Stanford | SCHOOL OF EARTH, ENERGY & ENVIRONMENTAL SCIENCES

**Homework 2 (100 points)**

ENERGY 294 - Electrochemical Energy Storage Systems: Modeling and Estimation

Spring Quarter 2018

Dr. Simona Onori

Due April 26, 2018 at 12 PM (Electronic pdf copy in CANVAS and hard-copy to the TA)

This assignment is aimed at testing your understanding of battery terminology learnt in class so far.

**Problem 1 (75 points)**

You will be provided data from experiments conducted on 18650 cylindrical lithium-ion cell M2 (NMC Cathode, Graphite Anode) at two temperatures ($T_1 = 25°\text{C}$ and $T_2 = 45°\text{C}$) and 5 C-rates of operation: [0.05, 1, 2, 5, 15]. The technical specifications provided by the manufacturer for the cell data to be analyzed has been provided to you. You are requested to perform the following tasks using MATLAB, and provide your MATLAB code for each task along with your answers.

1. Determine the capacity of the cell for each C-rate and temperature during the capacity test in discharge. Report your calculations and tabulate these values.
2. Provide the following:
   a. A 2-D plot of cell capacity $Q$ vs. C-rate at temperature $T_1$. Same axes or different?
   b. A 2-D plot of cell capacity $Q$ vs. C-rate at temperature $T_2$.
   c. A 3-D plot of cell capacity $Q$ as a function of C-rate and temperature. Preferably, plot C-rate on the X-Axis, $Q$ on the Y-Axis, and temperature on the Z-Axis.
3. At each temperature, determine the Peukert coefficients using an interpolation function and the Peukert equation from class notes. You may utilize the curve-fitting toolbox in MATLAB. Document all the steps taken and summarize your observations. A*x^n or A*x^n + C? check slides
4. For the five (C-rate, T) data sets at temperatures $T_1$ and $T_2$, plot:
   1.Discharge only or the whole series?
   2.Should we use nominal capacity for calculations?
   a. cell voltage as a function of Ah.
   b. cell voltage as a function of normalized Ah.
5. Choose the 5 C-rate of discharge experimental data set for temperatures $T_1$ and $T_2$.
   a. Plot the input current as a function of time for the two data sets on a single plot.
   b. Plot the cell voltage as a function of time for the two data sets on a single plot.
   c. Summarize your observations. Not totally sure what to plot here...

6. The coulometric efficiency, $\eta_c$, and energy efficiency, $\eta_e$, of a battery cell are defined as: [1]

| | |
|---|---|
| $\eta_c = \dfrac{\int_{discharge} Idt}{\int_{charge} Idt}$ | $\eta_e = \dfrac{\int_{discharge} IVdt}{\int_{charge} IVdt}$ |

where I and V denote current and voltage, respectively.

a. Between the voltage range of 3.65 V and 4.20 V, determine $\eta_c$ and $\eta_e$ of the battery cell for the 1, 2, and 15 C-rate data sets from the 25°C experiments.

b. Repeat the same for the 1, 2, and 15 C-rate data sets from the 45°C experiments.

c. Tabulate the results and summarize your observations.

**Problem 2 (25 points)**

You are provided data from 1 C-rate of discharge experiments conducted on a second NMC cell H1 (same manufacturer) at 5 temperatures [5℃, 23℃, 40℃, 45℃, 52℃]. Perform the following tasks using these data sets:

a. Tabulate the cell capacity $Q$ as a function of temperature. Then, provide an analytical expression for $Q$ as a function of temperature $T$.

b. Provide a 2-D plot of cell capacity $Q$ vs. temperature $T$. On the same figure, plot the temperature-dependent capacity curve from your analytical expression. Clearly distinguish the data points and the curve in your plot. How to do this???

**Note:** All the experiments are conducted using an Arbin BT-2000 tester, for which the current convention is positive during charge and negative during discharge. As mentioned in the slides, the general current convention is the opposite for charge and discharge. Make adjustments accordingly.

<u>Reference</u>

1. Rahn, Christopher D., and Chao-Yang Wang. *Battery Systems Engineering*. John Wiley & Sons, 2013.