporary fill port on the bottom of the cell, which is then welded closed.

A safety vent is located at the bottom of the cell can. This vent releases when the internal cell pressure reaches excessive levels due to inadvertent abusive use such as overheating or short circuit, and prevents cell rupture or explosion. The vent activates at approximately 105 °C (220 °F) (Fig. 4), well above the upper temperature limit for operation and storage, safely relieving the excess pressure and preventing possible cell rupture. The principle of the vent design is illustrated in Fig. 6. Two diametrically opposed convolutions (A) are connected by two narrow bridges (C–C) where the can thickness has been reduced to approximately 50% of its original thickness. As the internal cell pressure increases, the area confined by the convolutions moves outward, causing the convolutions to unfold. However, the thinner material cross section at the bridges leads to a tearing action which results in mechanical rupture for a controlled release of the electrolyte. The maximum deflection of

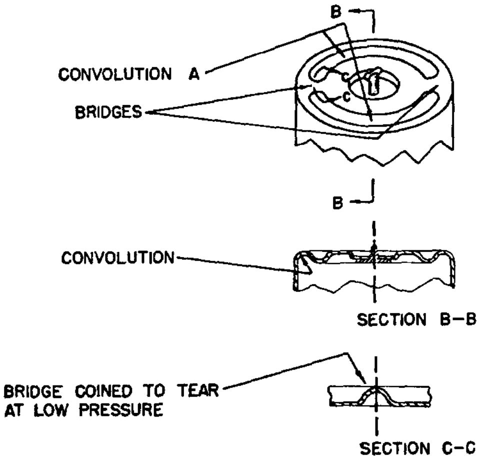

Fig. 6. Base of Li–SO_2 can with convolution vent.

the vent is proportional to the cell diameter; for a cell of approximately 1.3 in. (3.3 cm) dia. the maximum deflection is 0.05 in. (0.125 cm).

Performance

Voltage

The nominal voltage of the Li/SO_2 cell is 3 V. The specific voltage on discharge is dependent on the discharge rate, discharge temperature, and state-of-charge. The end or cut-off voltage, the voltage by which most of the cell capacity has been expended, is 2 V.

Discharge

Typical discharge curves for the Li/SO_2 cell at 21 °C (70 °F) are given in Fig. 7. The high cell voltages and the flat discharge curves are characteristic of the Li/SO_2 cell. Another unique feature is the ability of the Li/SO_2 cell to be efficiently discharged over a wide range of current or power levels — from as high as the two hour rate to low-drain, continuous discharges for periods as long as one to two years — with good voltage regulation even at the extremes of the discharge load.

Figure 8 compares the high rate capability of various primary batteries ("D" cell size). The Li/SO_2 cell maintains a high capacity almost to the one hour or 10 watt rate, whereas the zinc and magnesium batteries begin to drop off significantly at the 20 - 50 hour rate.

Effect of temperature

The Li/SO_2 cell is noted for its ability to perform over a wide temperature range, from −54 °C (−65 °F) to over 70 °C (160 °F). Discharge curves for a standard Li/SO_2 "D" cell at various temperatures are shown in Fig. 9.

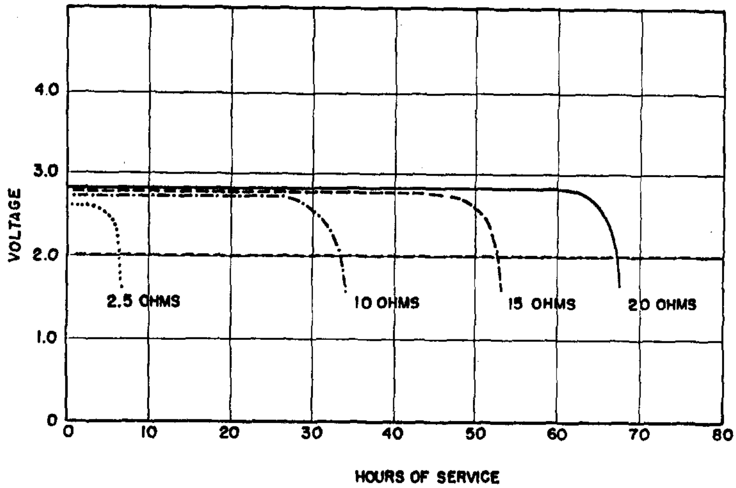

Fig. 7. Typical discharge characteristics of Li–SO_2 D size cell at various loads. 70 °F.

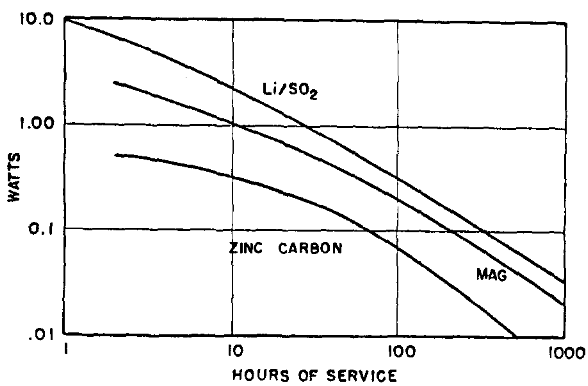

Fig. 8. High rate advantage of Li–SO_2 cell (D-size cell performance at 70 °F).

