Table of Contents


```
clearvars
close all
clc
```

Read in Data for Problem 1

```
% Create variables for file name components
path = 'Experimental Data Sets/NMC_Cell_M2_';
temp_str = string({'T25_', 'T45_'});
temp_val = [25, 45];
Crate_str = string({'0_05C_', '1C_', '2C_', '5C_', '15C_'});
Crate_val = [0.05, 1, 2, 5, 15];
N_MAX_OBS = 94695;

% Initialize arrays for results
times = NaN(length(temp_val), length(Crate_val), N_MAX_OBS);
currents = NaN(length(temp_val), length(Crate_val), N_MAX_OBS);
voltages = NaN(length(temp_val), length(Crate_val), N_MAX_OBS);
I_discharge = NaN(length(temp_val), length(Crate_val));

% Iterate through files
for i = 1:length(temp_str)
    for j = 1:length(Crate_str)

            % Read data file
            name = strcat(path, temp_str(i),
 Crate_str(j), 'CTID.xlsx');
            curr = xlsread(char(name));
            % Read second sheet of file if it is for the 0.05 C-rate
            if j==1
                curr2 = xlsread(char(name), 2);
                curr = [curr; curr2];
            end
```

```
            % Extract the desired series
            times(i,j,1:length(curr)) = curr(:,2);
            currents(i,j,1:length(curr)) = curr(:,3);
            voltages(i,j,1:length(curr)) = curr(:,4);

    end
end
```

