Created in COMSOL Multiphysics 6.1

Isolator Thickness Effect

Introduction

Magnesium (Mg) alloy being the lightest structural material is an attractive alternative for light weighting purpose in various engineering fields. However, Mg alloys are prone to galvanic corrosion when they are joined with steel structures (See models - Galvanic Corrosion of a Magnesium Alloy in Contact with Steel and Galvanic Corrosion with Electrode Deformation - which are available in the Application Libraries). Aluminum (Al) alloys are commonly used as isolators to mitigate galvanic corrosion between Mg alloy and steel structures.

This model example simulates the effect of isolator thickness on galvanic corrosion and is based on a paper by Deshpande (Ref. 1).

Model Definition

The model geometry considered in this example is shown in Figure 1 where Mg alloy, Al alloy and mild steel (MS), joined together and exposed to the electrolyte, are highlighted. The Al isolator thickness is varied to simulate its effect on galvanic corrosion mitigation.

Use the Secondary Current Distribution interface to solve for the electrolyte potential, ϕ_l (SI unit: V), over the electrolyte domain according to:

$$\mathbf{i}_l = -\sigma_l \nabla \phi_l$$
$$\nabla \cdot \mathbf{i}_l = 0$$

where $\mathbf{i}_l$ (SI unit: A/m^2) is the electrolyte current density vector and σ_l (SI unit: S/m) is the electrolyte conductivity which is assumed to be a constant.

Use the default Insulation condition for all boundaries except the electrode surfaces:

$$\mathbf{n} \cdot \mathbf{i}_l = 0$$

where $\mathbf{n}$ is the normal vector, pointing out of the domain.

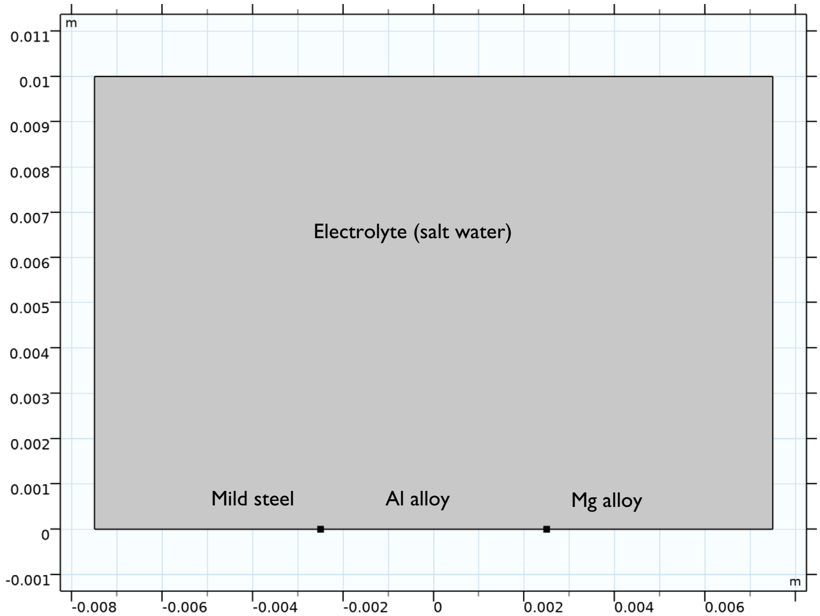

Figure 1: Model geometry consisting of Mg alloy, Al alloy and mild steel joined together and exposed to the electrolyte solution.

Use the Electrode Surface boundary node at the electrode surfaces which sets the boundary condition for the electrolyte potential according to

$$\mathbf{n} \cdot \mathbf{i}_l = \sum_m i_{\text{loc}, m}$$

where $i_{\text{loc},m}$ (SI unit: A/m^2) is the local individual electrode reaction current density.

Use a user defined electrode kinetics expression type to model the electrode reaction at the electrode surfaces.

Set the local current density at the Mg electrode surface to

$$i_{\text{Mg}} = f(\phi_{s,\text{ ext}} - \phi_1)$$

A relationship between the local current density and the electrolyte potential at the Mg electrode surface is incorporated in the model using a piecewise cubic interpolation function for the experimental polarization data as shown in Figure 2.

