Performance of Li-Ion Cells Under Battery Voltage Charge Control

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Objective

Determination of Cycling Performance as a Battery Pack under LEO regime

- Number of cycles
- Charge voltage
- Temperature
- Reconditioning Effect

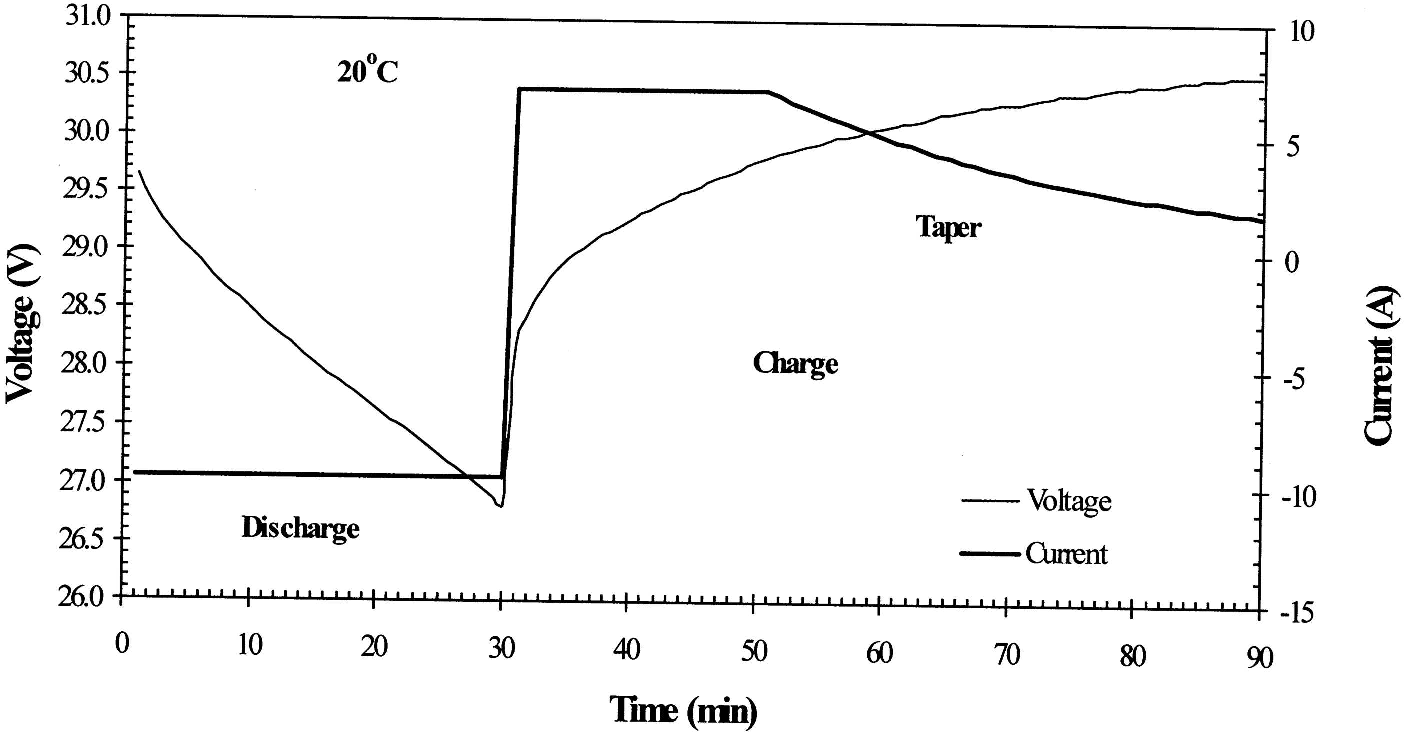
Cells Under Study

- Prismatic Cells
  - Yardney Technical Products, Inc. (YTP), 20 Ah, mixed-oxide (Co and Ni) positive, graphitic carbon negative, $LiPF_6$ salt mixed with organic Carbonate solvents
  - Mine Safety Appliances Company (MSA), 10 Ah, Co oxide positive, graphitic carbon negative, $LiPF_6$ salt mixed with organic Carbonate solvents
- Cylindrical Cells
  - SAFT, 12 Ah, mixed-oxide (Co and Ni) positive, graphitic carbon negative, $LiPF_6$ salt mixed with organic Carbonate solvents

