Primary Current Distribution in a Lead-Acid Battery Grid Electrode

Introduction

This example demonstrates the use of the **Primary Current Distribution** interface for modeling current distributions in electrochemical cells.

In primary current distribution, the potential losses due to electrode kinetics and mass transport are assumed to be negligible, and ohmic losses are govern the current distribution in the cell. Here you investigate primary current distribution in a positive lead-acid battery grid electrode during a high load (100 A) discharge.

In a traditional lead-acid electrode, the porous electrode is supported by a metal grid that also provides electronic conduction throughout the electrode. Optimizing the design of the grid leads to increased performance and lifetime as well as reduced weight (Ref. 1).

Model Definition

The half-cell geometry consists of a grid and a lug of the same metal material, a matrix of porous electrodes residing within the grid, and an electrolyte domain. The geometry is shown in Figure 1.

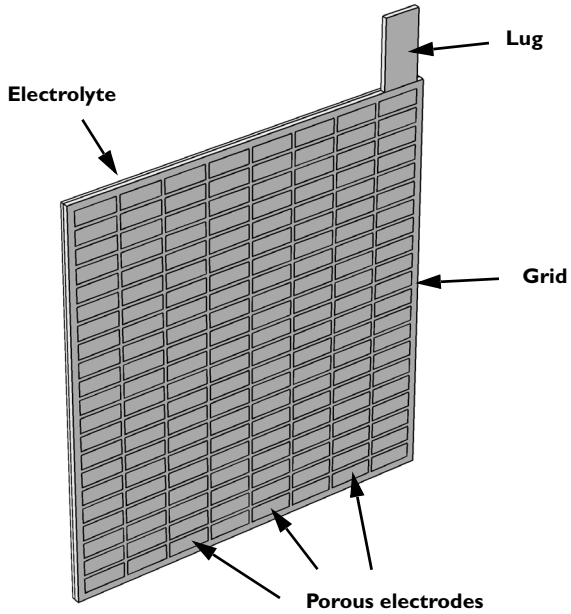


Figure 1: Modeled geometry

The Primary Current Distribution interface is used to model the current distribution in the half cell. The potential in the electrolyte is set to zero at the external boundary that is parallel to the grid. A discharge current of 100 A is applied to the end of the lug.

An Electrolyte-Electrode Domain Interface is used to set the primary current condition, relating the electrolyte and electrode potentials. The equilibrium potential for the positive electrode versus a reversible hydrogen electrode (RHE) is used in this case:

$$\phi_s + \phi_l = 1{,}7 \text{ V} \tag{1}$$

The above condition is applied to the boundary between the porous electrode and the electrode domains. (Note that the Primary Current Distribution interface only solves for the electrolyte potential in a porous electrode. This is as an effect of the primary current condition assumption, see the Batteries & Fuel Cells User's Guide). Isolation is used for all other boundaries.

The problem is solved using a Stationary Study.

Results and Discussion

Figure 2 shows the electrolyte potential in the electrolyte and the porous electrode domains. The potential drop is highest, roughly 0.2 V, in the area close to the lug.

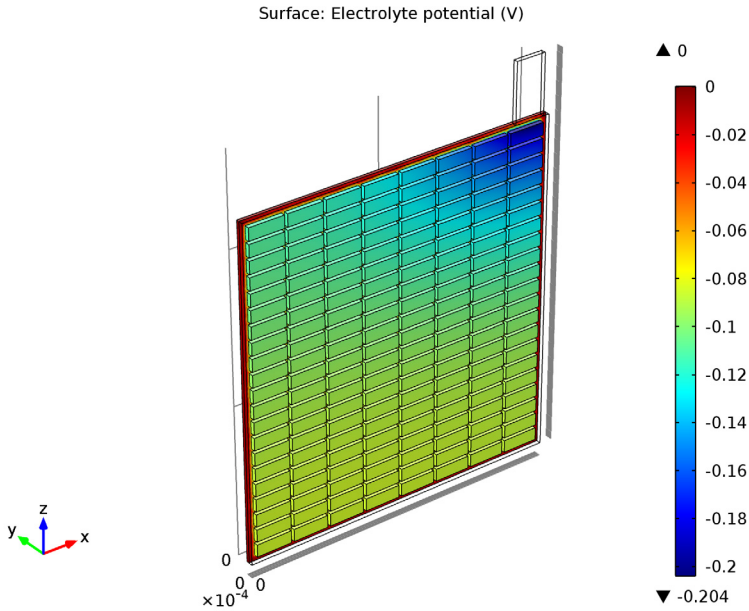


Figure 2: Electrolyte potential in the electrolyte and porous electrodes.