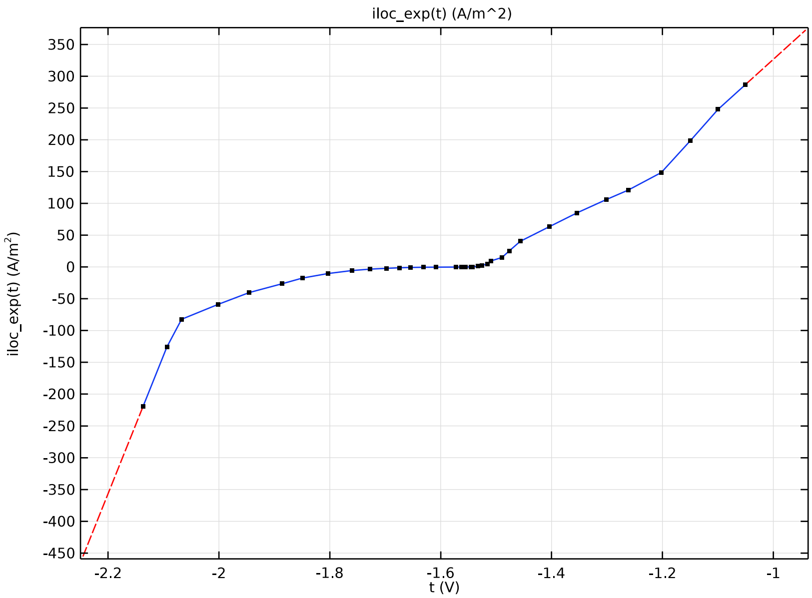

Figure 2: Polarization data for Mg alloy.

Similarly, set the local current density at the Al electrode surface to

$$i_{\mathrm{Al}} = f(\phi_{s,\,\mathrm{ext}} - \phi_1)$$

A relationship between the local current density and the electrolyte potential at the Al electrode surface is incorporated in the model using a piecewise cubic interpolation function for the experimental polarization data as shown in Figure 3.

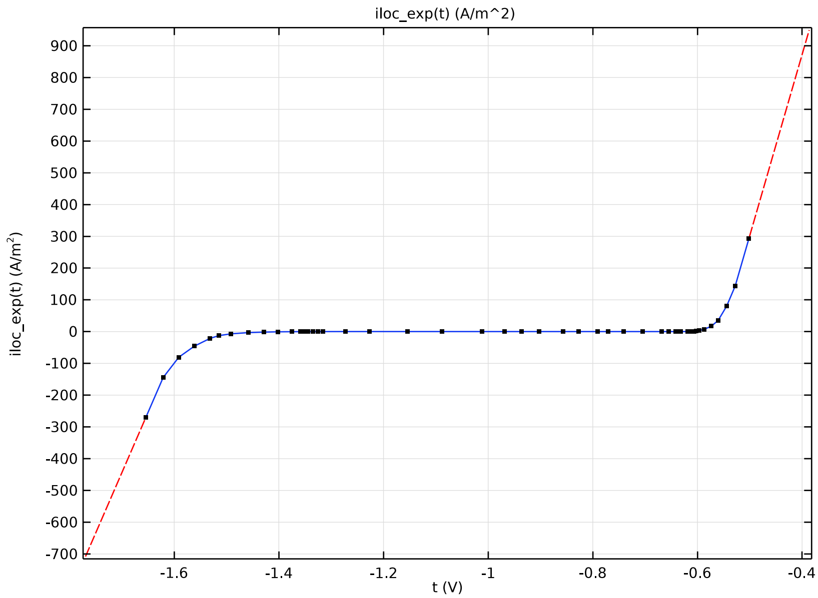

Figure 3: Polarization data for Al alloy.

Finally, set the local current density at the MS electrode surface to

$$i_{\mathrm{MS}} = f(\phi_{s,\mathrm{ext}} - \phi_1)$$

A relationship between the local current density and the electrolyte potential at the MS electrode surface is incorporated in the model using a piecewise cubic interpolation function for the experimental polarization data as shown in Figure 4.