LEO Cycling: Conditions

- Continuous cycling in a regime consisting of 30 min. discharge and 60 min. charge at the rate of 16 cycles/day
- Temperature = -20°C to 20°C
- Depth of discharge = 40%
- Voltage clamped at a Battery/Pack voltage at C/2 charge rate with current taper
- Recharge ratio = 1-1.01

TYPICAL BATTERY VOLTAGE CHARGE CONTROL PROFILE



TEMPERATURE VARIATION DURING CYCLING

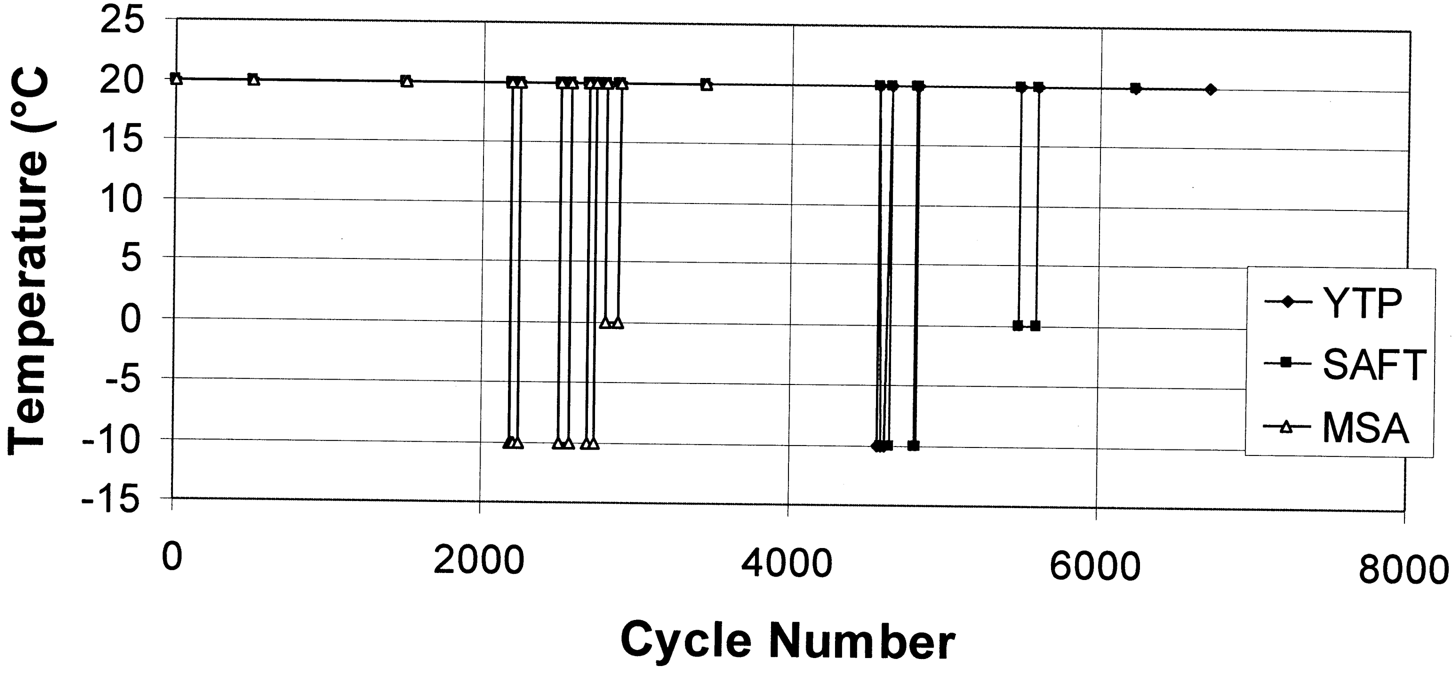


Table 1 - History YTP

Cycle Number		Temp °C	Avg. Discharge Pack Volt	Avg. Charge Pack Volt	[illegible]
1	4576	20	25.9	31.9	[illegible]
4576	4613	-10	23.1	33.4	[illegible]
4613		-10	23.5	34.2	[illegible]
4614	6[illegible]	20	24.4	32.9	[illegible]
6976	[illegible]	20	24.7	32.3	[illegible]

