Created in COMSOL Multiphysics 6.1

Stray Current Pipeline Corrosion

Introduction

The impressed current cathodic protection (ICCP) system is often employed to mitigate corrosion of buried pipelines in oil and gas industry. Metallic objects such as buried pipelines, which are present within the current flow of the ICCP system, may suffer from the stray current interactions leading to accelerated corrosion.

The present model example demonstrates stray current corrosion of a buried pipeline, which is in vicinity of the ICCP system, using the Current Distribution, Boundary Elements interface. The ICCP system is considered to consist of a protected pipeline and an anode. An interference pipeline is considered to be in vicinity of the protected pipeline and is affected due to stray current.

The example is based on a paper by G. Cui and others (Ref. 1).

Model Definition

The model geometry is shown in Figure 1.

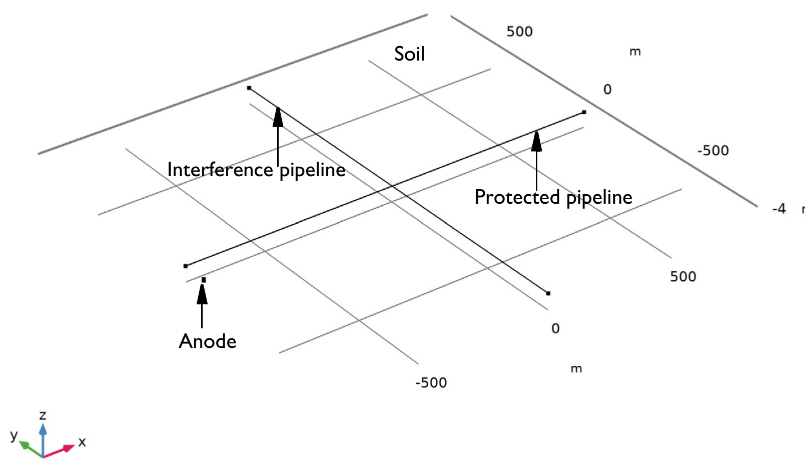


Figure 1: Model geometry consists of three line segments representing the anode, protected pipeline, and interference pipeline, which are surrounded by soil domain.

The model geometry consists of the protected pipeline, interference pipeline, and anode. Both the protected and interference pipelines are 1.6 km long and cross each other at an angle of 90° and at middle of their lengths. The protected pipeline diameter is 0.762 m, the interference pipeline diameter is 0.4064 m and the anode diameter is 0.1 m. The anode is 100 m away from the protected pipeline and 800 m away from the interference pipeline.

The two crossing pipelines and anode are considered to be the edge electrodes. The Current Distribution, Boundary Elements interface is used to solve for the electrolyte potential, ϕ_l (SI unit: V), over the edge domains 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 0.005 S/m for the soil domain.

At the anode edge, the applied current density is prescribed using the Electrolyte Current Density node as:

$$\mathbf{n} \cdot \mathbf{i}_l = i_{\mathrm{app}}$$

where $\mathbf{n}$ is the normal vector, pointing out of the domain and i_{app} is 1.528 A/m^2.

At the protected and interference pipelines, kinetics of electrochemical reactions is prescribed using the Edge Electrode node as:

$$\mathbf{n} \cdot \mathbf{i}_l = f(\phi_l)$$

where $f(\phi_l)$ is an interpolation function obtained form the experimental polarization data available in corrosion material library (Ref. 1).

For the interference pipeline, the electric potential model is set to floating potential with zero applied current, which indicates that the interference pipeline is electrically not connected to anything and it will interact with adjacent soil domain only through the electrochemical reactions occurring at the pipeline surface.

Results and Discussion

Figure 2 shows the electrode potential distribution over the protected and interference pipelines in the region closer to the pipelines crossing. It can be seen that the electrode potential over the protected pipeline is below its equilibrium potential (–0.56 V) indicating that the pipeline is fully protected. The electrode potential over the interference pipeline is above its equilibrium potential (–0.56 V), particularly in the region closer to the pipeline crossing, indicating the occurrence of corrosion.