Figure 3 shows the potential in the grid and the lug. The potential difference between the corner of the grid closest to the lug and the far end corner is about 0.15 V.

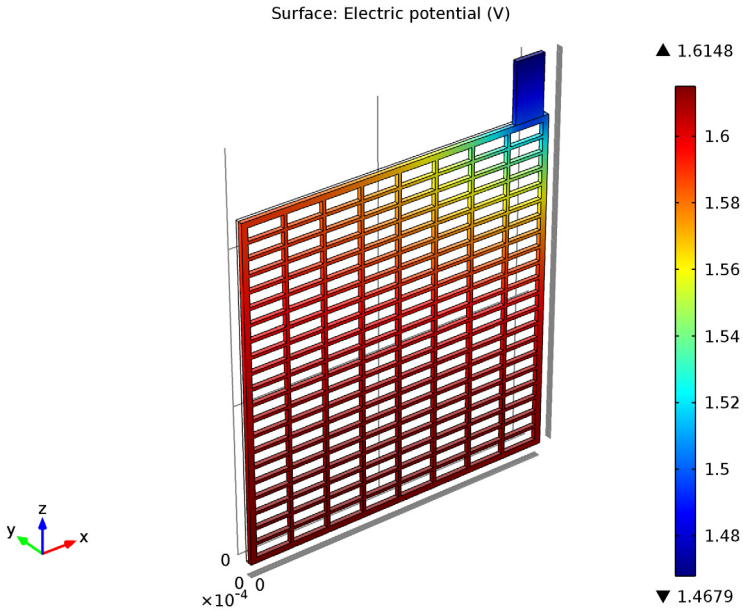


Figure 3: Electric potential in the grid and the lug.

Finally, the current density distribution in the electrolyte symmetry plane is plotted in Figure 4. The currents are about twice as high in the active region closest to the lug compared to the opposite corner of the cell.

In this case an improvement of the battery performance would be possible by making the frame of the grid thicker toward the lug corner, thereby achieving a more uniform current distribution.

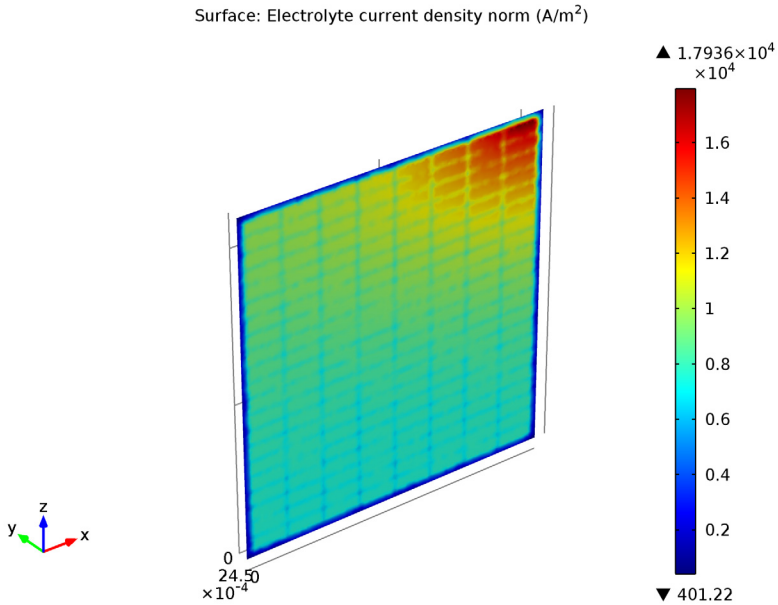


Figure 4: Electrolyte current density at the half-cell boundary.

Reference

1. K. Yamada and others, "Computer-aided Optimization of Grid Design for High-power Lead-acid Batteries," *Journal of Power Sources*, selected papers from the Ninth European Lead Battery Conference, vol. 144, no. 2, pp. 352–357, 2005.

