Survey Report

Investigation of Degradation Behavior of Lithium-Ion Battery

The degradation behavior of lithium-ion batteries was organized by parameter and electrode material. Trends of and factors relating to degradation were analyzed. Parameters included temperature, state of charge (SOC), depth of discharge (DOD), and charge/discharge rate (C rate). The electrodes which were made of $Li(Ni_xMn_yCo_{1-x-y})O_2$ (NMC) and lithium iron phosphate (LFP) were used as positive electrode materials. Graphite and lithium titanite (LTO) were used as negative electrode materials.

- The test results from various literature were organized, arranged by combination of positive and negative electrodes for each parameter, then, degradation trends and factors were analyzed (Table 1).

Table 1: Summary of degradation studies (excerpt)

Test method	Parameter	Positive electrode	Negative electrode	Effect
Calendar aging tests	SOC	NMC	Graphite	The lower the SOC, the less likely it is to degrade. Takes 220 days to degrade to 90% of capacity at 50% of SOC.
		LFP	Graphite	Similarly, lower SOC leads to slower degradation than NMC (>600 days under equivalent conditions).
	Temperature	LFP	Graphite	The higher the temperature (20°C to 60°C), the faster the degradation is. Film formation on the surface of the negative electrode is presumed to be a factor.
Cycling aging tests	SOC	NMC	Graphite	Tends to degrade easily in SOC regions that are high or low. Presumed to be electrode erosion at the sudden point of change where dV/dQ passes through.
		LFP	Graphite	Smaller dependence on SOC for degradation and less degradation than NMC.
	DOD	NMC	Graphite	The wider the DOD, the easier it degrades, with the capacity lowering to 80% after 500 cycles. Presumed to be erosion at the sudden point of change for dV/dQ.
		LFP	Graphite	Degradation is slower than that of NMC, and it takes about 3,000 cycles to reach 80% of capacity.
	Electrode materials	—	—	Positive NMC and negative LTO has the slowest rate of degradation; it takes about 3,000 cycles to reach 90% of capacity.
	Temperature	NMC	Graphite	34→46°C leads to capacity degrading to 80% in 1,200→500 cycles. Presumably an effect of preservation.
		LFP	Graphite	35→45°C leads to capacity degrading to 90% in >3,000 → <2,000 cycles. Presumably an effect of calendar aging.
	C-rate	NMC	Graphite	A C-rate of 6.5 degrades faster than one of 2 or less. 80% of capacity reached in 1,000 or less cycles.
		LFP	Graphite	If the c-rate is 8, takes 1,700 cycles or less to reach 80% of capacity. 2,000 cycles or more for <4C.

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