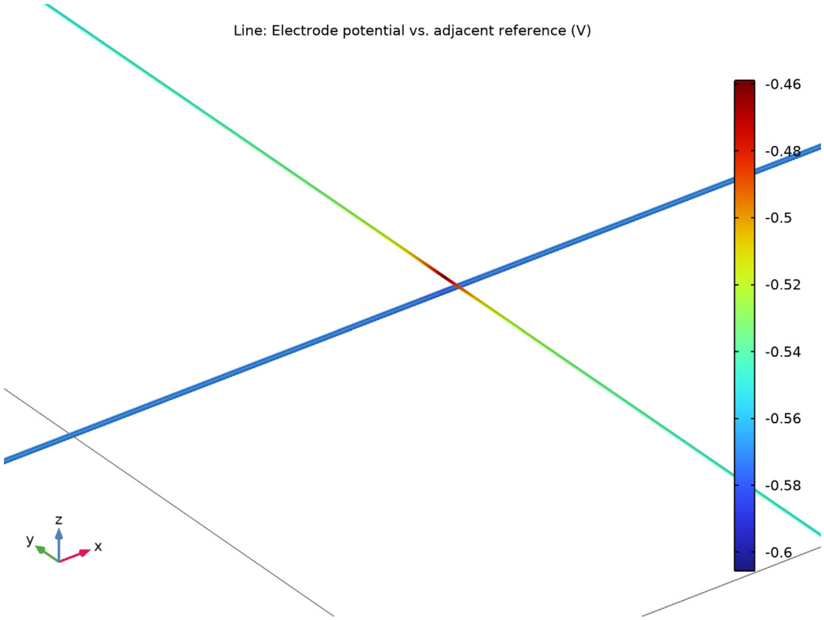


Figure 2: The electrode potential distribution over the protected and interference pipelines in the region closer to the pipelines crossing.

Figure 3 shows the electrode potential distribution over the entire length of the interference pipeline. It confirms the behavior seen in Figure 2 that the electrode potential is above its equilibrium potential in the region closer to the pipeline crossing (about 200 m on either side), indicating the occurrence of corrosion. It can also be seen in Figure 3 that the electrode potential further away from the pipeline crossing is below the equilibrium potential, indicating that the interference pipeline is protected in that region.

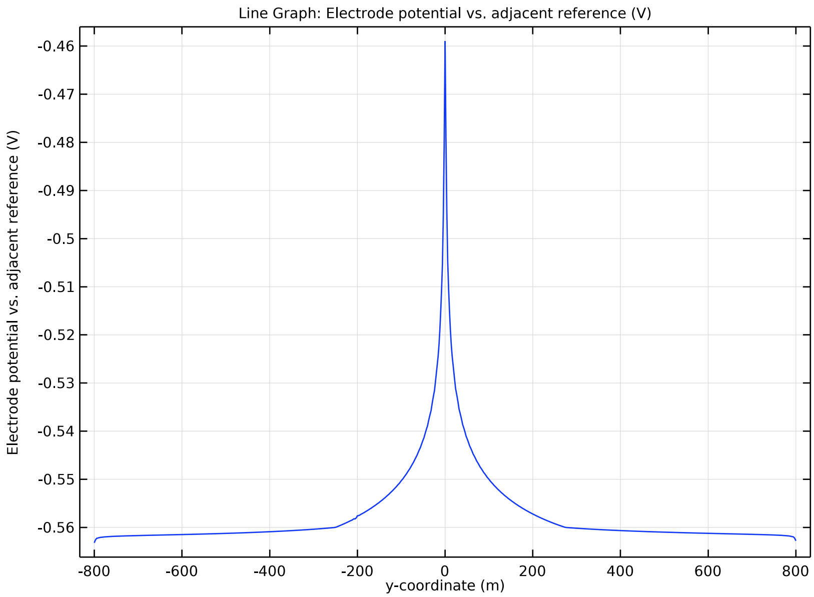


Figure 3: The electrode potential distribution over the entire length of the interference pipeline.