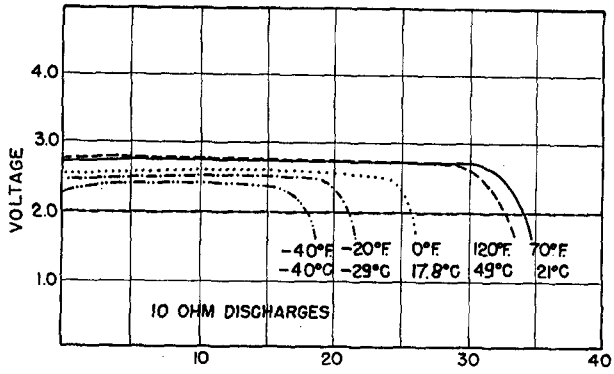

Fig. 9. Typical discharge characteristics of Li–SO_2 D-size cell at various temperatures.

Significant, again, are the flat discharge curves over the wide temperature range, the good voltage regulation, and the high percentage of the 21 °C (70 °F) performance available at the temperature extremes.

As with all battery systems, the relative performance of the Li/SO_2 battery is dependent on the rate of discharge. In Fig. 10, the discharge performance is plotted as a function of load and temperature. The advantage of the low rate discharge is evident; although, even at the high discharge rates, a high percentage of the 21 °C (70 °F) performance is available at the temperature extremes.

Internal resistance

The Li/SO_2 cell has a relatively low internal resistance compared with conventional primary batteries. The resistance of a "D" size cell at 21 °C (70 °F) and at various states of discharge is plotted in Fig. 11. The change in resistance is more noticeable at lower temperatures, reaching a minimum when the cell is about 30% discharged.

Service life

The capacity or service life of the standard Li/SO_2 cell at various discharge rates and temperatures is given in Fig. 12. The data are normalized for a 1 pound or 1 kilogram cell and presented in terms of hours of service at various discharge rates. The linear shape of these curves, except for the fall-off at high current levels and low temperatures, is again indicative of the lithium–sulphur dioxide system's capability to be efficiently discharged at these extreme conditions. These data are applicable to all standard Li/SO_2 cells and can be used in several ways to calculate the performance of a given cell or to select a Li/SO_2 cell of a suitable size for a particular application.

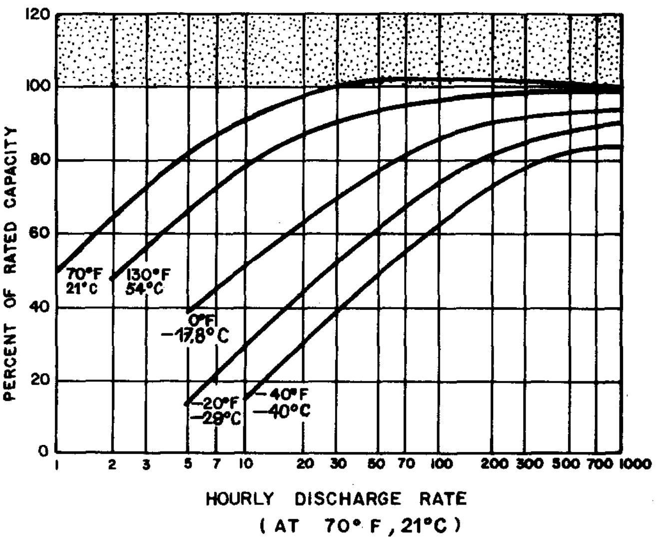

Fig. 10. Performance as a function of temperature and load.

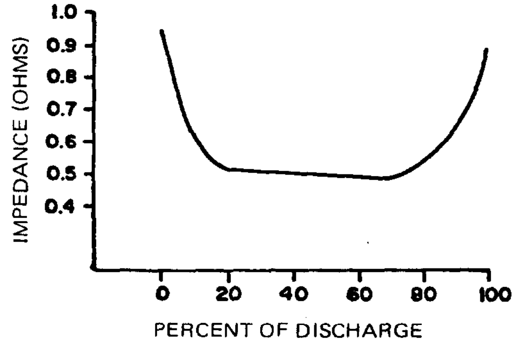

Fig. 11. Cell impedance. D-size cell, 70 °F.