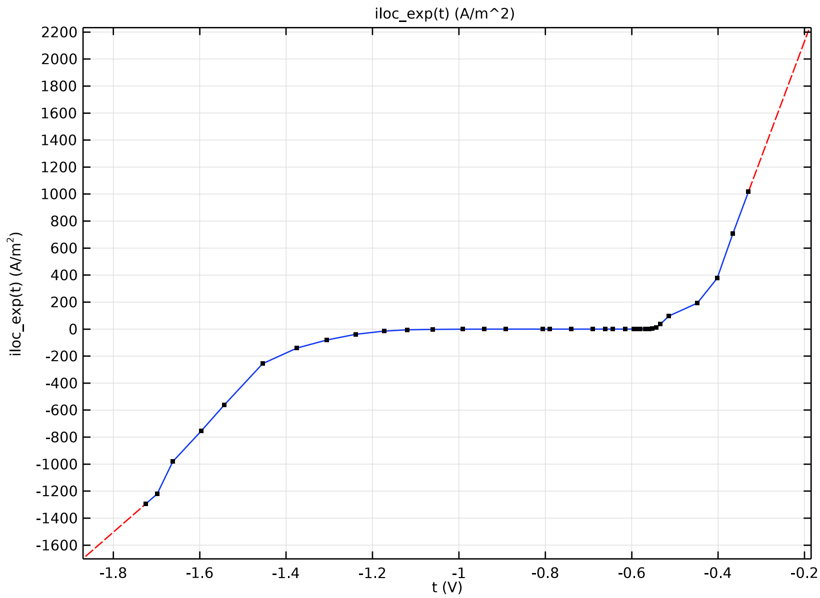

Figure 4: Polarization data for MS.

Results and Discussion

Figure 5 shows a surface plot of the electrolyte potential and a surface arrow plot of the electrolyte current density vector for a magnesium (Mg) - mild steel (MS) galvanic couple with 1 mm thick Al isolator sandwiched between them. The surface arrow plot indicates the electrolyte current density, which in this case coincides with the ionic path taken by the Mg^{2+} ions that get dissolved in the electrolyte solution from the Mg surface.

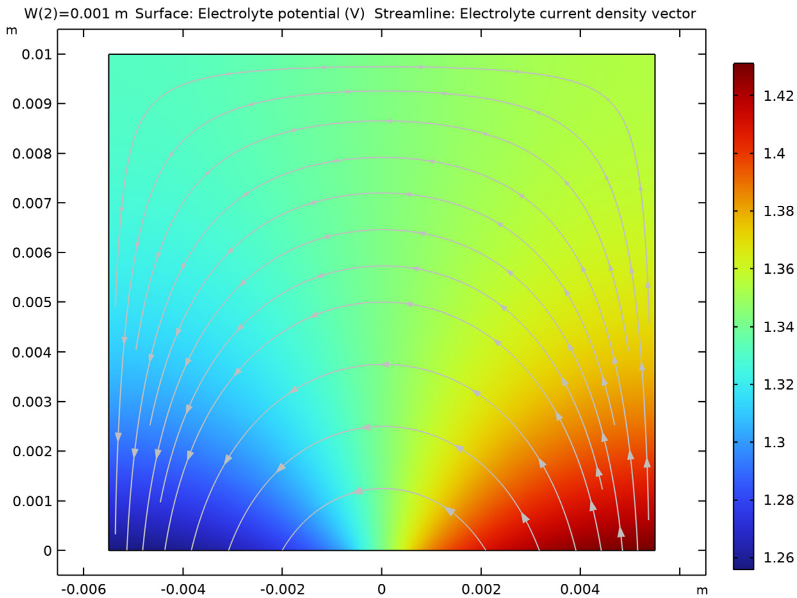

Figure 5: A surface plot of the electrolyte potential and surface arrow plot of electrolyte current density vector for 1 mm thick Al isolator.

