

Determination of Electric Potential Distribution and Cell Resistance of a Uranium Electrorefining Cell

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Abstract:

Electrorefining is an electrolytic process for obtaining high purity metal. In this process the impure metal is made anode and the high purity metal is deposited on cathode. Electrorefining is a key step in pyrochemical reprocessing of spent fuel from metal fuel fast reactors.

Development of an electrorefining cell, in which processing of 10 kg of simulated spent fuel will be demonstrated, is under progress in IGCAR. In this paper the preliminary study carried out to evaluate the cell resistance of the proposed design of electrorefining cell, is brought out. Specifically the effect of Bottom Insulation Plate of Cathode, provided to prevent the falling off of the cathode deposit into the molten salt electrolyte, is presented. The results were obtained by 3D simulation of the electrorefining cell using COMSOL Multiphysics software.

Keywords: Electrorefining, pyrochemical reprocessing, cell resistance, finite element analysis, COMSOL

1. Introduction

Electrorefining is an electrolytic process for obtaining high purity metal. In this process the impure metal is made anode and the high purity metal is deposited on cathode. Electrorefining is a key step in pyrochemical reprocessing the spent fuel from metal fuel fast reactors. Development of an electrorefining cell, in which processing of 10 kg of U alloys will be demonstrated, is under progress in IGCAR. Molten salt (LiCl-KCl eutectic) will be used as the electrolyte. Based on the design requirements of high throughput and ease of loading the simulated fuel in the anode and scrapping the U deposit from the cathode various configurations of the electrorefining cell have been suggested in

literature. Figure 1 shows the configuration of a commonly used electrorefining cell. Based on this configuration an engineering scale (10 kg of heavy metal) electrorefining cell for conducting studies with U alloys has been worked out.

In this paper the preliminary studies done, to determine the electrical resistance of the electrorefining cell, are brought out. The effect of Bottom Insulation Plate of Cathode, provided to prevent the falling off of the cathode deposit into the molten salt electrolyte, on the Resistance of Electrorefining Cell is also discussed.

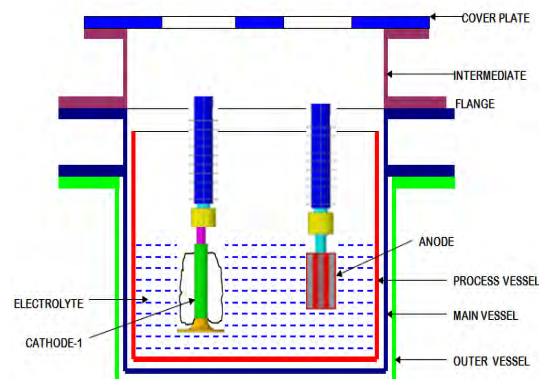


Figure 1. Schematic of Electrorefining Cell

2. Governing Equation

The governing equation for determining the static potential distribution in a continuum without current source or sink is:

$$-\nabla \cdot (\sigma \nabla V - J^e) = 0$$

Where,

V is the electrical potential,

σ is the electrical conductivity

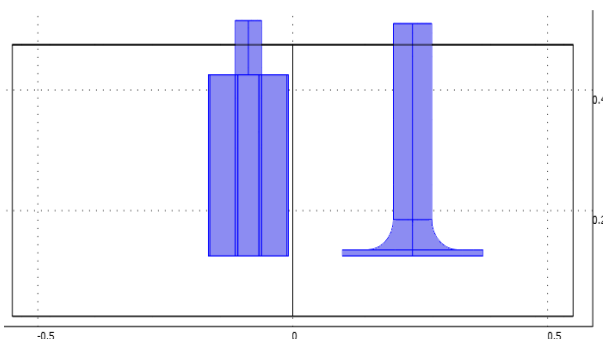
J^e externally applied current density

3. Method

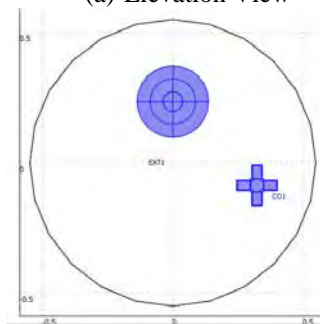
Finite Element Analysis of the electrorefining cell was carried out, to determine the electric potential distribution in the cell for a constant current flowing through the electrodes, using COMSOL Version. 3.5a. Then using Ohm's law the resistance of the cell was determined.

4. Geometry

Fig. 2 shows the geometric model of the electrorefining cell. As the electrodes are not located on any axis of symmetry of the cell, full 360° model was made. As no ion current is expected through the walls of the process vessel in the normal operating conditions, it is not included in the model [1]. Normally a Cadmium pool is also maintained below the molten salt to dissolve any U deposit falling from the cathode. In this study the Cd pool is not included. The electrodes are located as shown in Fig. 3. In the design the anode consisting of four perforated baskets, that can together hold 10 kg of heavy metal. In the model the perforations in the anode baskets are not included.