Figure 4 shows the local current density distribution over the entire length of the interference pipeline, and Figure 5 the same data depicted as an arrow line plot in the geometry in a close-up around the pipeline crossing. The local current density in the region closer to the pipeline crossing (about 200 m on either side) is positive (anodic) whereas the same away from the pipeline crossing is negative (cathodic). The interference pipeline is found to receive cathodic protection in terms of stray current in the region away from the pipelines crossing. The stray current leaves the interference pipe in a region closer to the pipelines crossing confirming, indicating corrosion in that region.

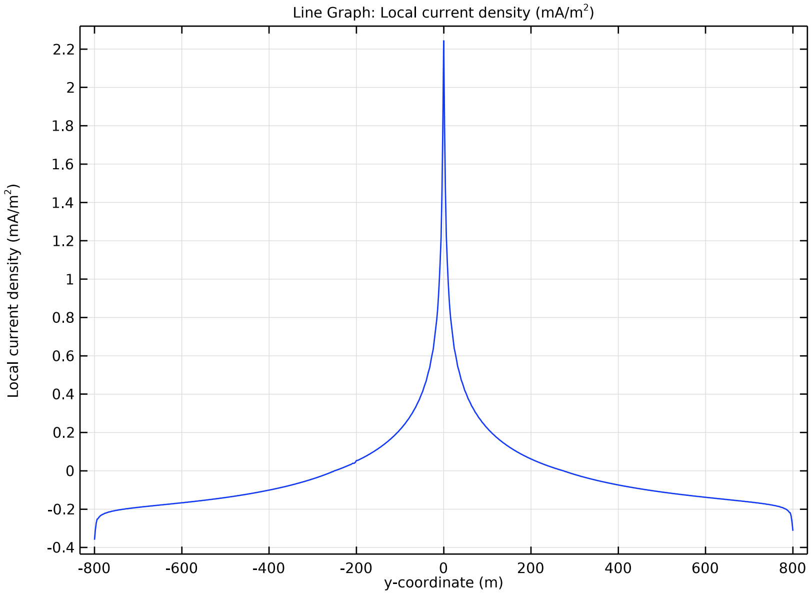


Figure 4: The local current density distribution over the entire length of the interference pipeline.

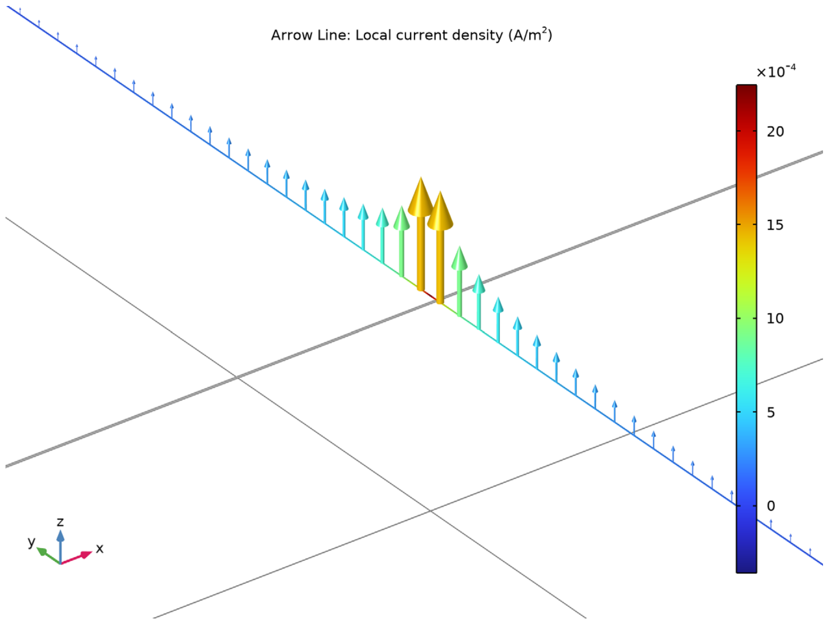


Figure 5: The local stray current density distribution depicted as an arrow line plot in the z-direction close to the pipe crossing.

Notes About the COMSOL Implementation

The model is implemented using the Current Distribution, Boundary Elements interface. Note that the governing equations are solved only over the edge domains, comprising the anode, protected pipeline, and interference pipeline; hence, only edge domains are discretized (meshed) in the model.