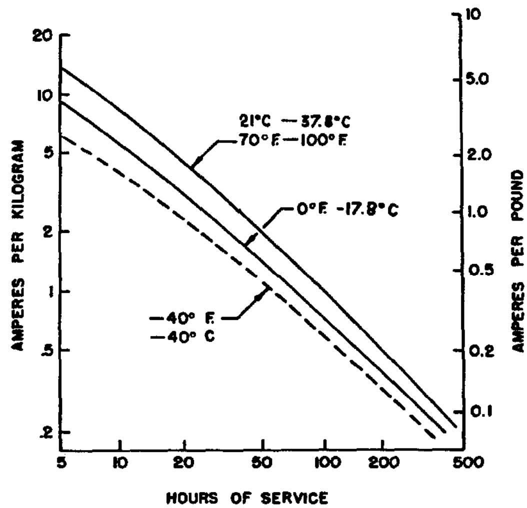

Fig. 12. Projected service life of a Li–SO_2 cell (to 2 V per cell).

Capacity of a specific Li/SO_2 cell

The service life of a cell at a given current load can be estimated by dividing the current (in amperes) by the weight of the cell in pounds or kilograms. This value is located on the ordinate and the service life, at a specific current and temperature, is read off the abscissa.

Selection of a specific Li/SO_2 cell

The weight of a cell needed to deliver a required number of hours of service at a specified current load can be estimated by locating a point on the curve corresponding to the required service hours and discharge temperature. The cell weight is calculated by dividing the value of the specified current (in amperes) by the value of amperes per kilogram (or pound) obtained from the ordinate.

These data are applicable to all standard Li/SO_2 cells; special designs, such as the high rate cells, may differ and the data for these cells should be obtained from the individual cell specification sheets provided by the manufacturer.

Shelf life

The Li/SO_2 battery is noted for its excellent storage characteristics, even at temperatures as high as 72 °C (160 °F). Shelf life data for the Li/SO_2 cell at various temperatures are presented in Fig. 13, which also gives comparative data for some conventional batteries. Most primary batteries lose capacity while idle or on stand due to anode corrosion, side chemical reactions or moisture loss. With the exception of the magnesium cell, most of the conventional primary cells cannot withstand temperatures in excess of 50 °C (120 °F) and should be refrigerated if stored for long periods. The lithium–sulphur dioxide cell, however, is constructed in an hermetically-sealed design and protected during storage by the formation of a film on the anode surface. Capacity losses during stand are minimal. Five year storage tests on the earlier, crimped-seal cells showed a capacity loss of about 25%, most of it accountable to the loss of SO_2 through the crimped seal. Three year storage data are presently available for the newer, hermetic seal; these data can be projected to a five year storage capability with less than a 5 - 10% capacity loss [3]. At elevated temperatures, after one year storage, the capacity loss is less than 35% at 72 °C (160 °F), and 20% at 55 °C (130 °F). In general, as plotted in Fig. 13, the rate of capacity loss is higher initially and decreases significantly as the storage period is extended.

Voltage delay

After extended long term storage at elevated temperatures, the Li/SO_2 cell may exhibit a delay in reaching its operating voltage (above 2.0 V) when

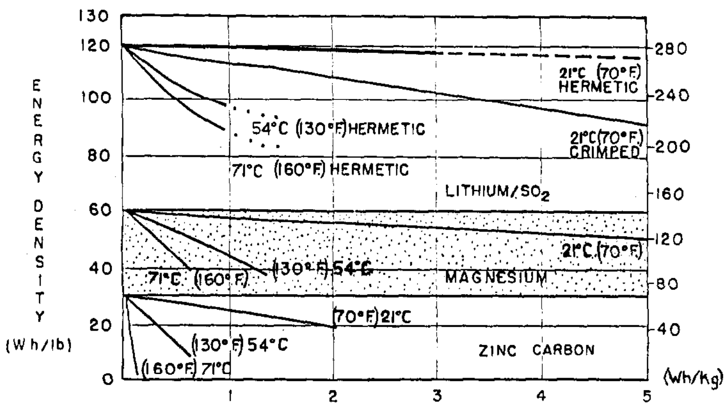

Fig. 13. Storability of batteries.

placed on discharge, especially at high current loads and at low temperatures. This start-up delay is basically caused by anode passivation or film formation, the characteristic responsible for the excellent shelf life of the cell. The voltage delay is minimal for discharge temperatures above −30 °C (−20 °F). No delay was measurable for discharges at 21 °C (70 °F) even after storage at 71 °C (160 °F) for one year. On −30 °C (−20 °F) discharges, the delay (time to 2 V) was less than 200 ms after 8 weeks of storage at 71 °C (160 °F) on discharges below the 40 hour rate. At higher rates, the voltage delay increased with an increase in storage temperature and time. However, even at the two hour discharge rate, the maximum start-up time was 80 s after 8 weeks of storage at 71 °C (160 °F). After two weeks of storage, the start-up time was only 7 s [3]. The start-up voltage delay can be eliminated by a short discharge until the operating voltage is reached, as the delay will return only after another extended storage period.

Voltage reversal

The design of a Li/SO_2 cell which can safely withstand extended discharge below zero volts into voltage reversal has been the subject of considerable study. The design features which affect the abuse resistance of the Li/SO_2 cell are:

(1) The Li/SO_2 ratio at the completion of the normal discharge.