Values for cycles 4576-46[illegible] are average values. The specific value fo[illegible] included since discharge voltage [illegible]

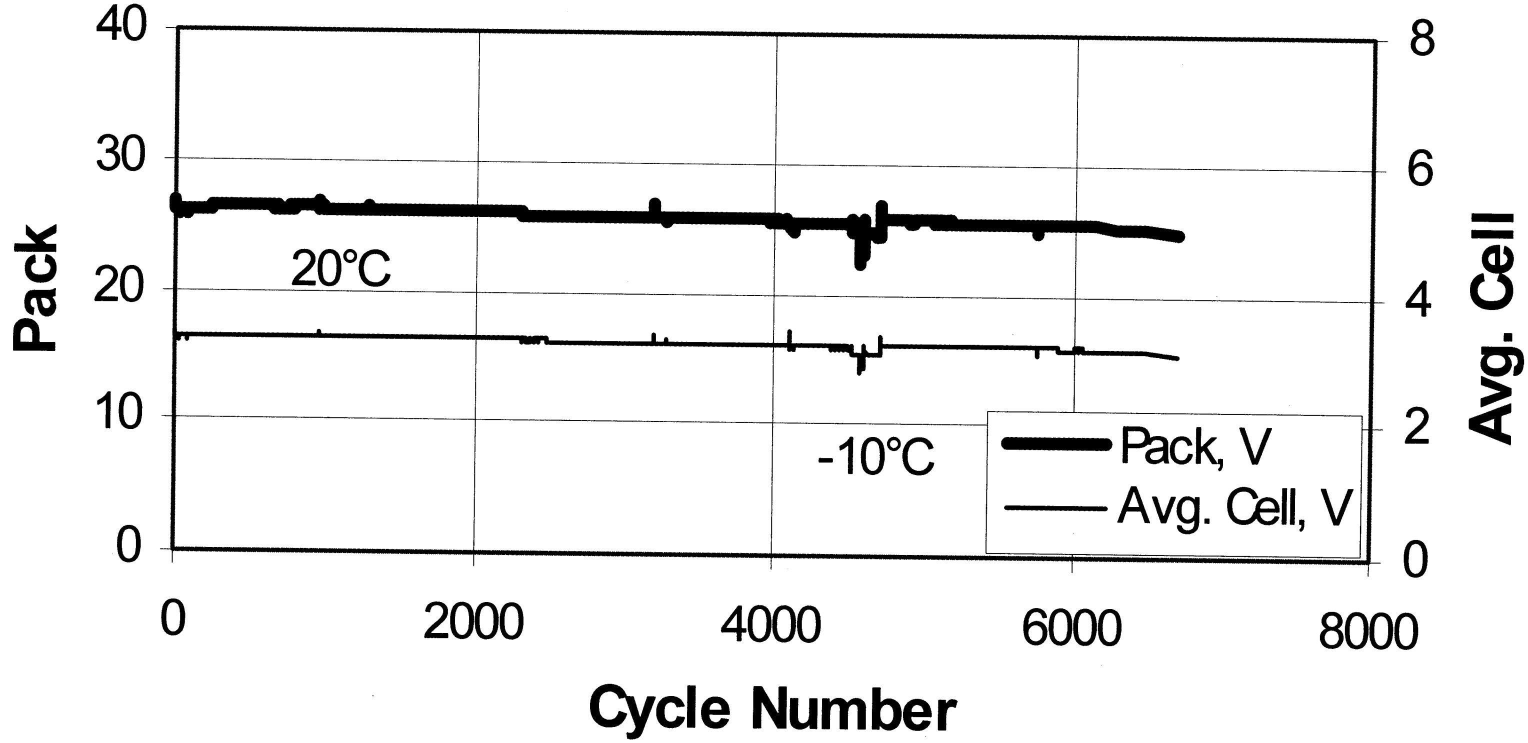
Table 2 - History SAFT

[illegible]	[illegible]	[illegible]	Avg. Discharge Pack Volt	Avg. Charge Pack Volt	[illegible]
[illegible]	[illegible]	[illegible]	27.0	30.6	[illegible]
[illegible]	[illegible]	[illegible]	25.5	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	25.8	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	26.4	33.4	[illegible]
[illegible]	[illegible]	[illegible]	26.7	33.4	[illegible]
[illegible]	[illegible]	[illegible]	26.9	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	27.7	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	26.6	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	26.7	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	28.3	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	24.6*	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	28.7	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	28.4	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	28.1	[illegible]	[illegible]

