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A Comparative Study of Lithium Poly-Carbon Monoflouride (Li/CF_x) and Lithium Iron Phosphate ($LiFePO_4$) Battery Chemistries for State of Charge Indicator Design

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***Abstract*—This paper determines if Li/CFx or LiFePO4 is beneficial for State of Charge Indicator (SOCI) design for military applications. This is achieved by analyzing and comparing data from the battery chemistry of Lithium Poly-Carbon Monoflouride (Li/CFx) and Lithium Iron Phosphate (LiFePO4). The chemistry of Li/CFx and LiFePO4 have different discharge responses based on environmental conditions that can affect how a SOCI responds.**

***Index Terms*—Batteries, Battery Chargers, Detectors, Nonlinear estimation, Power electronics.**

I. Nomenclature

Lithium Poly-Carbon Monoflouride (Li/CF_x), Lithium Iron Phosphate ($LiFePO_4$)

II. Introduction

The market for personal, mobile electronic devices is growing at a rapid pace. Large numbers of consumers are participating in a portable technology revolution by using electronic watches, cellular telephones, pagers, personal compact disc players, calculators, and hand held computer games, to name just a few examples. Portable medical devices, such as hearing aids and heart pacemakers, are also increasingly prevalent [1]. The growth trend for mobile electronic devices is projected to continue as well, especially in the medical and communication fields. Additionally, many applications are incorporating more features that decrease power consumption [1]. The energy to operate these devices is supplied by electrochemical power sources (cells or batteries). The primary objective of this paper is to compare LiFePO4 to Li/CFx battery chemistries in order to select an appropriate chemistry to target for a SOCI design that will accurately account for environmental and storage factors. More specifically, LiFeP04 and Li-CFx chemistries will be compared with respect to commercial availability, energy density, discharge characteristics, cost per cell, and applications. The paper also includes a diagram of the proposed SOCI architecture design to be developed and prototyped. The successful development of the SOCI will require the following:

- Collection of data from representative Li-CFx and / or LiFePO4.
- Batteries at various environmental, operational and storage conditions.
- Selection of appropriate sensors, hardware components and SOCI.
- Algorithms with respect to cost, size, power consumption and SOCI accuracy.
- Internal testing and verification of SOCI prototype at various environmental and storage conditions.

III. Background

A. Li/CFx

Lithium poly-carbon monoflouride (Li/CFx) is a primary battery in lithium poly-carbon monoflouride (Li/CFx) batteries as a cathode. This compound is synthesized by direct fluorination of carbon, in the form of graphite and coke, with flourine gas at temperatures of 300°C to over 600°C. Lithium poly-carbon monoflouride (Li/CFx) is used as a positive electrode material together with acetylene black (AB) conductor and poly-tetrafluorethulene (PTFE) binder. Li metal solid is press-filtered onto a current collector or onto the inner surface of top-cap of count cell to form negative electrode. Non-woven fabric of polypropylene is used as a separator. Organic electrolyte used is gamma-butyrolactone for cylindrical cell and a mixture of propylene carbonate and 1, 2-dimethoxyergane for coin cell, with LiBF4 in each solvent [3]

Discharge reaction is shown in the following equation (1):

$$CFx + xLi^{(+)} + xe^{(-)} \rightarrow xLiF + xC \qquad (1)$$

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B. Lithium iron phosphate ($LiFePO_4$)

Lithium iron phosphate ($LiFePO_4$) has the best safety characteristics, long cycle life (up to 2000 cycles), and substantial availability. The specific energy and energy density are 150Wh/kg and 400Wh/l, respectively. It is well suited for high discharge rate requirements such as the demands of the military, electrical vehicles, power tools, mobile needs, UPS (Interrupt / Back-Up) and solar energy systems.

The advantages of traditional Lithium-ion coupled with the safety features of phosphates, make LiFePO4 technology the Lithium-ion technology for the future. LiFePO4 Lithium-ion technology utilizes natural, phosphate-based material and offers the greatest combination of performance, safety, cost, reliability and environmental characteristics.

IV. Results

The Li/CFx a good choice as it offers more pros for primary battery solutions. Li/CFx primary cells are known to have the highest energy density of all lithium primary cells, with a theoretical energy density of 2180Whkg−1, cf. 1470Whkg−1 for lithium/thionyl chloride or 1005Whkg−1 for lithium/manganese dioxide shown in Figs 1-4.