(2) The performance limiting process.

A low Li/SO_2 ratio and maximum cathode utilization above zero volts are the desired design features from a safety standpoint. The presence of SO_2 at the completion of the cell discharge is most critical because of a possible reaction between excess lithium and the acetonitrile in the absence of SO_2.

Figure 14 shows the forced discharge of a Li/SO_2 "D" cell with a Li/SO_2 ratio of 1.5:1 at −20 °C (−30 °F). The cell delivered over 6 A h of service to 2.0 V, about 60% of the cell's rated capacity. The forced discharge was continued into voltage reversal. After the discharge of 11.5 A h, a peak cell wall temperature of 207 °C (405 °F) was reached as the cell vented. The cell voltage as well as the cathode *vs.* reference voltage were similar, but the anode voltage remained unchanged. Close to the venting point, the anode showed a marked voltage excursion with the cell voltage fluctuations following the anode fluctuations.

Figure 15 shows the advantage of a design with a balanced Li to SO_2 ratio. On reversal, more negative voltage excursions were encountered than in the unbalanced cells; peak temperature reached was 97 °C (175 °F) and no venting occurred [4, 5].

Cell types and sizes

The Li/SO_2 cells are manufactured in a variety of cylindrical cell sizes, ranging in capacity from 0.450 to 30 A h. Larger cells are under development

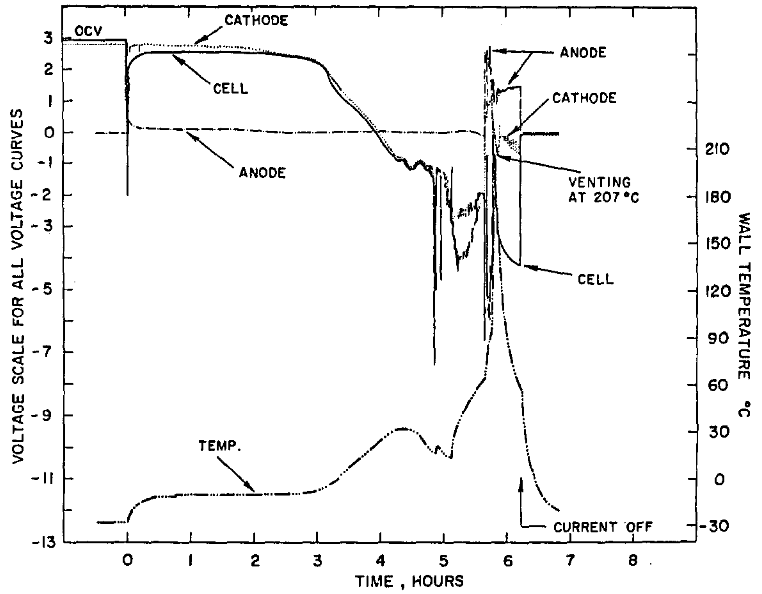

Fig. 14. Forced discharge of a Li–SO_2 "D" cell with a Li–SO_2 ratio of 1.5:1 at −20 °C (−30 °F).

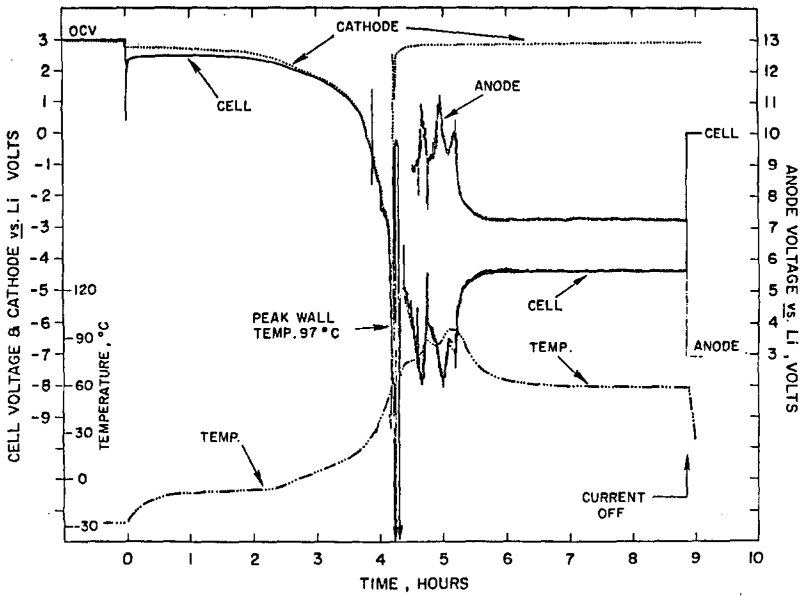

Fig. 15. Advantages of a design with a balanced Li/SO_2 ratio.

but currently are not available on a commercial basis. A number of the cells are manufactured in standard ANSI (American National Standards Institute) cell sizes in dimensions of popular conventional zinc primary cells. While these single cells may be physically interchangeable, they are not electrically interchangeable because of the higher cell voltage of the lithium cell (3.0 V for lithium; 1.5 V for the conventional zinc cells.)