Figure 6 shows a surface plot of the electrolyte potential and a surface arrow plot of the electrolyte current density vector for a magnesium (Mg) - mild steel (MS) galvanic couple with 5 mm thick Al isolator sandwiched between them. The surface arrow plot indicates that the ionic path taken by Mg^{2+} ions which get dissolved in the electrolyte solution from the Mg electrode surface is longer in case of 5 mm thick Al isolator. The increased distance and hence, IR drop, decreases the galvanic current density at the Mg electrode surface, mitigating galvanic corrosion.

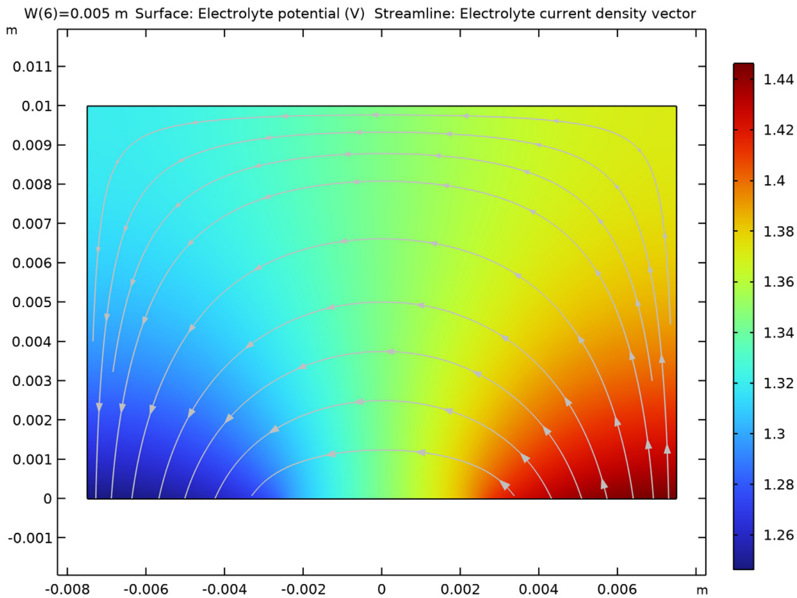

Figure 6: A surface plot of the electrolyte potential and surface arrow plot of electrolyte current density vector for 5 mm thick Al isolator.

Figure 7 shows the electrolyte potential variation over the electrode surfaces for the varied isolator thicknesses. The Mg surface is the most anodically polarized in case of the thinnest isolator and the least polarized in case of the thickest isolator indicating its corrosion propensity.

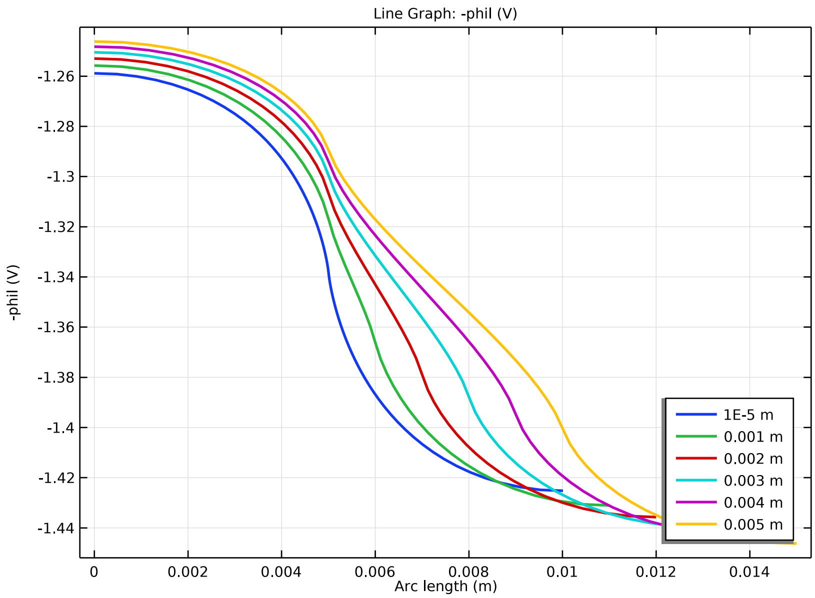

Figure 7: Electrolyte potential variation over the electrode surfaces for the varied isolator thicknesses.