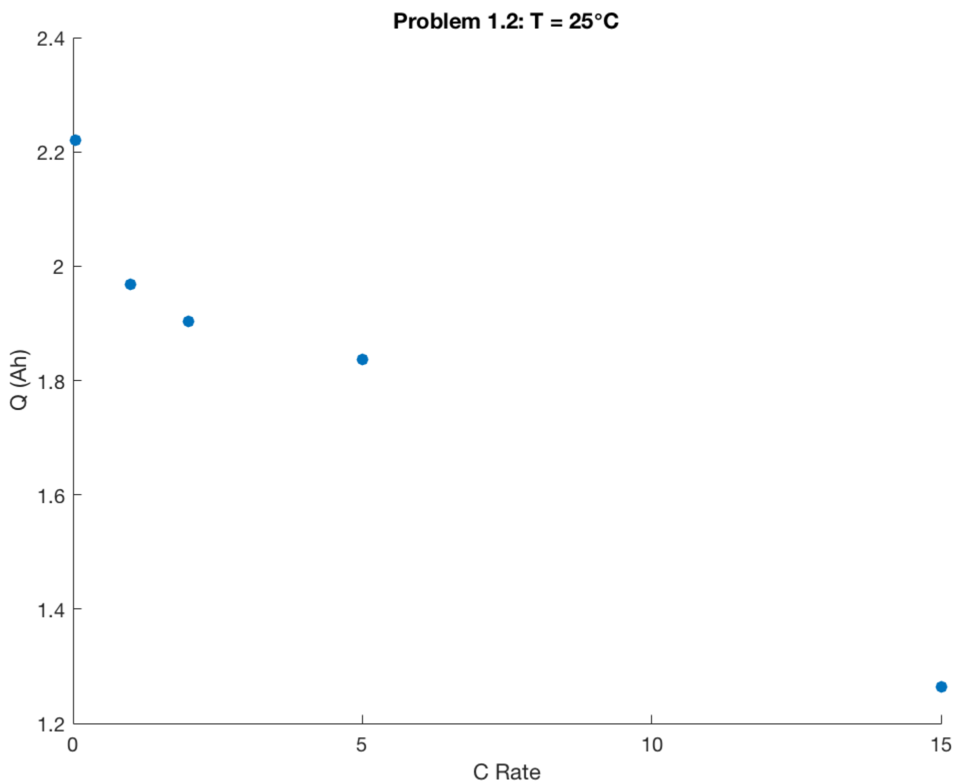
1.1) Calculate capacity

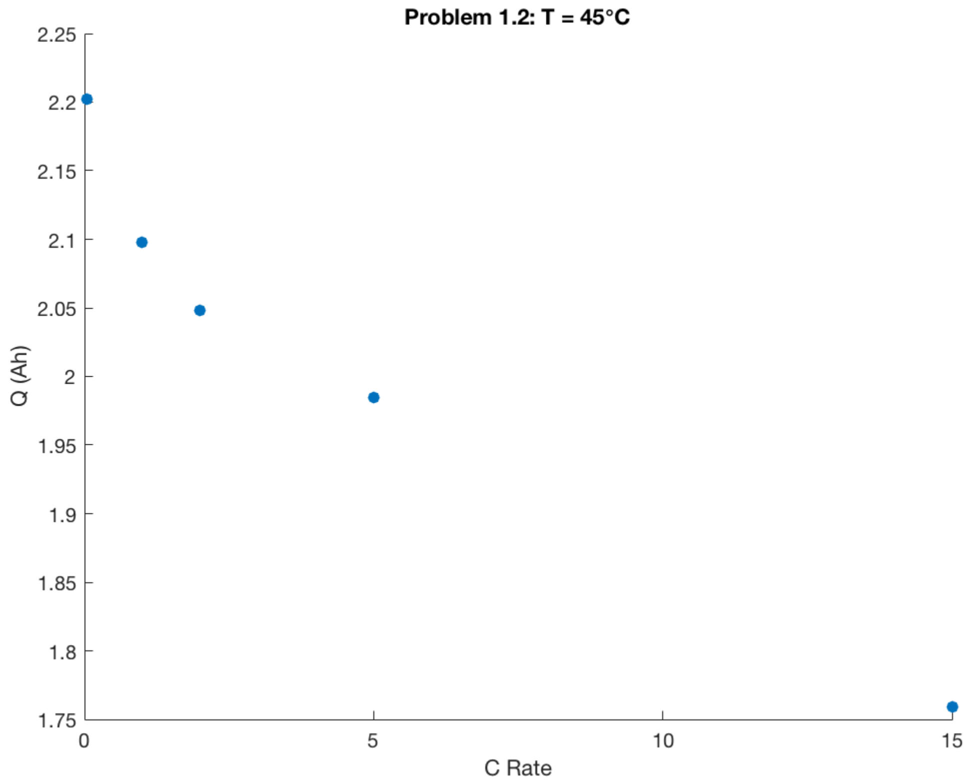
```
% Initialize array for results
capacities = zeros(length(temp_val), length(Crate_val));

% Iterate through the trials
for i = 1:length(temp_str)
    for j = 1:length(Crate_str)

        % Pull out the current time and current vectors
        t = times(i,j,:);
        I = currents(i,j,:);

        % Find discharge data by finding the indexes of negative
 current
        t = squeeze(t(I<0));
        I = squeeze(I(I<0));

        % Store discharge current for each C rate (for Peukert
 fitting)
        I_discharge(i,j) = -1 * mean(I);

        % Calculate battery capacity
        capacities(i,j) = -1 * trapz(t, I) / 3600;