Model Library path: `Batteries_and_Fuel_Cells_Module/Tutorial_Models/primary_cd_grid`

Modeling Instructions

MODEL WIZARD

1 Go to the **Model Wizard** window.

2 Click **Next**.

3 In the **Add physics** tree, select **Electrochemistry>Primary Current Distribution (piec)**.

4 Click **Add Selected**.

5 Click **Next**.

6 Find the **Studies** subsection. In the tree, select **Preset Studies>Stationary**.

7 Click **Finish**.

GLOBAL DEFINITIONS

Parameters

1 In the **Model Builder** window, right-click **Global Definitions** and choose **Parameters**.

2 In the **Parameters** settings window, locate the **Parameters** section.

3 Click **Load from File**.

4 Browse to the model's Model Library folder and double-click the file `primary_cd_grid_parameters.txt`.

GEOMETRY 1

Start building the geometry with a block representing the outer contours of the grid and the porous electrodes.

Block 1

1 In the **Model Builder** window, under **Model 1** right-click **Geometry 1** and choose **Block**.

2 In the **Block** settings window, locate the **Size and Shape** section.

3 In the **Width** edit field, type `W`.

4 In the **Depth** edit field, type `d_electrode`.

5 In the **Height** edit field, type `H`.

6 Click the **Build Selected** button.

Block 2

Draw one porous electrode section, then use it to create an array of porous electrodes.

1 In the **Model Builder** window, right-click **Geometry 1** and choose **Block**.

2 In the **Block** settings window, locate the **Size and Shape** section.

3 In the **Width** edit field, type `W_porous`.

4 In the **Depth** edit field, type `d_electrode`.

5 In the **Height** edit field, type `H_porous`.

6 Locate the **Position** section. In the **x** edit field, type `s_frame`.

7 In the **z** edit field, type `s_frame`.

8 Click the **Build Selected** button.

Array 1

1 Right-click **Geometry 1** and choose **Transforms>Array**.

2 Select the object **blk2** only.

3 In the **Array** settings window, locate the **Size** section.

4 In the **x size** edit field, type `N_x`.

5 In the **z size** edit field, type `N_z`.

6 Locate the **Displacement** section. In the **x** edit field, type `W_porous+s_grid`.

7 In the **z** edit field, type `H_porous+s_grid`.

8 Locate the **Selections of Resulting Entities** section. Select the **Create selections** check box.

9 Right-click **Model 1>Geometry 1>Array 1** and choose **Rename**.

10 Go to the **Rename Array** dialog box and type `Porous Electrodes` in the **New name** edit field.

11 Click **OK**.

12 Right-click **Model 1>Geometry 1>Array 1** and choose **Build Selected**.

Union 1

1 Right-click **Geometry 1** and choose **Boolean Operations>Union**.

Create a union of all objects at this stage.

2 Click in the **Graphics** window, press Ctrl+A to highlight all objects, and then right-click to confirm the selection.

3 Click the **Build Selected** button.

Block 3

Draw the lug as a block with the same thickness as the electrode.

1 Right-click **Geometry 1** and choose **Block**.

2 In the **Block** settings window, locate the **Size and Shape** section.

3 In the **Width** edit field, type `W_lug`.

4 In the **Depth** edit field, type `d_electrode`.

5 In the **Height** edit field, type `H_lug`.

6 Locate the **Position** section. In the **x** edit field, type `W-s_frame-W_lug`.

7 In the **z** edit field, type `H`.

8 Right-click **Model 1>Geometry 1>Block 3** and choose **Rename**.

9 Go to the **Rename Block** dialog box and type `Lug` in the **New name** edit field.

10 Click **OK**.

11 Right-click **Model 1>Geometry 1>Block 3** and choose **Build Selected**.

Block 4

Finalize the geometry by drawing the electrolyte domain.

