The Lithium/Iodine-Polyvinylpyridine Pacemaker Battery – 35 years of Successful Clinical Use

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April 2007 marks the thirty-fifth anniversary of the first implantation of a pacemaker powered by a lithium/iodine power source. Since 1972, literally millions of lithium/iodine cells have seen clinical use, providing health-giving and life-saving therapy to patients throughout the world. Indeed, the battery has compiled an excellent record of reliability and safety.

The lithium/iodine battery has its genesis in work done at the Jet Propulsion Laboratory and published in 1967. These workers described cells made using “charge transfer complexes” synthesized from iodine and polyvinylpyridine (PVP). Later, James Moser and Alan Schneider developed the first lithium/iodine cells, taught by two patents issued in 1972. Further improvements were made in the Greatbatch laboratories, including the development of precoating the anode with PVP and the case-grounded cell design.

The lithium/iodine battery has been described as an “elegant” battery system. It is elegant in its simplicity – the cell reaction is the simple combination of the elements lithium and iodine to form lithium iodide, the solid electrolyte in the cell. It is also elegant in its complexity – the reaction of iodine and PVP to form the cathode material, an electronic conductor, is a complicated and interesting synthesis.

The cathode material is formed by a thermal reaction between iodine and PVP. The exothermic reaction occurs just above the melting point of iodine (113.5°C). Batteries produced today are made with an iodine/PVP combination ranging from weight ratios of 30/1 to 50/1. At these ratios, the material is mostly elemental iodine at unit thermodynamic activity, with a small amount of the reaction product of iodine with polyvinylpyridine (shown in Figure 1). The cathode material is an electronic conductor, and electron spin resonance studies have confirmed the presence of free (unpaired) electrons in the material.

The battery exhibits high internal impedance that increases as the cell is discharged, due to the increasing thickness of the solid electrolyte and the decreasing electronic conductivity of the cathode material. It therefore is not capable of delivering high power. Moreover, it does not operate well at low temperatures or at temperatures above 60°C. But at 37°C, it can deliver from 10 to around 200 microamperes of current with a volumetric energy density approaching 0.9 Wh/cc, making it a very useful power source for the implantable pacemaker, which requires this level of power.

As shown in Figure 2, the discharge curve exhibits a gradual, predictable approach to the end-of-service point, allowing the electronic circuitry of the device to detect this approach and, through telemetry, alert the attending physician to the coming end-of-service point several months before the pacemaker ceases to operate.

Over the years several significant improvements to the technology have been developed. One of the more important was the development of anode coating. Mead and coworkers discovered that coating the anode of the battery with a solution of PVP in a volatile solvent that evaporated as part of the process had a significant positive effect on the performance of the system. Holmes and Brown showed through scanning electron microscopy that significant macro- and microstructural differences between the structures of the lithium iodide formed in the cell reaction lead to this enhancement.

A second improvement, the development of the case-grounded design, effectively tripled the energy density of the system by eliminating unneeded inert material such as polyester potting compounds used in earlier designs.

Today the lithium/iodine battery remains the system of choice for most implantable pacemakers, though lower impedance systems are beginning to be used for pacemakers with features requiring higher current-delivery capability. The system is likely to be used for many more years in this important medical application.

Figure 1. The iodine/PVP reaction product

Figure 2. Discharge curve of a lithium/iodine battery under 100 kohm resistive load at 37°C.

REFERENCES