    end
end
```

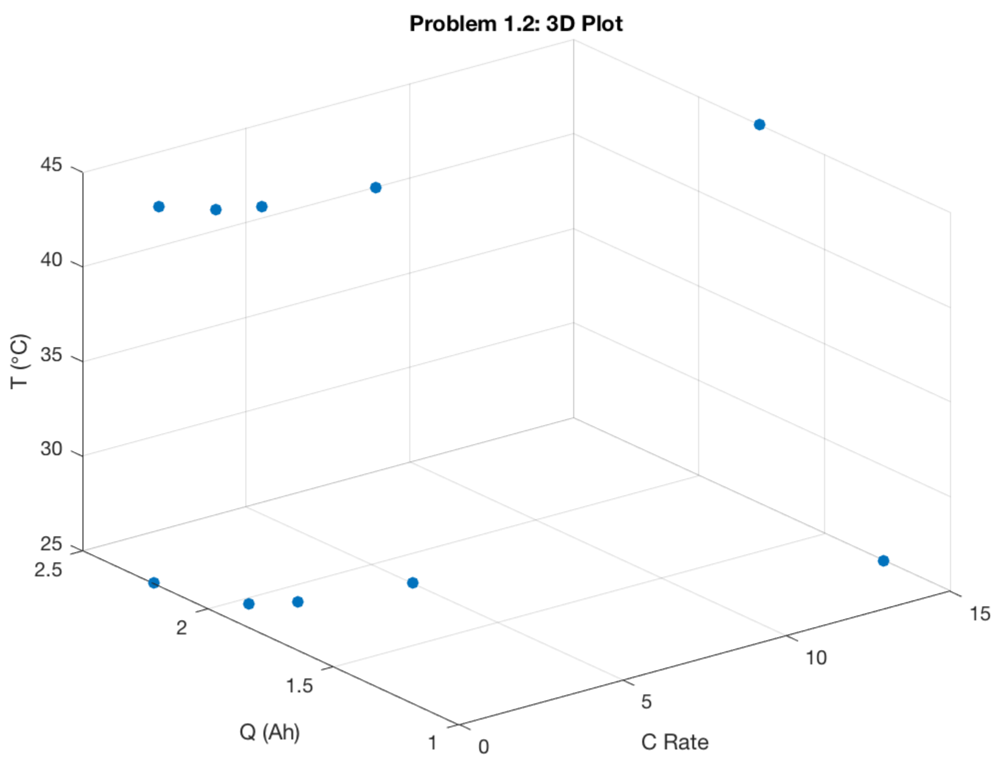
1.2) Plots

```
% 2D plot for 25C
figure
hold on
scatter(Crate_val, capacities(1,:), 'filled')
xlabel('C Rate')
ylabel('Q (Ah)')
title('Problem 1.2: T = 25\circC')

% 2D Plot for 45C
figure
hold on
scatter(Crate_val, capacities(2,:), 'filled')
xlabel('C Rate')
```

```
ylabel('Q (Ah)')
title('Problem 1.2: T = 45\circC')

% Concatenate arrays into 1-row vectors for 3D plotting
capacity3 = [capacities(1,:), capacities(2,:)];
Crate3 = repmat(Crate_val, 1, 2);
temp3 = [repmat(25, 1, 5), repmat(45, 1, 5)];

% Make 3D Plot
figure
scatter3(Crate3, capacity3, temp3, 'filled')
xlabel('C Rate')
ylabel('Q (Ah)')
zlabel('T (\circC)')
title('Problem 1.2: 3D Plot')
```