Table 1 lists some of the cells currently available and gives their major physical and electrical characteristics [6]. The cells are classified in two categories; the standard cells (Mallory "S" designation) and the high rate cells (Mallory "SH" designation). The standard cell is optimized to deliver high energy output over a wide range of discharge loads and temperatures. The high rate cell is designed with longer and thinner electrodes than the standard cell and delivers more service at a high discharge rate (higher than the 10 hour rate) and at low temperatures. At lower discharge rates, the service life of the high rate cell is less than that delivered by the standard cell.

In addition, Mallory is beginning the manufacture of a lithium-limited (or balanced) cell (designated by "SX"). This cell is designed with a stoichiometric ratio of lithium to sulfur dioxide in the order of 1:1 rather than the excess of lithium used in the other designs. The lithium-limited feature assures the presence of sulfur dioxide throughout the life of the cell to protect the lithium from chemically reacting with the other cell components. This design has been found successfully to withstand extended over discharge below zero volts at rated loads. These cells also do not produce the toxic chemicals that form when standard cells are fully discharged, thus simplifying disposal procedures. The lithium-limited cell does, however, deliver lower capacity, compared with the standard cell, at low discharge rates (below the 5 hour rate).

Cost

The cost of the lithium cell is rapidly decreasing as production facilities become available and production rates increase. The lithium cell will be cost-competitive with conventional primary cells on a cost-per-watt-hour service basis.

Applications

The advantageous performance characteristics of the lithium battery and its ability to deliver a high energy output and operate over a wide range of temperature, discharge load and storage conditions have resulted in its use in an increasing number of applications. Its light weight and small size, high drain capability and low temperature operation have, in fact, opened up new applications for primary batteries that, heretofore, were beyond the capability of primary battery systems. Some typical uses of the lithium battery are presented; the examples have been selected to illustrate the wide variety of applications in which the Li/SO_2 battery has, and can be, beneficially employed.

TABLE 1

Major physical and electrical characteristics of some currently available cells

Cell	Weight		Dia., in. (tolerance ±0.015 in., ±0.38 mm)	Length, in. tabs included (tolerance ±0.025 in., ±0.635 mm)	Rated capacity (30 h rate) (A h)
	(g)	(Oz.)			
L025S	95	3.32	1.525 (38.7)	2.055 (52.2)	9.6
L026S	85	2.96	1.330 (33.8)	2.354 (59.8)	9.0
L026SH	85	2.96	1.330 (33.8)	2.354 (59.8)	7.0 (at 1 amp)
L026SX	85	2.96	1.330 (33.8)	2.354 (59.8)	7.5
L027S	47	1.65	1.010 (25.7)	2.354 (59.8)	5.0
L028S	37	1.30	0.955 (24.3)	1.978 (50.2)	3.5
L029S	39	1.37	1.010 (25.7)	1.989 (50.5)	4.0
L030S	64	2.22	1.145 (29.1)	2.354 (59.8)	6.7
L030SH	64	2.22	1.145 (29.1)	2.354 (59.8)	5.0 (at 1 amp)
L030SX	64	2.22	1.145 (29.1)	2.354 (59.8)	5.5
L032S	12	0.42	0.645 (16.4)	1.350 (34.3)	0.95
L034S	17	0.58	1.010 (25.7)	0.769 (19.5)	1.0
L036S	13	0.46	0.955 (24.3)	0.743 (18.9)	0.65
L037S	6.5	0.23	0.546 (13.9)	0.917 (23.3)	0.45
L042SHX	36	1.26	1.145 (29.1)	1.270 (32.3)	2.4
L050S	207.0	7.23	1.525 (38.7)	4.504 (114.4)	22.0

Radio-transceivers

A major application of the lithium battery is in portable or manpack radio-transceivers. The use of the lithium battery offers the advantages of size and weight reduction and low temperature operation. Figure 16 [7] compares the performance of the Li/SO_2 Battery BA-5598 with the conventional zinc–carbon and magnesium batteries in the military man-pack radio AN/PRC-77. The transmit discharge load for the lithium battery is at the C/10 rate; the receive load is at the C/200 rate; the transmit to receive duty cycle is 1:9. As shown in Fig. 16, the lithium battery, which is one-half the size and weight of the zinc and magnesium batteries, outperforms the larger, conventional batteries at 21 °C (70 °F). At −18 °C (0 °F), the zinc battery delivers no service and the performance of the magnesium battery has dropped considerably from its 21 °C (70 °F) performance. At −40 °C (−40 °F), only the lithium battery is capable of operation; the half-size battery delivering at −40 ° the same service that the full-size zinc battery delivers at 21 °C (70 °F).