References

1. G. Cui, Z. Li, C. Yang and M. Wang, "The influence of DC stray current on pipeline corrosion", *Petroleum Science*, vol. 13, pp. 135–145, 2016.

Application Library path: `Corrosion_Module/General_Corrosion/stray_current`

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 **3D**.

2 In the **Select Physics** tree, select **Electrochemistry> Primary and Secondary Current Distribution>Current Distribution, Boundary Elements (cdbem)**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **General Studies>Stationary**.

6 Click **Done**.

GLOBAL DEFINITIONS

Parameters 1

First, load the model parameters.

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

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

3 Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `stray_current_parameters.txt`.

GEOMETRY 1

The model geometry consists of three line segments representing the anode, protected pipe and interference pipe, respectively.

Anode

1 In the **Geometry** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 From the **Specify** list, choose **Coordinates**.

4 In the **x** text field, type `-lpipe/2`.

5 In the **y** text field, type `-100`.

6 In the **z** text field, type `-1`.

7 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

8 In the **x** text field, type `-lpipe/2`.

9 In the **y** text field, type `-100`.

10 In the **z** text field, type `-1-lanode`.

11 Locate the **Selections of Resulting Entities** section. Select the **Resulting objects selection** check box.

12 In the **Label** text field, type `Anode`.

Pipeline 1 (Protected)

1 In the **Geometry** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, type `Pipeline 1 (Protected)` in the **Label** text field.

3 Locate the **Starting Point** section. From the **Specify** list, choose **Coordinates**.

4 In the **x** text field, type `-lpipe/2`.

5 In the **z** text field, type `-4`.

6 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

7 In the **x** text field, type `lpipe/2`.

8 In the **z** text field, type `-4`.

9 Locate the **Selections of Resulting Entities** section. Select the **Resulting objects selection** check box.

Pipeline 2 (Interference)

1 In the **Geometry** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, type `Pipeline 2 (Interference)` in the **Label** text field.

3 Locate the **Starting Point** section. From the **Specify** list, choose **Coordinates**.

4 In the **y** text field, type `-lpipe/2`.

5 In the **z** text field, type `-2`.

6 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

7 In the **y** text field, type `lpipe/2`.

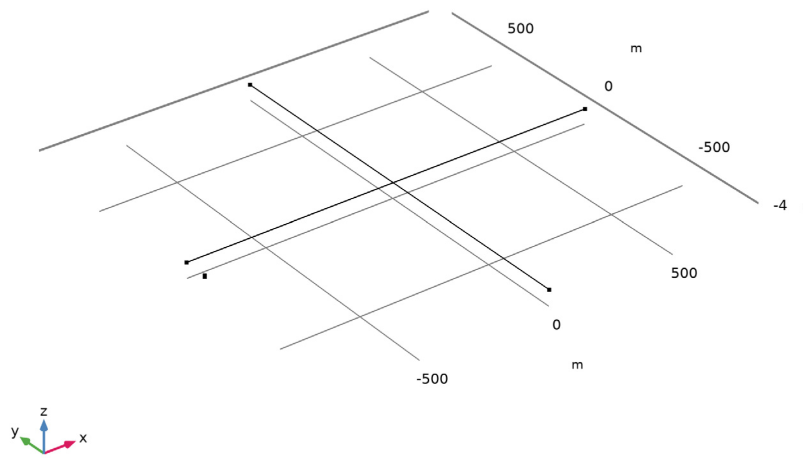
8 In the **z** text field, type `-2`.

9 Locate the **Selections of Resulting Entities** section. Select the **Resulting objects selection** check box.

10 Click **Build All Objects**.

11 Click the **Zoom Extents** button in the **Graphics** toolbar.

Your geometry should like this.



MATERIALS

Use the Corrosion Material Library to set up the material properties for the electrode kinetics at the Q235 steel electrode surface.

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)>Q235 steel in soil**.
4. Click **Add to Component** in the window toolbar.
5. In the **Home** toolbar, click **Add Material** to close the **Add Material** window.

CURRENT DISTRIBUTION, BOUNDARY ELEMENTS (CDBEM)

Now, set up the physics of the model. Start with selecting the reference electrode. Then, set the electrolyte conductivity, set the applied current density at the anode and electrochemical reaction kinetics at the two pipelines.