Problem 1.2: T = 45°C
Q (Ah)
C Rate
2.25
2.2
2.15
2.1
2.05
2
1.95
1.9
1.85
1.8
1.75
0
5
10
15


Problem 1.2: 3D Plot
T (°C)
Q (Ah)
C Rate
45
40
35
30
25
2.5
2
1.5
1
0
5
10
15

1.3) Fitting Peukert Equation

```
% Calculate Peukert Equation fit for each temperature
[fit1, out1] =
 fit(I_discharge(1,:)',capacities(1,:)','power1'); %T=25C
[fit2, out2] =
 fit(I_discharge(2,:)',capacities(2,:)','power1'); %T=45C

fit1
out1.rmse
fit2
out2.rmse

% Calculate Peukert Equation fit - ignore 0.05C trial
[fit1, out1] = fit(I_discharge(1,:)',capacities(1,:)','power1',...
                    'Exclude', 5);
[fit2, out2] = fit(I_discharge(2,:)',capacities(2,:)','power1',...
                    'Exclude', 5);

fit1
out1.rmse
fit2
out2.rmse
```

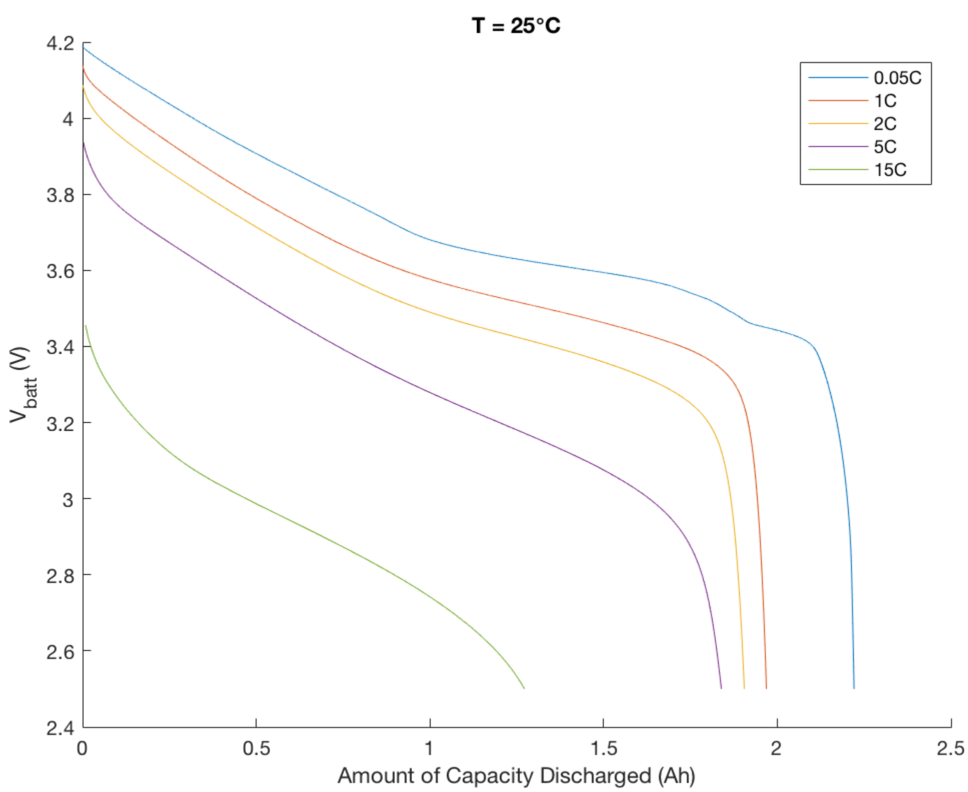
```
fit1 =

     General model Power1:
     fit1(x) = a*x^b
     Coefficients (with 95% confidence bounds):
       a =       1.968  (1.633, 2.303)
       b =    -0.06993  (-0.1497, 0.009826)

ans =

    0.2155


fit2 =

     General model Power1:
     fit2(x) = a*x^b
     Coefficients (with 95% confidence bounds):
       a =       2.088  (1.949, 2.226)
       b =    -0.03268  (-0.06318, -0.002182)

ans =

    0.0869


fit1 =
```