(a) Elevation View



(b) Top View (minimized)

Figure 2. Geometric Model of Electrorefining Cell

The cathode is a steel rod with a ceramic bottom plate attached to its bottom. This plate is provided to reduce the quantity of U, deposited on the cathode, from falling to the bottom of the vessel due to self weight and weak bond with the cathode rod. Also the U deposit can grow and touch the Cd and short the cathode if the plate is not provided. To reduce the complexity the stirrer is not modeled in this preliminary analysis.

5. FE Model & Boundary Conditions

To evaluate the current density & potential distribution in the ER for a constant current flowing through the electrodes, Lagrange-quadratic element with single degree of freedom (voltage) at each node is used. The mesh is shown in Figure 3. Electrical conductivity of the molten salt at 500°C, is taken as 190 S/m [1,2]. The Electrical insulation boundary condition is given at the salt outer surfaces. 100 A inward current is given through the top cross-section of the anode and grounded boundary condition is specified for the top cross-section of the cathode.

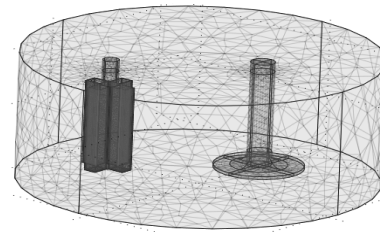


Figure 3. FE Mesh

6. Results

6.1 Current Density

As the surface area of the anode is significantly larger than that of the cathode the highest current densities are expected near the cathode surface.

Also, in electrolytic cells polarization can take place at the anode and cathode under certain operating conditions. It is reported in Ref. 2 that under normal operating conditions of the cell polarization did not occur for cathode current densities of the order 1000 A/m². If present, polarization can significantly increase the cell resistance. Therefore, the current density on the cathode surface was checked and was found to be about 1500 A/m² for most of the surface. So

any significant polarization is not expected to occur in this case also and so the model is expected to give reasonable results for cell resistance. There is a small region where the current density is as high as 3400 A/m^2 . The U deposit is expected to grow faster in this region. The ceramic plate prevents the deposit from extending upto the bottom of the vessel, or upto the Cd pool when present, and shorting the cathode.

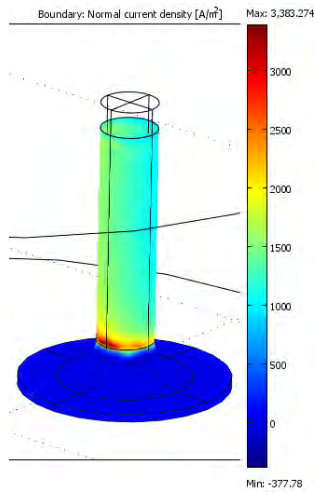


Figure 4. Cathode surface current density

6.2 Electric Potential Distribution

The Electric Potential Distribution obtained from the FEA results is shown in Figure 4. The arrows in the figure indicate the current density. The electric potential drop across the cell was found to be 1.176 V.

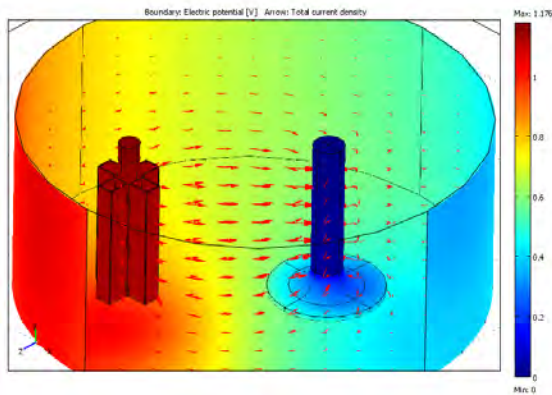


Figure 5. Electric potential and current density (arrows) plot

6.3 Cell Resistance

For the applied constant DC of 100 A the voltage drop obtained from analysis is 1.18 V. Using Ohm's law, the electrical resistance is calculated as 0.012Ω .

7. Comparison with Experimental Results

In Table 1 experimental data, taken from Ref. 4, of cell voltage and current for an electrolytic cell of similar dimensions and operating conditions are given. Significant difference between the model and the cell for which data are available is that in the cell is having Cd pool below the molten salt electrolyte. In Ref. 5 it is brought out that the Cd pool acts an intermediate electrode. From Table 1 it can be concluded that the Cd pool does not affect the cell resistance and therefore the deposition rate significantly. This is contrary to what is expected as the electrical conductivity of the Cd is very high. But the conclusion needs to be further verified by experiments.

	Average Current (A)	Cell Voltage (V)	Cell Resistance (Ω)
Expt. Data	79	1.00	0.013
	97	0.99	0.010
	107	1.28	0.012
Computed data	100	1.18	0.012

Table 1. Experimental & Analysis Results

8. Conclusions

A three dimensional finite element analysis of the electrorefining cell was done, using COMSOL Multiphysics software, for determining the electric potential distribution inside the cell. Using the current and voltage drop values across the electrodes, obtained from the analysis, the cell resistance was found to be 0.012Ω . A comparison was made with the data available in literature and the results were found to be satisfactory. Inclusion of the Cd pool in the model can further improve the accuracy of the results.

8. References

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