Figure 8 shows the total interface current density variation over the electrode surfaces for the varied isolator thicknesses. The current density over the Mg surface is the highest in case of the thinnest isolator and the lowest in case of the thickest isolator once again indicating its corrosion propensity.

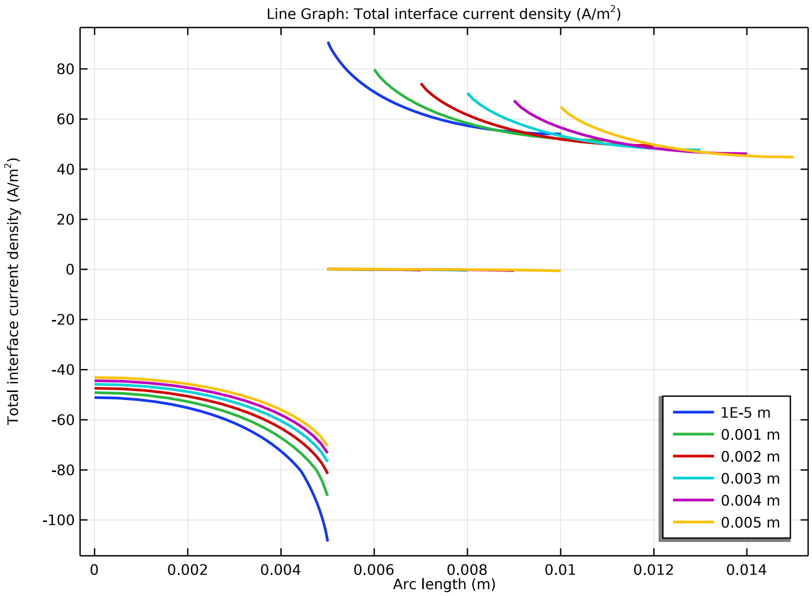

Figure 8: Total interface current density variation over the electrode surfaces for the varied isolator thicknesses.

Notes About the COMSOL Implementation

The Secondary Current Distribution interface is used to model the problem, using Electrode Surface nodes for the three electrode surfaces.

Electrode kinetics is incorporated in the model using a piecewise cubic interpolation function for the experimental polarization data obtained separately for three electrode surfaces.

A stationary study step is used to solve the problem, with a parametric sweep to vary the isolator thickness.

A free triangular mesh is used for meshing, with a finer resolution at the contact points between different materials.

Reference

1. K.B. Deshpande, "Effect of aluminium spacer on galvanic corrosion between magnesium and mild steel using numerical model and SVET experiments," *Corrosion Science*, vol. 62, pp. 184–191, 2012.

Application Library path: `Corrosion_Module/Galvanic_Corrosion/isolator_thickness`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1. In the **Model Wizard** window, click **2D**.
2. In the **Select Physics** tree, select **Electrochemistry>Primary and Secondary Current Distribution>Secondary Current Distribution (cd)**.
3. Click **Add**.
4. Click **Study**.
5. In the **Select Study** tree, select **General Studies>Stationary**.
6. Click **Done**.

GLOBAL DEFINITIONS

Add some model parameters.

Parameters 1

1. In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.
2. In the **Settings** window for **Parameters**, locate the **Parameters** section.
3. In the table, enter the following settings:

Name	Expression	Value	Description
sigma	2.5[S/m]	2.5 S/m	Electrolyte conductivity
W	0.005[m]	0.005 m	Isolator thickness

GEOMETRY 1

Now create the geometry by using a rectangle and two points. The isolator width W is varied using a parametric study.

Rectangle 1 (r1)

1. In the **Geometry** toolbar, click **Rectangle**.
2. In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.
3. In the **Width** text field, type `0.01+W`.
4. In the **Height** text field, type `0.01`.
5. Locate the **Position** section. In the **x** text field, type `-0.005-W/2`.

Point 1 (pt1)

1. In the **Geometry** toolbar, click **Point**.
2. In the **Settings** window for **Point**, locate the **Point** section.
3. In the **x** text field, type `-W/2`.

Point 2 (pt2)

1. In the **Geometry** toolbar, click **Point**.
2. In the **Settings** window for **Point**, locate the **Point** section.
3. In the **x** text field, type `W/2`.
4. Click **Build All Objects**.
5. Click the **Zoom Extents** button in the **Graphics** toolbar.