The advantageous flat discharge characteristic of the Li/SO_2 battery is illustrated in Fig. 17 [6]. The lithium battery does not have a sharp voltage drop at the start of the discharge, and has a flatter discharge and less of a voltage difference between transmit and receive than the magnesium battery. In addition, in these applications, the Li/SO_2 battery does not have the voltage delay at the start of the discharge that is typical of the magnesium battery.

The performance of the Li/SO_2 battery was confirmed in field tests performed by the United States and Norwegian Armies. Figure 18, summarizes the results of tests conducted by the Norwegian Army in the Winter 1977/1978 using 2000 full-size Li/SO_2 and zinc–carbon batteries. The lithium battery outperformed the zinc battery by 6:1 at 21 °C (70 °F) and by more than 10:1 at −20 °C (−4 °F) [8].

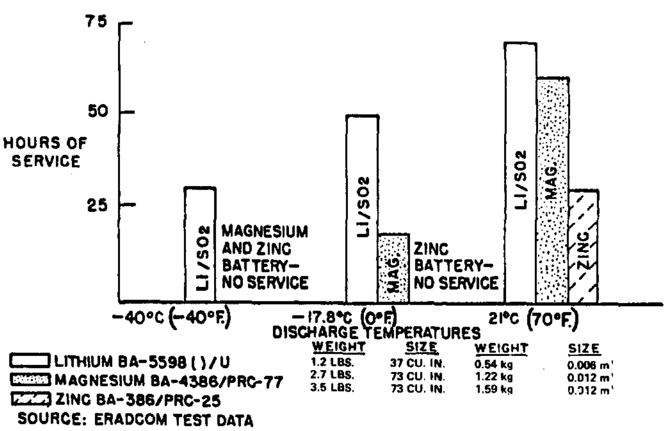

Fig. 16. Performance of Li–SO_2 batteries and other systems in radio set AN/PRC-77.

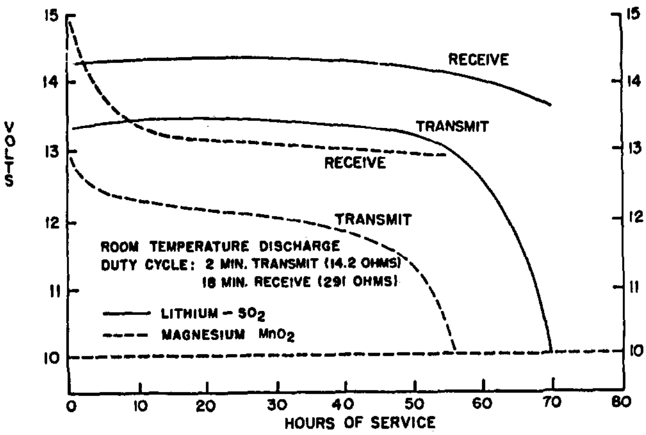

Fig. 17. Comparison of battery performance. Lithium BA-5598( )/U *vs.* magnesium BA-4386/PRC-25,77 at simulated AN/PRC-77 usage loads.

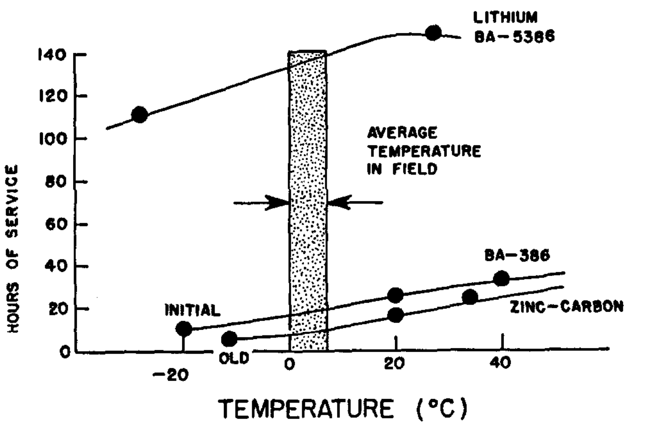

Fig. 18. Comparative performance of lithium *vs.* zinc–carbon batteries.

Military applications

In addition to radio-transceivers, the advantageous characteristics of the lithium battery open up a wide range of applications heretofore beyond the capability of conventional batteries. Several applications are listed in Table 2, comparing the performance of the Li/SO_2 battery with the conventional battery systems.

The man-portable message device provides a digital information display and requires a relatively high current drain for this display. The nickel–cadmium battery now used operates for four hours. The estimated performance of competitive primary battery systems for this application are shown in Table 2. The mercury battery, noted for its high volumetric efficiency, approaches the lithium battery service at 21 °C (70 °F), but is more than twice as heavy and cannot perform at low temperatures. The selection of a primary *vs.* secondary battery depends on a number of considerations, including size and weight, the combat area and equipment deployment, and the life cycle cost advantage when the secondary battery can be recharged.