1 Right-click **Geometry 1** and choose **Block**.

2 In the **Block** settings window, locate the **Size and Shape** section.

3 In the **Width** edit field, type `W`.

4 In the **Depth** edit field, type `d_electrolyte`.

5 In the **Height** edit field, type `H`.

6 Locate the **Position** section. In the **y** edit field, type `d_electrode`.

7 Locate the **Selections of Resulting Entities** section. Select the **Create selections** check box.

8 Right-click **Model 1>Geometry 1>Block 4** and choose **Rename**.

9 Go to the **Rename Block** dialog box and type `Electrolyte` in the **New name** edit field.

10 Click **OK**.

Union 2

1 Right-click **Geometry 1** and choose **Boolean Operations>Union**.

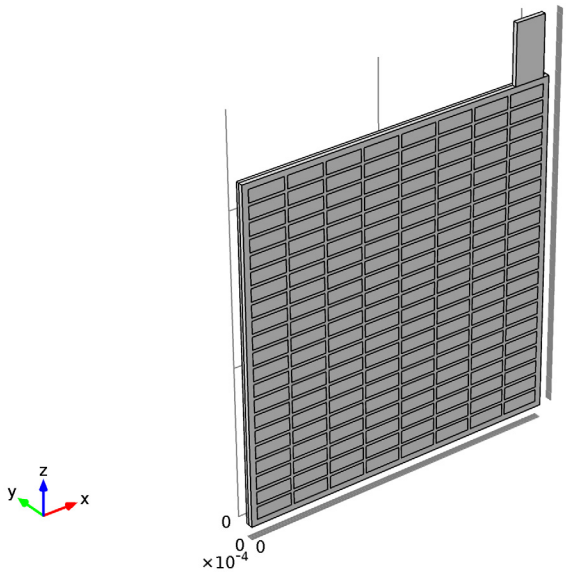
Create a union of all objects.

2 Click in the **Graphics** window, press Ctrl+A to highlight all objects, and then right-click to confirm the selection.

3 Click the **Build Selected** button.

4 Click the **Zoom Extents** button on the Graphics toolbar.

The completed geometry should look as shown in the following figure:



DEFINITIONS

Create a selection for the union of the grid and lug domains to facilitate setting up the model.

Explicit 1

1 In the **Model Builder** window, under **Model 1** right-click **Definitions** and choose **Selections>Explicit**.

2 Select Domains 1 and 171 only.

3 Right-click **Model 1>Definitions>Explicit 1** and choose **Rename**.

4 Go to the **Rename Explicit** dialog box and type `Grid+Lug` in the **New name** edit field.

5 Click **OK**.

PRIMARY CURRENT DISTRIBUTION

Electrode 1

1 In the **Model Builder** window, under **Model 1** right-click **Primary Current Distribution** and choose **Electrode**.

2 In the **Electrode** settings window, locate the **Domain Selection** section.

3 From the **Selection** list, choose **Grid+Lug**.

4 Locate the **Electrode** section. From the σ_s list, choose **User defined**. In the associated edit field, type `sigma_metal`.

Porous Electrode 1

1 In the **Model Builder** window, right-click **Primary Current Distribution** and choose **Porous Electrode**.

2 In the **Porous Electrode** settings window, locate the **Domain Selection** section.

3 From the **Selection** list, choose **Porous Electrodes**.

4 Locate the **Electrolyte Current Conduction** section. From the σ_l list, choose **User defined**. In the associated edit field, type `sigma_electrolyte`.

5 Locate the **Electrode Current Conduction** section. From the σ_s list, choose **User defined**. In the associated edit field, type `sigma_porous`.

Electrolyte 1

1 In the **Model Builder** window, under **Model 1>Primary Current Distribution** click **Electrolyte 1**.

2 In the **Electrolyte** settings window, locate the **Electrolyte** section.

3 From the σ_l list, choose **User defined**. In the associated edit field, type `sigma_electrolyte`.

Electrolyte Potential 1

1 In the **Model Builder** window, right-click **Primary Current Distribution** and choose **Electrolyte>Electrolyte Potential**.

2 Select Boundary 9 only.

Electrode Current 1

1 Right-click **Primary Current Distribution** and choose **Electrode>Electrode Current**.

2 Select Boundary 1000 only.

3 In the **Electrode Current** settings window, locate the **Electrode Current** section.

4 In the $I_{s,total}$ edit field, type `-100`.

Electrolyte-Electrode Domain Interface 1

1 In the **Model Builder** window, under **Model 1>Primary Current Distribution** click **Electrolyte-Electrode Domain Interface 1**.