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Current Distribution, Boundary Elements (cdbem)**.

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

3 From the list, choose **0.314 V (CSE vs. SHE)**.

Electrolyte 1

1 In the **Model Builder** window, under **Component 1 (comp1)>Current Distribution, Boundary Elements (cdbem)** click **Electrolyte 1**.

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

3 In the σ_l text field, type `sigma`.

Electrolyte Current Density 1

1 In the **Physics** toolbar, click **Edges** and choose **Electrolyte Current Density**.

2 In the **Settings** window for **Electrolyte Current Density**, locate the **Edge Selection** section.

3 From the **Selection** list, choose **Anode**.

4 Locate the **Electrolyte Current Density** section. In the $i_{n,l}$ text field, type `iapp`.

Edge Electrode 1

1 In the **Physics** toolbar, click **Edges** and choose **Edge Electrode**.

2 In the **Settings** window for **Edge Electrode**, locate the **Edge Selection** section.

3 From the **Selection** list, choose **Pipeline 1 (Protected)**.

4 Locate the **Edge Radius** section. In the **Edge radius** text field, type `rpipe1`.

5 Locate the **Electric Potential** section. From the **Electric potential model** list, choose **Fixed**.

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 $i_{\mathrm{loc,expr}}$ list, choose **From material**.

Edge Electrode 2

1 In the **Model Builder** window, under **Component 1 (comp1)>Current Distribution, Boundary Elements (cdbem)** right-click **Edge Electrode 1** and choose **Duplicate**.

2 In the **Settings** window for **Edge Electrode**, locate the **Edge Selection** section.

3 From the **Selection** list, choose **Pipeline 2 (Interference)**.

4 Locate the **Edge Radius** section. In the **Edge radius** text field, type `rpipe2`.

5 Locate the **Electric Potential** section. From the **Electric potential model** list, choose **Floating potential**.

MESH 1

Set the fine mesh at all line segments.

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Mesh 1**.

2 In the **Settings** window for **Mesh**, locate the **Sequence Type** section.

3 From the list, choose **User-controlled mesh**.

Size 1

1 In the **Model Builder** window, right-click **Edge 1** and choose **Size**.

2 In the **Settings** window for **Size**, locate the **Element Size** section.

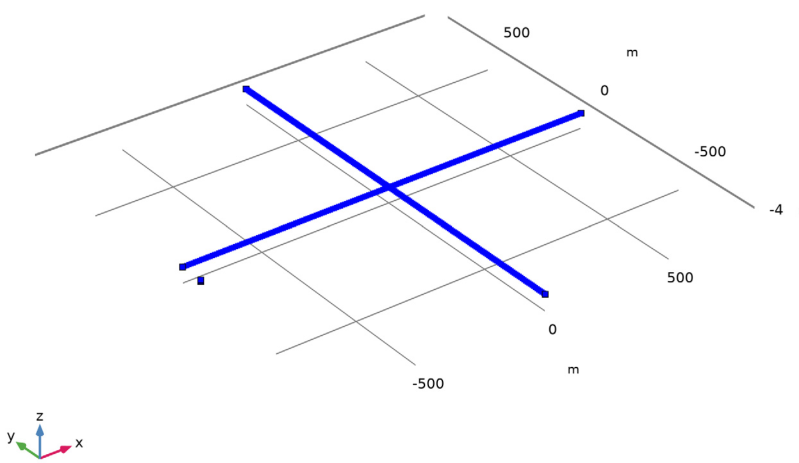
3 Click the **Custom** button.

4 Locate the **Element Size Parameters** section.

5 Select the **Maximum element size** check box. In the associated text field, type 8.

6 Click **Build All**.

The mesh should look like this.



STUDY 1

The model is now ready to be solved.

1 In the **Home** toolbar, click **Compute**.

RESULTS

Some plots are generated by default.

Electrode Potential vs. Adjacent Reference (cdbem)

One can zoom in a region closer to intersection of the two pipelines using a **Zoom Box** to visualize the electrode potential variation along the pipelines.