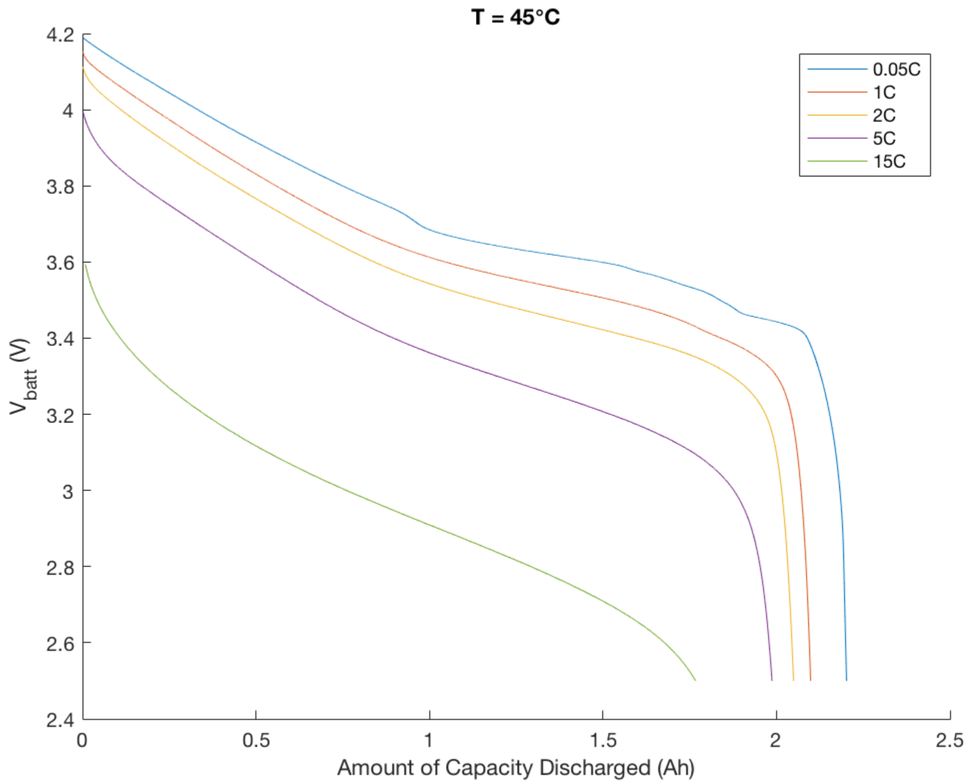
```
     General model Power1:
     fit1(x) = a*x^b
     Coefficients (with 95% confidence bounds):
       a =        2.02  (2.01, 2.03)
       b =    -0.04135  (-0.04404, -0.03865)

ans =

    0.0045


fit2 =

     General model Power1:
     fit2(x) = a*x^b
     Coefficients (with 95% confidence bounds):
       a =       2.105  (2.054, 2.156)
       b =    -0.02129  (-0.03465, -0.007941)

ans =

    0.0229
```

1.4a) Plotting OCV Curves

```
% Nominal capacity (Ah)
Qnom = 2.1;

% Iterate through files
for i = 1:length(temp_str)

    figure
    hold on

    for j = 1:length(Crate_str)

        % Extract time, current, and voltage vectors
        t = squeeze(times(i,j,:));
        I = squeeze(currents(i,j,:));
        V = squeeze(voltages(i,j,:));

        % Calculate time duration of each measurement
        t_lag = t((find(I<0,1)-1):(find(I<0,1,'last')-1));
        delta_t = t(I<0) - t_lag;

        % Calculate capacity decrease for each timestep
        delta_Q = I(I<0) .* delta_t / 3600;

        % Calculate capacity vector
        Q = Qnom + cumsum(delta_Q);

        % Plot data
```

```
        plot(Qnom - Q, V(I<0))

    end

    % Add axis labels and legend
    xlabel('Amount of Capacity Discharged (Ah)')
    ylabel('V_{batt} (V)')
    legend('0.05C', '1C', '2C', '5C', '15C')
    if i == 1
        title('T = 25\circC')
    else
        title('T = 45\circC')
    end

end
```