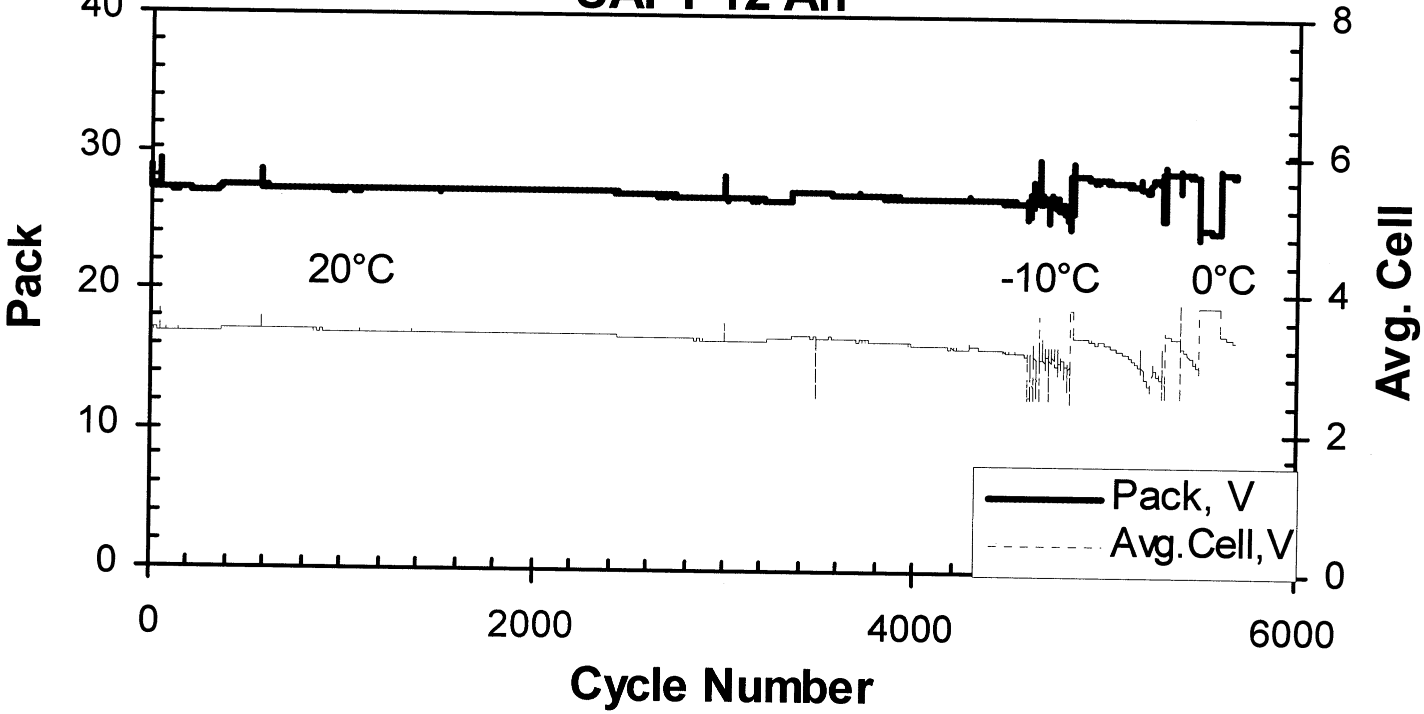
[illegible] 1 - History MCA

[illegible]	[illegible]	Avg Discharge Pack Volt	[illegible]	[illegible]
[illegible]	[illegible]	26.8	[illegible]	[illegible]
[illegible]	[illegible]	21.6	[illegible]	[illegible]
[illegible]	[illegible]	21.4	[illegible]	[illegible]
[illegible]	[illegible]	23.5	[illegible]	[illegible]
[illegible]	[illegible]	23.6	[illegible]	[illegible]
[illegible]	[illegible]	22.4	[illegible]	[illegible]
[illegible]	[illegible]	20.3	[illegible]	[illegible]
[illegible]	[illegible]	22.2	[illegible]	[illegible]
[illegible]	[illegible]	24.7	[illegible]	[illegible]
[illegible]	[illegible]	21.4	[illegible]	[illegible]
[illegible]	[illegible]	18.7	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	19.6	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