1 In the **Model Builder** window, click **Electrode Potential vs. Adjacent Reference (cdbem)**.

2 In the **Electrode Potential vs. Adjacent Reference (cdbem)** toolbar, click **Plot**.

The plot should look like Figure 2.

Electrode Potential

Now, plot the electrode potential and local current density variation along the interference pipe.

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

2 In the **Settings** window for **1D Plot Group**, type `Electrode Potential` in the **Label** text field.

Line Graph 1

1 In the **Electrode Potential** toolbar, click **Line Graph**.

2 In the **Settings** window for **Line Graph**, locate the **Selection** section.

3 From the **Selection** list, choose **Pipeline 2 (Interference)**.

4 Click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)>Current Distribution, Boundary Elements> cdbem.Evsref - Electrode potential vs. adjacent reference - V**.

5 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

6 In the **Expression** text field, type `y`.

7 In the **Electrode Potential** toolbar, click **Plot**.

The plot should look like Figure 3.

Local current density

1 In the **Model Builder** window, right-click **Electrode Potential** and choose **Duplicate**.

2 In the **Settings** window for **1D Plot Group**, type `Local current density` in the **Label** text field.

Line Graph 1

1 In the **Model Builder** window, expand the **Local current density** 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)> Current Distribution, Boundary Elements>Electrode kinetics>cdbem.iloc_er1 - Local current density - A/m²**.

3 Locate the **y-Axis Data** section. In the **Unit** field, type `mA/m^2`.

4 In the **Local current density** toolbar, click **Plot**.

The plot should look like Figure 4.

Electrolyte Current Density (cdbem)

Follow the instructions below to reproduce the plot in Figure 5.

Stray Current Density

1 In the **Model Builder** window, right-click **Electrolyte Current Density (cdbem)** and choose **Duplicate**.

2 In the **Settings** window for **3D Plot Group**, type `Stray Current Density` in the **Label** text field.

Line 1

1 In the **Model Builder** window, expand the **Stray Current Density** node, then click **Line 1**.

2 In the **Settings** window for **Line**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)>Current Distribution, Boundary Elements>Electrode kinetics>cdbem.iloc_er1 - Local current density - A/m²**.

3 Click to expand the **Title** section. From the **Title type** list, choose **None**.

Selection 1

1 Right-click **Line 1** and choose **Selection**.

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

3 From the **Selection** list, choose **Pipeline 2 (Interference)**.

Line 2

1 Right-click **Line 1** and choose **Duplicate**.

2 In the **Settings** window for **Line**, locate the **Expression** section.

3 In the **Expression** text field, type `1`.

4 Locate the **Coloring and Style** section. From the **Coloring** list, choose **Uniform**.

5 From the **Color** list, choose **Gray**.

Selection 1

1 In the **Model Builder** window, expand the **Line 2** node, then click **Selection 1**.

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

3 From the **Selection** list, choose **Pipeline 1 (Protected)**.

Arrow Line 1

1 In the **Model Builder** window, right-click **Stray Current Density** and choose **Arrow Line**.

2 In the **Settings** window for **Arrow Line**, locate the **Expression** section.

3 In the **X-component** text field, type 0.

4 In the **Y-component** text field, type 0.

5 In the **Z-component** text field, type cdbem.iloc_er1.

6 Click to expand the **Title** section. From the **Title type** list, choose **Manual**.

7 In the **Title** text area, type Arrow Line: Local current density (A/m²).

8 Click to expand the **Inherit Style** section. From the **Plot** list, choose **Line 1**.

Selection 1

1 Right-click **Arrow Line 1** and choose **Selection**.

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

3 From the **Selection** list, choose **Pipeline 2 (Interference)**.

Color Expression 1

1 In the **Model Builder** window, right-click **Arrow Line 1** and choose **Color Expression**.

2 In the **Settings** window for **Color Expression**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **cdbem.iloc_er1 - Local current density - A/m^2**.

Stray Current Density

1 Click the **Zoom Out** button in the **Graphics** toolbar.

2 In the **Model Builder** window, under **Results** click **Stray Current Density**.

3 In the **Stray Current Density** toolbar, click **Plot**.

The plot should look like Figure 5.