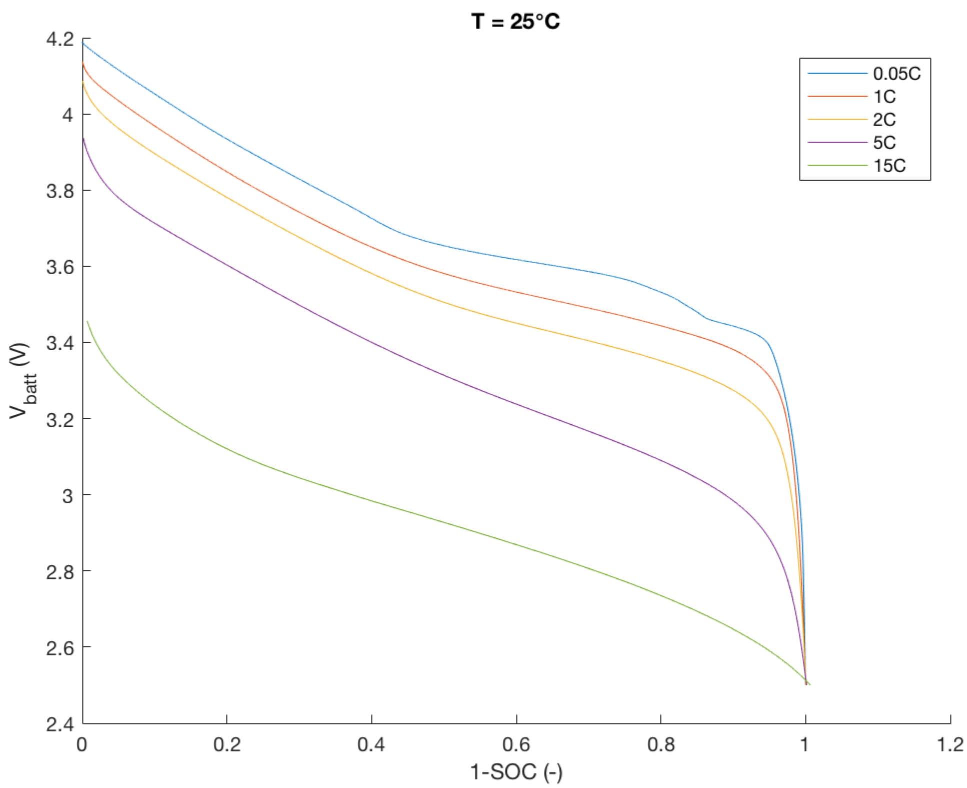


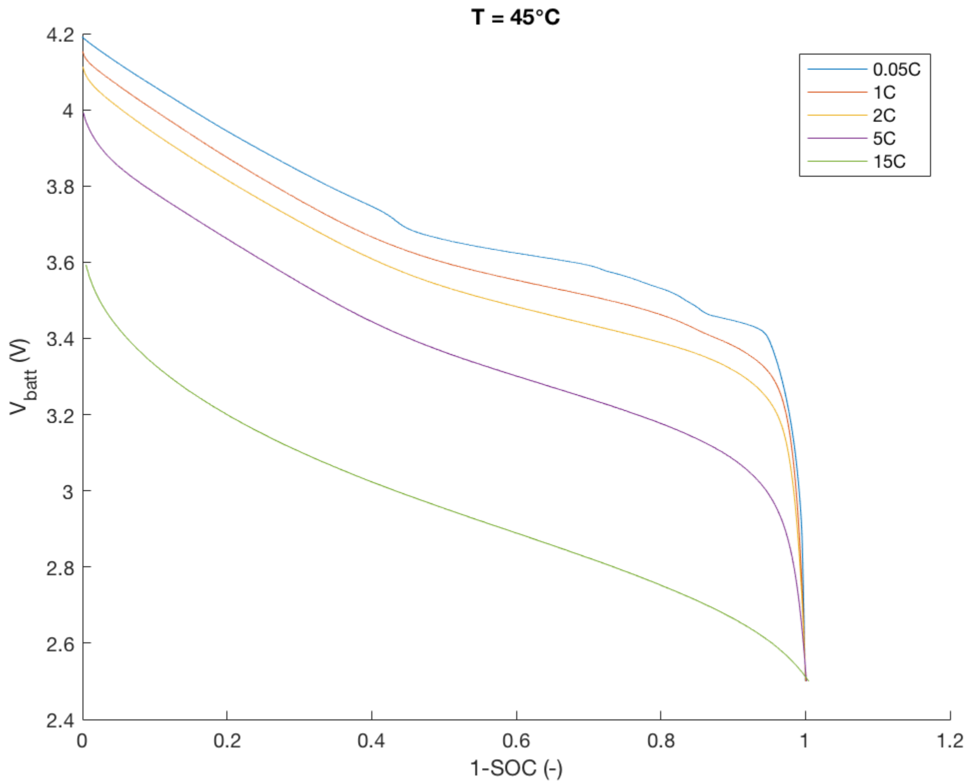


1.4b) Plotting OCV Curves - Normalized Capacity

```
% Iterate through files
for i = 1:length(temp_str)

    figure
    hold on

    for j = 1:length(Crate_str)

        % Extract time, current, and voltage vectors
        t = squeeze(times(i,j,:));
        I = squeeze(currents(i,j,:));
        V = squeeze(voltages(i,j,:));

        % Calculate time duration of each measurement
        t_lag = t((find(I<0,1)-1):(find(I<0,1,'last')-1));
        delta_t = t(I<0) - t_lag;

        % Calculate capacity decrease for each timestep
        delta_Q = I(I<0) .* delta_t / 3600;

        % Get full capacity
```

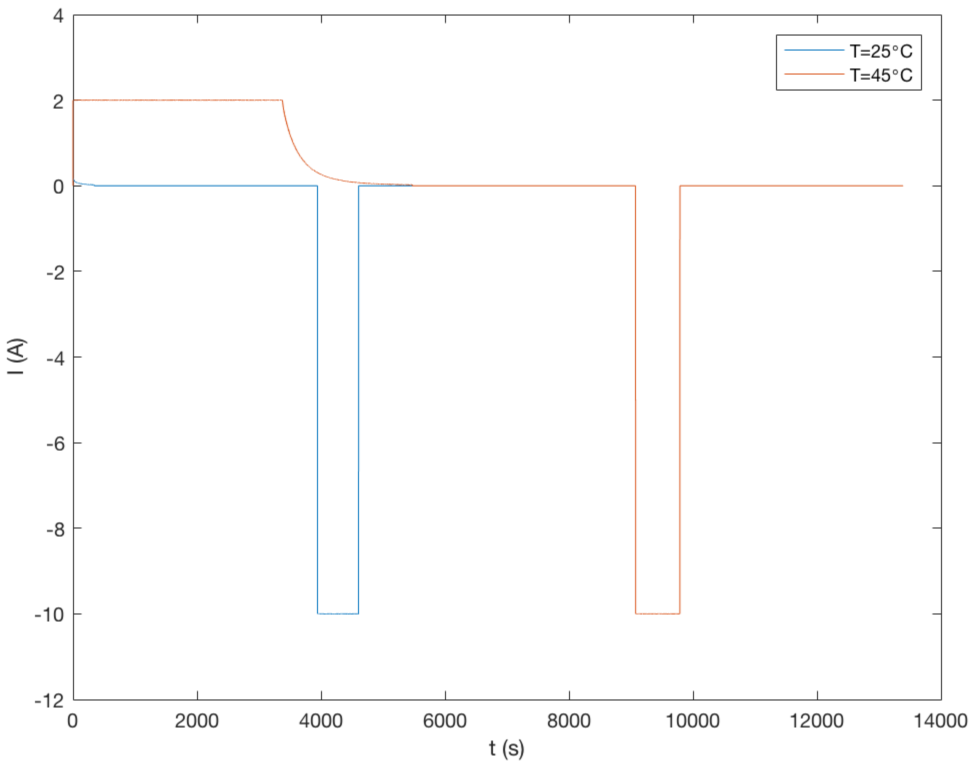
```
        Qnom = capacities(i,j);

        % Calculate capacity vector
        Q = Qnom + cumsum(delta_Q);

        % Plot data
        plot((Qnom - Q)/Qnom, V(I<0))

    end

    % Add axis labels and legend
    xlabel('1-SOC (-)')
    ylabel('V_{batt} (V)')
    legend('0.05C', '1C', '2C', '5C', '15C')
    if i == 1
        title('T = 25\circC')
    else
        title('T = 45\circC')
    end

end
```