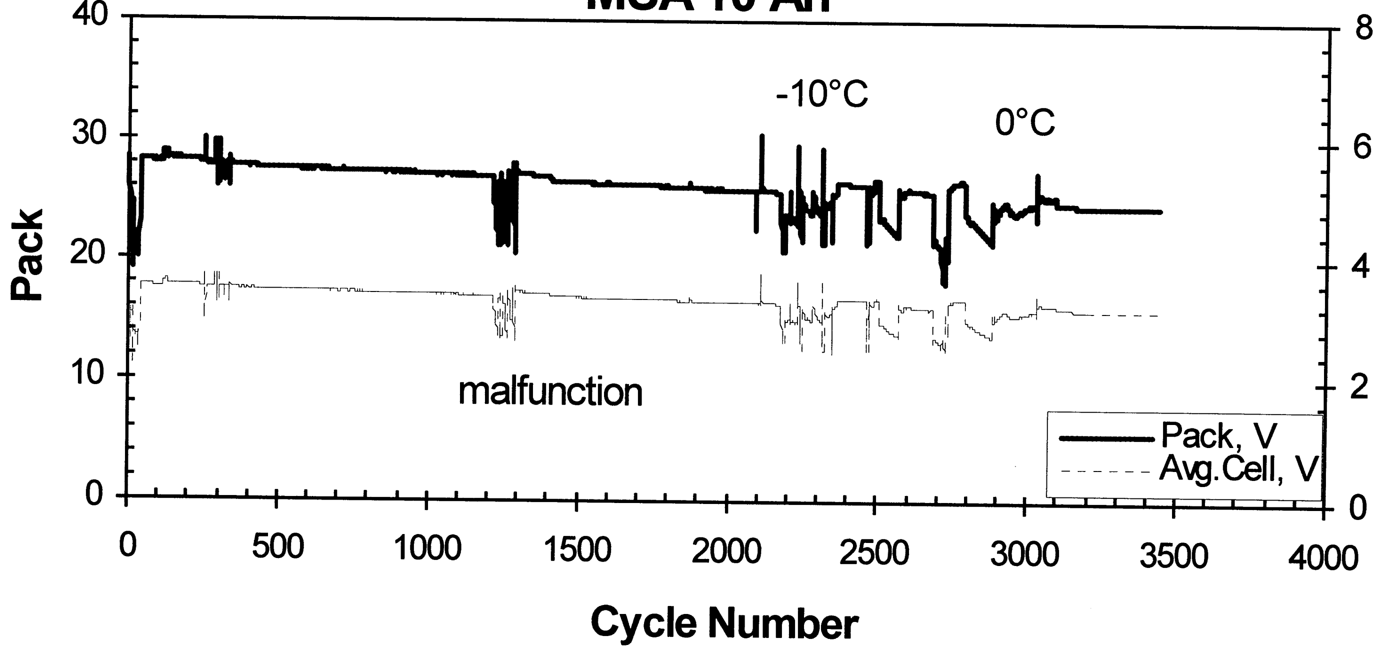
END OF DISCHARGE VOLTAGES:
YTP 20 Ah



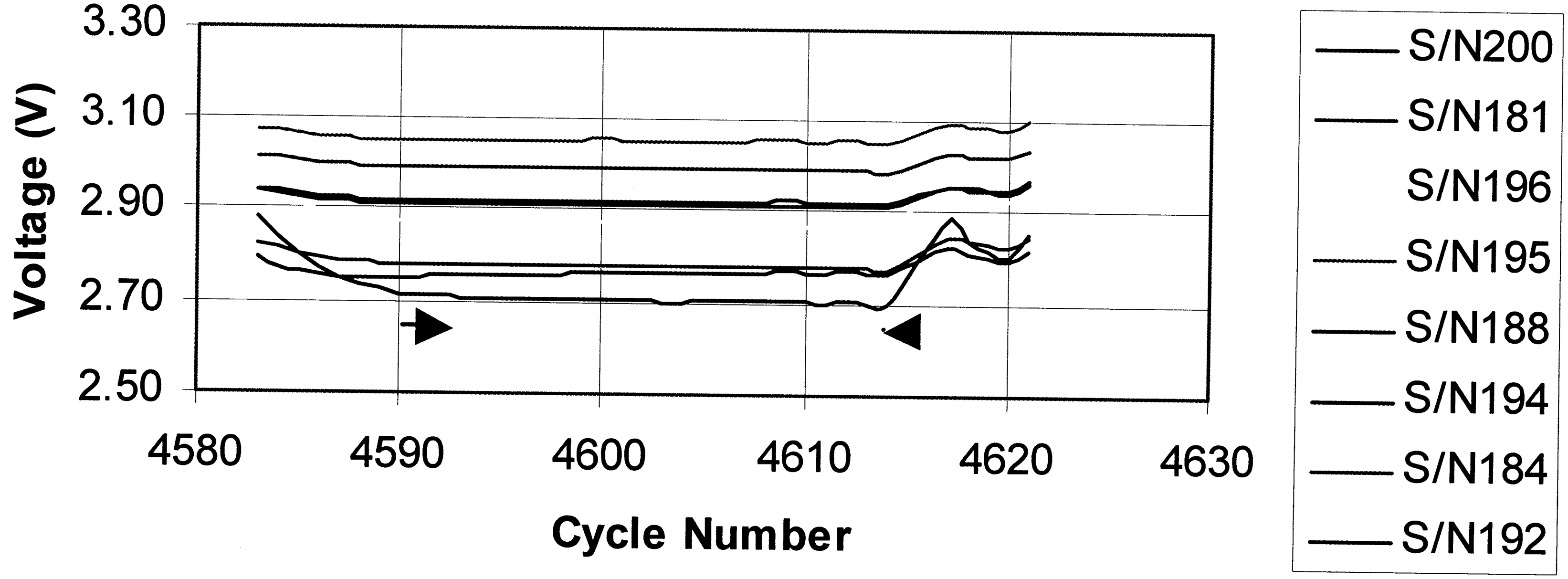
END OF DISCHARGE VOLTAGES:
SAFT 12 Ah



END OF DISCHARGE VOLTAGES:
MSA 10 Ah



END OF DISCHARGE VOLTAGES:
YTP Cells at -10°C



Test Status

- One cell in the SAFT pack is showing 2.954V after 6226 cycles with low end of charge voltage of 4.09V.
- One cell in the YTP pack is showing low end of discharge (2.84V) and high end of charge voltage (4.5V) after 6714 cycles.
- One cell in the MSA pack is showing low voltage(2.905 decreasing to 2.77V) during discharge after 3441 cycles. The voltage is high during charge 4.47 increasing to 4.48V.
- Tests stopped and the health of cells under evaluation.