   The geometry should now look like Figure 1 in the documentation.

MATERIALS

Use the Corrosion Material Library to set up the material properties for the electrode kinetics at the magnesium, aluminum and mild steel electrode surfaces.

ADD MATERIAL

1. In the **Home** toolbar, click **Add Material** to open the **Add Material** window.
2. Go to the **Add Material** window.
3. In the tree, select **Corrosion>Iron Alloys (Steels)>Mild steel in 1.6 wt% NaCl**.
4. Click **Add to Component** in the window toolbar.

MATERIALS

Mild steel in 1.6 wt% NaCl (mat1)

1. In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.
2. From the **Geometric entity level** list, choose **Boundary**.
3. Select Boundary 2 only.
4. In the **Model Builder** window, expand the **Mild steel in 1.6 wt% NaCl (mat1)** node.

Interpolation 1 (iloc_exp)

1. In the **Model Builder** window, expand the **Component 1 (comp1)>Materials>Mild steel in 1.6 wt% NaCl (mat1)>Local current density (lcd)** node, then click **Interpolation 1 (iloc_exp)**.
2. In the **Settings** window for **Interpolation**, click **Plot**.

   Compare the function plot with Figure 4.

ADD MATERIAL

1. Go to the **Add Material** window.
2. In the tree, select **Corrosion>Aluminum Alloys>AA6063 in 1.6 wt% NaCl**.
3. Click **Add to Component** in the window toolbar.

MATERIALS

AA6063 in 1.6 wt% NaCl (mat2)

1. In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.
2. From the **Geometric entity level** list, choose **Boundary**.
3. Select Boundary 4 only.
4. In the **Model Builder** window, expand the **AA6063 in 1.6 wt% NaCl (mat2)** node.

Interpolation 1 (iloc_exp)

1. In the **Model Builder** window, expand the **Component 1 (comp1)>Materials>AA6063 in 1.6 wt% NaCl (mat2)>Local current density (lcd)** node, then click **Interpolation 1 (iloc_exp)**.
2. In the **Settings** window for **Interpolation**, click **Plot**.

   Compare the function plot with Figure 3.

ADD MATERIAL

1. Go to the **Add Material** window.

2 In the tree, select **Corrosion>Magnesium Alloys>AE44 in 1.6 wt% NaCl**.

3 Click **Add to Component** in the window toolbar.

MATERIALS

AE44 in 1.6 wt% NaCl (mat3)

1 In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.

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

3 Select Boundary 5 only.

4 In the **Model Builder** window, expand the **AE44 in 1.6 wt% NaCl (mat3)** node.

Interpolation 1 (iloc_exp)

1 In the **Model Builder** window, expand the **Component 1 (comp1)>Materials> AE44 in 1.6 wt% NaCl (mat3)>Local current density (lcd)** node, then click **Interpolation 1 (iloc_exp)**.

2 In the **Settings** window for **Interpolation**, click **Plot**.

Compare the function plot with Figure 2.

3 In the **Home** toolbar, click **Add Material** to close the **Add Material** window.

SECONDARY CURRENT DISTRIBUTION (CD)

Now set up the physics for the current distribution. Start with selecting the reference electrode potential.

1 In the **Settings** window for **Secondary Current Distribution**, click to expand the **Physics vs. Materials Reference Electrode Potential** section.

2 From the list, choose **0.241 V (SCE vs. SHE)**.

Electrolyte 1

1 In the **Model Builder** window, under **Component 1 (comp1)> Secondary Current Distribution (cd)** click **Electrolyte 1**.

2 In the **Settings** window for **Electrolyte**, locate the **Electrolyte** section.

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

Electrode Surface 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Electrode Surface**.