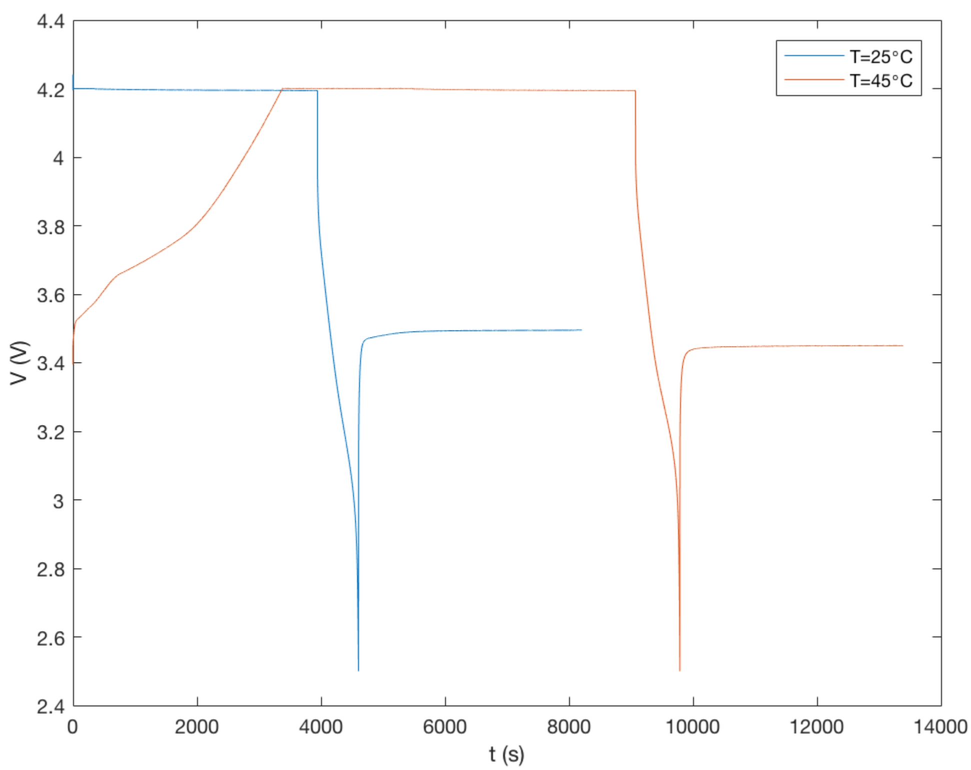




1.5) Time Series Plots

```
% Find discharge times, currents and voltages
I1 = squeeze(currents(1,4,:));
I2 = squeeze(currents(2,4,:));
t1 = squeeze(times(1,4,:));
t2 = squeeze(times(2,4,:));
V1 = squeeze(voltages(1,4,:));
V2 = squeeze(voltages(2,4,:));

figure
plot(t1, I1, t2, I2);
xlabel('t (s)')
ylabel('I (A)')
legend('T=25\circC', 'T=45\circC')

figure
plot(t1, V1, t2, V2);
xlabel('t (s)')
ylabel('V (V)')
legend('T=25\circC', 'T=45\circC')
```


T=25°C
T=45°C
I (A)
t (s)


T=25°C
T=45°C
V (V)
t (s)

1.6) Calculate efficiencies

```
Q_charge = zeros(2,3);
Q_dis = zeros(2,3);
E_charge = zeros(2,3);
E_dis = zeros(2,3);
eta_coul = zeros(2, 3);
eta_energy = zeros(2, 3);

Crates_use = [2 3 5];

for i = 1:2
    for j = 1:length(Crates_use)

        j2 = Crates_use(j);

        t = squeeze(times(i,j2,:));
        I = squeeze(currents(i,j2,:));
        V = squeeze(voltages(i,j2,:));

        charge_indices = I>0 & V>=3.65 & V<=4.20;
        dis_indices = I<0 & V>=3.65 & V<=4.20;

        t_charge = squeeze(times(i,j2, charge_indices));
        I_charge = squeeze(currents(i,j2, charge_indices));
        V_charge = squeeze(voltages(i,j2, charge_indices));

        t_dis = squeeze(times(i,j2, dis_indices));
        I_dis = squeeze(currents(i,j2, dis_indices));
        V_dis = squeeze(voltages(i,j2, dis_indices));

        Q_charge(i,j) = trapz(t_charge, I_charge);
        Q_dis(i,j) = trapz(t_dis, I_dis);
        eta_coul(i,j) = -1 * Q_dis(i,j) / Q_charge(i,j);

        E_charge(i,j) = trapz(t_charge, I_charge .* V_charge);
        E_dis(i,j) = trapz(t_dis, I_dis .* V_dis);
        eta_energy(i,j) = -1 * E_dis(i,j) / E_charge(i,j);

    end
end

eta_coul
eta_energy
```

```
eta_coul =

    0.4362    0.3520         0
    0.5537    0.4356         0


eta_energy =
```

```
    0.4310    0.3452         0
    0.5496    0.4310         0
```