Two examples of potential applications in night-vision equipment illustrate the high rate performance of the lithium battery and its capability to replace secondary batteries. In both applications, the lithium battery is lighter and delivers more service (on an energy density basis) than the secondary battery. In the second example, a relatively large silver–zinc secondary battery was used which could not be contained within the equipment. The battery was carried on the soldier's belt, connected by an umbilical cord to the equipment. The ability to eliminate the use of secondary batteries requiring recharging in the field, also provides an important asset under combat conditions.

A missile firing system is another application for lithium batteries. Heavy current pulses at the C/2 rate are required at temperatures down to −29 °C (−20 °F). The Li/SO_2 battery developed for the Norwegian Army, as shown in Fig. 19 [8] is capable of providing up to 10 times the number of firings (14 A for 100 ms) of the nickel–cadmium battery at all operating temperatures. In addition, the lithium battery offers increased shelf life, a minimum of maintenance, no recharging and tactical operational readiness.

Another requirement is for batteries for use in artillery-delivered equipments, such as sensors, electronic warfare devices, weapons, etc. These batteries must withstand the high shock, up to 15000 g, and spin of the firing acceleration as well as having a high energy density, low temperature performance, and long shelf life. Electrically, the Li/SO_2 battery is a logical selection for this application. Recent tests showed that the cylindrical, hermetically-sealed Li/SO_2 cell could meet the stringent acceleration requirement.

TABLE 2

Typical applications of lithium batteries

	(lb. (kg))	21 °C (70 °F) service (h)	−40 °C (−40 °F) service (h)
Man-portable message device			
Lithium	1.3 (0.59)	20	9
Magnesium	1.5 (0.68)	6	0
Mercury	3.3 (1.5)	16	0
Night vision equipment			−20 °F service
(1) Lithium	0.5 (0.23)	6	2.5
Magnesium	1.5 (0.68)	3.5	0
Nickel–cadmium	2.0 (0.91)	2	1.2
(2) Lithium	0.8 (0.36)	4	2
Magnesium	1.6 (0.73)	3	0
Silver–zinc	3.5 (1.59)	12	4

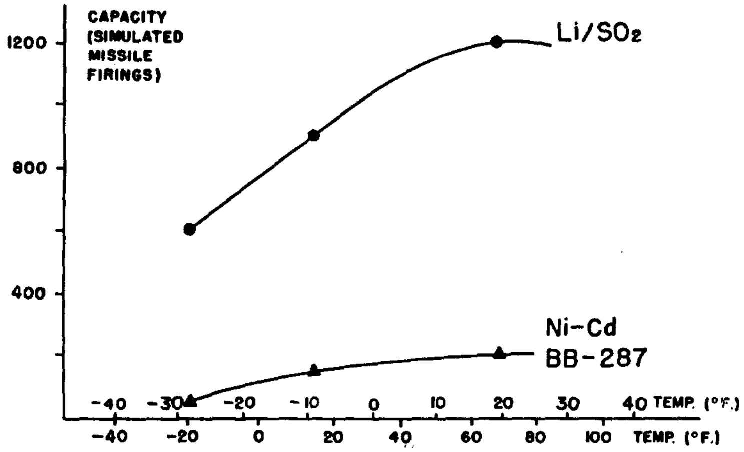

Fig. 19. Comparison of Li–SO_2 *vs.* nickel–cadmium batteries for TOW missile launcher.

Sonobuoys

The Li/SO_2 battery is being considered for replacing the reserve magnesium–silver chloride sea-water-activated battery used in most sonobuoys now in production. The cost of the silver battery is as high as 15% of the total cost of the sonobuoy. Increasing cost and scarcity of silver requires its replacement by a less costly battery. The critical requirements are a repeated heavy pulse (about the 3C rate) for a one second duration and a storage life of up to five years. This latter requirement dictated the use of a reserve battery. The lithium battery readily meets the performance and storage requirement, with an advantage over the seawater-activated battery in cold temperature performance and in the absence of electrical "noise". Plans are now current to replace the silver battery with the Li/SO_2 system [9].

Aircraft applications

An important application taking advantage of the low temperature and good storability characteristics of the lithium battery is its use in aircraft rescue beacons and emergency locator transmitters (ELT), in both civilian and military aircraft. The predominant requirements are the ability to withstand excessively high temperatures that may be attained in an aircraft while on the ground, to operate at extremely low temperatures that may be encountered in a forced landing or crash, and a five year shelf life to minimize equipment maintenance. The new Li/SO_2 battery is uniquely qualified for these applications; mercury, magnesium and other conventional batteries now used are not capable of meeting all of these requirements. Government regulations are now being established by which the lithium battery will be authorized for aircraft use.

Space applications

The high energy output, reliability and ease of application of the lithium primary battery make it an excellent candidate for certain space vehicle applications. The lithium battery has about five times the energy density of the rechargeable nickel–cadmium battery. In some space experiments, it can provide sufficient service, and avoid the need for solar cells and a recharging capability aboard the spacecraft. A lithium battery power source is being developed for use in the LDEF (Long Duration Exposure Facility), a 20-month long experiment now being planned by NASA [10].