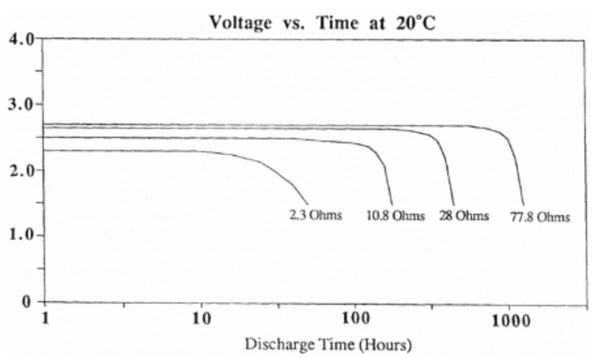

Fig 1: Typical Li-CFx Discharge Curve (Eagle Picher cell LCF-112) [4]

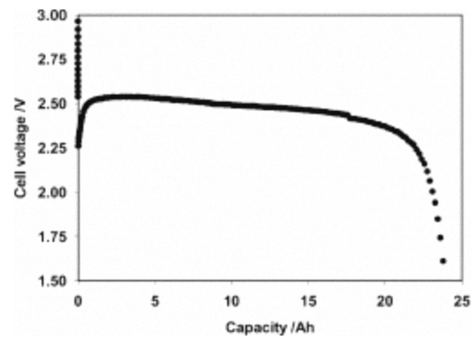

Fig 2: Voltage–capacity plot for a 25Ah cell discharged at the C/100 rate.

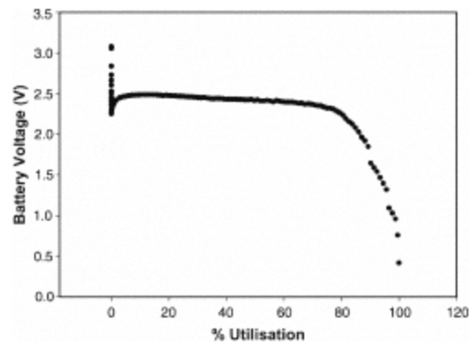

Fig 3: Constant current discharge of a 7-cell, 2.5V parallel string module at the C/100 rate.

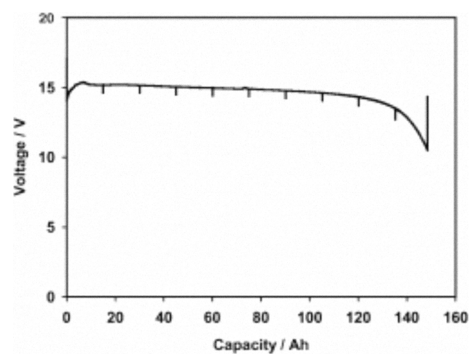

Fig 4: Discharge curve for battery pack under pulse load conditions.

TABLE I: PROS AND CONS OF LI/CFX VS. LIFEPO4

	Pros	Cons
Li/CFx	Lower cost by using a low temperature fluorination process and selection of starting carbon materials. [2] Utilize less fluorine (sub fluorinate) to improve performance and conductivity. [2] Use multi-walled carbon nano-tubes to provide increased surface area to achieve better rate capabilities as well as improve conductivity. [2] Higher energy density than Li/MnO2, but it is equivalent to traditional Li/CFx [2] Dramatically improved power or rate density [2] Achieves longer shelf life [2] Battery designed to be manufactured on existing [2] Li/MnO2 equipment, which offers flexibility to either manufacture the battery directly or license [2] Improved low temperature performance through innovative electrolyte research. Battery is operational at -60 degrees Celsius (C) as compared to conventional Li/CFx batteries that are operational only to -20 degrees C. [2] Expanded high temperature operation. CFX Battery's primary battery can achieve advanced performance attributes up to 160 degrees C, versus conventional Li/CFx batteries high temperature rating of only 60 degree C. [2] No need to monitor O2 or Humidity	Cells are high cost Companies not forthcoming with information Not much public information regarding discharge State of Charge Indicator (SOCI) is not adequate Pattern is difficult to recognize as current and voltage levels may appear flat at times. This may prove difficult for SOC indication. Fuzzy Neural Network is last option for non-linear solution
LiFePO4	Can be used for (hybrid) electric vehicle, higher power applications Market expected to be larger in the future Better reliability, safety characteristics, cheaper; Commercially available Lower energy density	State of Charge Indicator (SOCI) is not adequate Rechargeable adds complexity to SOCI SOCI is present, But needs modifications.