2 In the **Electrolyte-Electrode Domain Interface** settings window, locate the **Electrolyte-Electrode Domain Interface** section.

3 In the $E_{\mathrm{eq},ref}$ edit field, type `1.7`.

Insulation 2

1 In the **Model Builder** window, right-click **Primary Current Distribution** and choose **Insulation**.

2 Select Boundary 6 only.

DEFINITIONS

The highest gradients in the model are to be expected at the edges between the porous electrode and the electrolyte. Create a selection of these edges to use later when setting up the mesh.

Adjacent 1

1 In the **Model Builder** window, under **Model 1** right-click **Definitions** and choose **Selections>Adjacent**.

2 In the **Adjacent** settings window, locate the **Input Entities** section.

3 Under **Input selections**, click **Add**.

4 Go to the **Add** dialog box.

5 In the **Input selections** list, select **Porous Electrodes**.

6 Click the **OK** button.

7 In the **Adjacent** settings window, locate the **Output Entities** section.

8 From the **Geometric entity level** list, choose **Adjacent edges**.

Adjacent 2

1 In the **Model Builder** window, right-click **Definitions** and choose **Selections>Adjacent**.

2 In the **Adjacent** settings window, locate the **Input Entities** section.

3 Under **Input selections**, click **Add**.

4 Go to the **Add** dialog box.

5 In the **Input selections** list, select **Electrolyte**.

6 Click the **OK** button.

7 In the **Adjacent** settings window, locate the **Output Entities** section.

8 From the **Geometric entity level** list, choose **Adjacent edges**.

Intersection 1

1 Right-click **Definitions** and choose **Selections>Intersection**.

2 In the **Intersection** settings window, locate the **Geometric Entity Level** section.

3 From the **Level** list, choose **Edge**.

4 Locate the **Input Entities** section. Under **Selections to intersect**, click **Add**.

5 Go to the **Add** dialog box.

6 In the **Selections to intersect** list, choose **Adjacent 1** and **Adjacent 2**.

7 Click the **OK** button.

MESH 1

Edge 1

1 In the **Model Builder** window, under **Model 1** right-click **Mesh 1** and choose **More Operations>Edge**.

2 In the **Edge** settings window, locate the **Edge Selection** section.

3 From the **Selection** list, choose **Intersection 1**.

Size 1

1 Right-click **Model 1>Mesh 1>Edge 1** and choose **Size**.

2 In the **Size** settings window, locate the **Element Size** section.

3 Click the **Custom** button.

4 Locate the **Element Size Parameters** section. Select the **Maximum element size** check box.

5 In the associated edit field, type `s_grid/2`.

Free Tetrahedral 1

1 In the **Model Builder** window, right-click **Mesh 1** and choose **Free Tetrahedral**.

2 Right-click **Mesh 1** and choose **Build All**.

STUDY 1

In the **Model Builder** window, right-click **Study 1** and choose **Compute**.

RESULTS

Electrolyte Potential (piec) 1

Figure 2 is plotted by default. To plot Figure 3, do the following steps.

3D Plot Group 3

1 In the **Model Builder** window, right-click **Results** and choose **3D Plot Group**.

2 Right-click **3D Plot Group 3** and choose **Surface**.

3 In the **Surface** settings window, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Primary Current Distribution>Electric potential (phis)**.

4 Click the **Plot** button.

Data Sets

To create Figure 4, create new solution for a selection of the geometry.

1 In the **Model Builder** window, under **Results** right-click **Data Sets** and choose **Solution**.

2 Right-click **Results>Data Sets>Solution 2** and choose **Add Selection**.

3 In the **Selection** settings window, locate the **Geometric Entity Selection** section.

4 From the **Geometric entity level** list, choose **Boundary**.

5 Select Boundary 9 only.

3D Plot Group 4

1 In the **Model Builder** window, right-click **Results** and choose **3D Plot Group**.

2 In the **3D Plot Group** settings window, locate the **Plot Settings** section.

3 Clear the **Plot data set edges** check box.

4 Right-click **Results>3D Plot Group 4** and choose **Surface**.

5 In the **Surface** settings window, locate the **Data** section.

6 From the **Data set** list, choose **Solution 2**.

7 Click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Primary Current Distribution>Electrolyte current density norm (piec.NormII)**.

8 Click the **Plot** button.