Industrial applications

The advantageous characteristics of the Li/SO_2 battery are attracting a variety of new applications with users either shifting from conventional primary or secondary batteries or considering new applications now feasible with the high energy battery. These applications range from large multi-cell batteries delivering kilowatt-hours of capacity, replacing larger or more expensive secondary batteries, to small single cell batteries for monitoring or telemetering, instrumentation and electronics. A newly developing application is the use of small Li/SO_2 cells for memory protection in random access memory circuits in computers. Some other typical applications are:

Instrumentation

A number of applications are being successfully met in the field of portable instrumentation where long battery life without the need for either frequent replacement or recharging are required. The light weight of the lithium battery also is an important feature in applications of this type.

Memory and microprocessors

Lithium batteries with their long shelf life and high energy density, provide an excellent power source for insuring memory retention in volatile semiconductor memories during power failures. With the advances in semiconductor technology providing highly complex data management capabilities at very low drain rates, lithium batteries offer the possibility for a long-term, built-in power source for remotely located systems.

Vehicle monitoring

The lithium battery is used in transmitters in systems which constantly monitor the location of emergency and municipal vehicles. These systems require long battery life and reliable operation over a wide temperature range.

Larger systems

The lithium battery is being considered for larger applications, *e.g.*, in sizes up to 2000 W h for powering electric motors. Weight is critical. A lead–acid battery to power a 3 hp motor for 3 h weighs in excess of 500 pounds; a lithium battery with the same capacity weighs less than 100 pounds. A zinc–silver oxide secondary battery would be close in weight, but would be prohibitively expensive for this application.

Consumer applications

The Li/SO_2 battery has had limited application, to date, in the consumer market, but its performance characteristics predict wide use in applications requiring heavy-duty and long shelf life. Lanterns, flashlights, cameras, electronic flash, tape recorders, wherever the battery is required for heavy current loads, the lithium battery has a significant advantage over conventional batteries. Figures 2 and 8 compare the performance of various types of "D" size cylindrical cells and show the advantage of the Li/SO_2 cell, particularly at high current discharges and low temperatures. The use of the lithium battery would easily double the service life of the equipment, reduce weight, as the lithium cell is lighter than a conventional cell of the same size, and provide low temperature performance and longer shelf life.

At the other end of the spectrum, the long-term low drain and long shelf life capability of the lithium battery provide a means of reliably powering safety, security, and emergency devices, alarms, sensor, and monitoring equipment. These may be unattended for long periods of time in stand-by or on low drain service, but must operate immediately when signalled or interrogated. Figure 20 summarizes tests conducted on Li/SO_2 cells at the 2 and 4 year discharge rate. At least 90% of the cell's rated capacity may be expected on the four year discharge, showing the suitability of the lithium battery for these long-term applications where the service life exceeds the shelf life of conventional aqueous electrolyte primary batteries. Many other applications can be forecast as the Li/SO_2 battery increases in popularity and consumer acceptance.

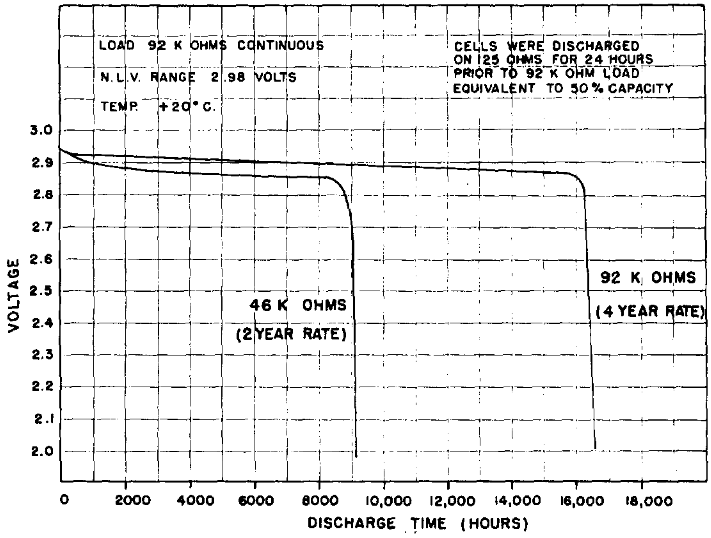

Fig. 20. Long-term discharge LO-32s $Li-SO_2$ cell.

Conclusion

The Li/SO_2 battery is a new primary battery system with many advantages over conventional primary batteries. Its high energy output, good low temperature performance, high power density, and long shelf life provide an all-purpose, all-climate primary battery that is capable of successfully filling a wide variety of applications that, heretofore, were beyond the capability of primary batteries. With increasing production and cost reduction, the Li/SO_2 battery will be cost-competitive with conventional battery systems and will receive wide acceptability and use in military, industrial, and consumer applications.

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