V. CONCLUSION

The Lithium carbon monoflouride (Li/CFx) is a good choice as it offers more pros for primary battery solutions (Table I). Li/CFx primary cells are known to have the highest energy density of all lithium primary cells, with a theoretical energy density of 2180Whkg−1, cf. 1470Whkg−1 for lithium/thionyl chloride or 1005Whkg−1 for lithium/manganese dioxide. Fig 3 demonstrates the suggested hardware design of the state of charge indicator that will use an Artificial Neural Network (ANN) as a non-linear solution. A equivalent circuit will be designed and programmed into the microprocessor.

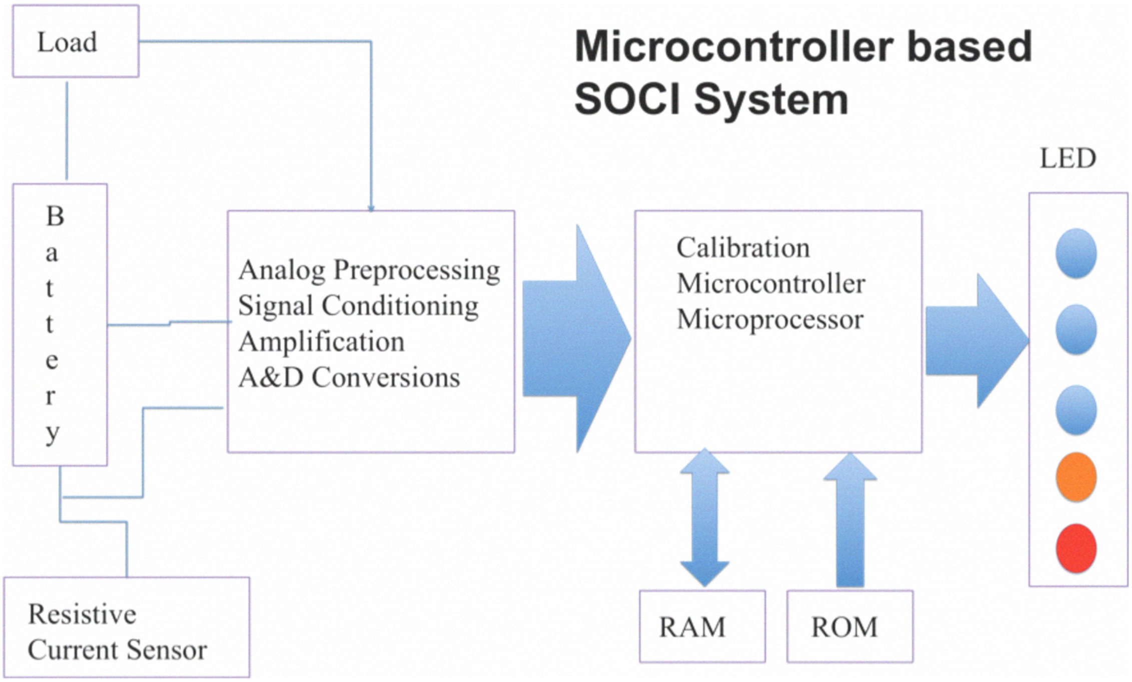

Fig 5: Microcontroller based SOCI system for Li/CFx

Once the system is completed the system will be placed into final product prototype that will appear as displayed in Fig 5.

In conclusion, this state of charge indicator (SOCI) for batteries will help the United States Military by providing an economical and efficient solution when recharging devices in the field of combat. The Li/CFx SOCI will save time and lives using efficiency and offering an advantageous use when needing to know the state of charge of the latest Li/CFx batteries.

VI. References

[1] D. Linden, T. Reddy, Handbook of Batteries, 3rd edition, chapter 38.3, McGraw-Hill.

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[3] C.O. Giwa, A.G. Ritchie, P.G. Bowles, E.L. Price, Burgess, A. Gilmour, J. Allan, Scale-up of lithium carbon, monofluoride envelope cells, in: Proceedings of the 39th Power Sources Conference, Cherry Hill, NJ, USA, June, 2000, pp. 32–35.

[4] http://www.eaglepicher.com/NR/rdonlyres/B51C9EAF-FF71-444D-BE70-660A51506F5B/0/LiProducts.pdf