Read in Data for Problem 2

```
clearvars
close all
clc

% Variables for file name components
path = 'Experimental Data Sets/NMC_Cell_H1_';
temp_str = string({'T05_', 'T23_', 'T40_', 'T45_', 'T52_'});
temp_val = [5, 23, 40, 45, 52]';
N_MAX_OBS = 30931;

% Initialize arrays for results
times = NaN(length(temp_val), N_MAX_OBS);
currents = NaN(length(temp_val), N_MAX_OBS);
voltages = NaN(length(temp_val), N_MAX_OBS);

% Iterate through files
for i = 1:length(temp_str)

    % Read data file
    name = strcat(path, temp_str(i), '1C_CTID.xlsx');
    curr = xlsread(char(name));

    % Extract series
    times(i, 1:length(curr)) = curr(:,2);
    currents(i, 1:length(curr)) = curr(:,3);
    voltages(i, 1:length(curr)) = curr(:,4);

end
```

2.2a) Calculate Capacity

```
capacities = zeros(length(temp_val),1);
I_discharge = zeros(length(temp_val),1);

for i = 1:length(temp_str)

    t = times(i,:);
    I = currents(i,:);

    % Find discharge data by negative current data points
    t = squeeze(t(I<0));
    I = squeeze(I(I<0));

    % Calculate battery capacity
    capacities(i) = -1 * trapz(t, I) / 3600;
```

```
end

capacities
```

```
capacities =

    1.7423
    1.9561
    2.0628
    2.1337
    2.1559
```

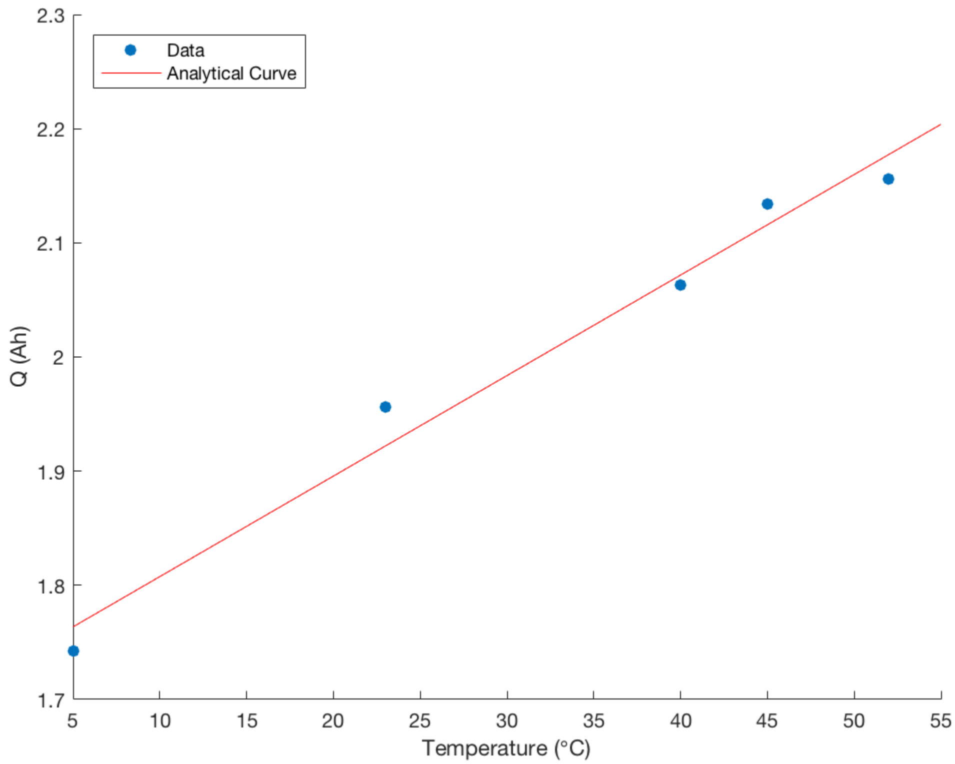
2.2a) Analytical Expression

```
fit1 = fit(temp_val, capacities, 'poly1')
```

```
fit1 =

     Linear model Poly1:
     fit1(x) = p1*x + p2
     Coefficients (with 95% confidence bounds):
       p1 =    0.008805  (0.006395, 0.01122)
       p2 =        1.72  (1.63, 1.809)
```

2.2b) Plot Results

```
figure
hold on
scatter(temp_val, capacities, 'filled')
plot(fit1)
legend('Data', 'Analytical Curve','Location', 'Northwest')
xlabel('Temperature (\circC)')
ylabel('Q (Ah)')
```



Published with MATLAB® R2016b