2 Select Boundary 2 only.

Electrode Reaction 1

1 In the **Model Builder** window, click **Electrode Reaction 1**.

2 In the **Settings** window for **Electrode Reaction**, locate the **Electrode Kinetics** section.

3 From the $i_{loc,expr}$ list, choose **From material**.

Electrode Surface 2

1 In the **Physics** toolbar, click **Boundaries** and choose **Electrode Surface**.

2 Select Boundary 4 only.

Electrode Reaction 1

1 In the **Model Builder** window, click **Electrode Reaction 1**.

2 In the **Settings** window for **Electrode Reaction**, locate the **Electrode Kinetics** section.

3 From the $i_{loc,expr}$ list, choose **From material**.

Electrode Surface 3

1 In the **Physics** toolbar, click **Boundaries** and choose **Electrode Surface**.

2 Select Boundary 5 only.

Electrode Reaction 1

1 In the **Model Builder** window, click **Electrode Reaction 1**.

2 In the **Settings** window for **Electrode Reaction**, locate the **Electrode Kinetics** section.

3 From the $i_{loc,expr}$ list, choose **From material**.

STUDY 1

Use a parametric solver to vary the isolator width.

Parametric Sweep

1 In the **Study** toolbar, click **Parametric Sweep**.

2 In the **Settings** window for **Parametric Sweep**, locate the **Study Settings** section.

3 Click **Add**.

4 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
W (Isolator thickness)	`1e-5 0.001 0.002 0.003 0.004 0.005`	`m`

Now solve the secondary current distribution model.

5 In the **Study** toolbar, click **Compute**.

RESULTS

The model is now solved. Follow the remaining steps below to reproduce the plots from the Results and Discussion section.

Electrolyte Potential for 0.001 m Wide Isolator

1 In the **Model Builder** window, under **Results** click **Electrolyte Potential (cd)**.

2 In the **Settings** window for **2D Plot Group**, locate the **Data** section.

3 From the **Parameter value (W (m))** list, choose **0.001**.

4 In the **Electrolyte Potential (cd)** toolbar, click **Plot**.

5 In the **Label** text field, type `Electrolyte Potential for 0.001 m Wide Isolator`.

Electrolyte Potential for 0.005 m Wide Isolator

1 Right-click **Electrolyte Potential for 0.001 m Wide Isolator** and choose **Duplicate**.

2 In the **Settings** window for **2D Plot Group**, locate the **Data** section.

3 From the **Parameter value (W (m))** list, choose **0.005**.

4 In the **Electrolyte Potential for 0.001 m Wide Isolator 1** toolbar, click **Plot**.

5 In the **Label** text field, type `Electrolyte Potential for 0.005 m Wide Isolator`.

1D Plot Group 5

In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

Line Graph 1

1 Right-click **1D Plot Group 5** and choose **Line Graph**.

2 Select Boundaries 2, 4, and 5 only.

3 In the **Settings** window for **Line Graph**, locate the **y-Axis Data** section.

4 In the **Expression** text field, type `-phil`.

5 Click to expand the **Coloring and Style** section. From the **Width** list, choose **2**.

6 Click to expand the **Legends** section. Select the **Show legends** check box.

Electrolyte Potential Comparison

1 In the **Model Builder** window, click **1D Plot Group 5**.

2 In the **Settings** window for **1D Plot Group**, locate the **Data** section.

3 From the **Dataset** list, choose **Study 1/Parametric Solutions 1 (sol2)**.

4 Locate the **Legend** section. From the **Position** list, choose **Lower right**.

5 In the **1D Plot Group 5** toolbar, click **Plot**.

6 In the **Label** text field, type `Electrolyte Potential Comparison`.

Electrolyte Potential Comparison 1

Right-click **Electrolyte Potential Comparison** and choose **Duplicate**.

Line Graph 1

1 In the **Model Builder** window, expand the **Electrolyte Potential Comparison 1** node, then click **Line Graph 1**.

2 In the **Settings** window for **Line Graph**, click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Secondary Current Distribution>Electrode kinetics>cd.itot - Total interface current density - A/m²**.

3 In the **Electrolyte Potential Comparison 1** toolbar, click **Plot**.

Current Density Comparison

1 In the **Model Builder** window, right-click **Electrolyte Potential Comparison 1** and choose **Rename**.

2 In the **Rename 1D Plot Group** dialog box, type `Current Density Comparison` in the **New label** text field.

3 Click **OK**.