Reconditioning

- The low voltage cell increased to 3.6V from 2.77 V in the SAFT pack and pack voltage increased by 430 mV when reconditioned by discharging at C/20.
- The low voltage cell increased to 2.77V from 2.5 V in the MSA pack and the pack voltage increased by 800 mV when reconditioned.
- YTP pack did not show any significant effect.

Conclusions

- Li-ion cells manufactured by YTP, SAFT and MSA have completed 6714, 6226 and 3441 cycles, respectively.
- An increase in charge voltage limit was required in all cases to maintain the discharge voltage.
- SAFT and MSA cells were capable of cycling at -10°C and 0°C with an increase in the charge voltage limit, whereas Yardney cells could not be cycled.
- Reconditioning improved the discharge voltage of SAFT and MSA cells; it is important to note that the effect has been temporary as in Nickel-Hydrogen and Nickel-Cadmium batteries.
- Demonstrated that the charge operation with VT clamp at battery rather than at cell level is feasible.
- Continuation of testing depends on the health of the cells and on the funding situation.

ABSTRACT

Performance of Li-Ion Cells under Battery Voltage Charge Control

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A study consisting of electrochemical characterization and Low-Earth-Orbit (LEO) cycling of Li-Ion cells from three vendors was initiated in 1999 to determine the cycling performance and to infuse the new technology in the future NASA missions. The 8-cell batteries included in this evaluation are prismatic cells manufactured by Mine Safety Appliances Company (MSA), cylindrical cells manufactured by SAFT and prismatic cells manufactured by Yardney Technical Products, Inc. (YTP). The three batteries were cycle tested in the LEO regime at 40% depth of discharge, and under a charge control technique that consists of battery voltage clamp with a current taper. The initial testing was conducted at 20 C; however, the batteries were cycled also intermittently at low temperatures.

YTP 20 Ah cells consisted of mixed-oxide (Co and Ni) positive, graphitic carbon negative, LiPF6 salt mixed with organic carbonate solvents. The battery voltage clamp was 32 V. The low temperature cycling tests started after 4575 cycles at 20 C. The cells were not capable of cycling at low temperature since the charge acceptance at battery level was poor. There was a cell in the battery that showed too high an end-of-charge (EOC) voltage thereby limiting the ability to charge the rest of the cells in the battery. The battery has completed 6714 cycles.

SAFT 12 Ah cells consisted of mixed-oxide (Co and Ni) positive, graphitic carbon negative, LiPF6 salt mixed with organic carbonate solvents. The battery voltage clamp was for 30.8 V. The low temperature cycling tests started after 4594 cycles at 20 C. A cell that showed low end of discharge (EOD) and EOC voltages and three other cells that showed higher EOC voltages limited the charge acceptance at the selected voltage limit during charge. The cells were capable of cycling at —10 C and 0 C, but the charge voltage limit had to be increased to 34.3 V (4.3 V per cell). The low temperature cycling may have induced poor chargeability since the voltage had to be increased to achieve the required charge input. The battery has completed 6226 cycles.

MSA 10 Ah cells consisted of Co oxide positive, graphitic carbon negative, LiPF6 salt mixed with organic carbonate solvents. The battery voltage clamp was 30.8 V. The low temperature cycling tests were started after 2182 cycles at 20 C. The cells were capable of cycling at —10 C and 0 C. Like SAFT, the voltage limit on charge had to be increased to 36 V (4.5 V per cell). There was a cell (cell S/N 13) in the battery that showed poor performance features such as low EOD voltage and high EOC voltage. The battery has completed 3441 cycles.

A reconditioning procedure that consisted of C/5 charge to a taper current of C/100 and C/20 discharge improved the voltage behavior of SAFT and MSA cells with no significant effect on YTP cells.

We have demonstrated that the charge operation with VT clamp at battery rather than at cell level is feasible for onboard Li-Ion battery operation.