Electrochemical Pickling of Steel for Industrial Applications: Modelling

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Introduction: The present work is aimed at ***simulating*** the steel ***electrochemical pickling*** process by means of experimental investigation in industrial field and the development of a mathematical ***model***. The reference system is characterized by a cell in which an electrolyte is present. A group of electrodes (cathodes and anodes) is immersed in the electrolytic bath. A steel strip, to be submitted to the ***pickling*** treatment, is interposed between the electrodes.

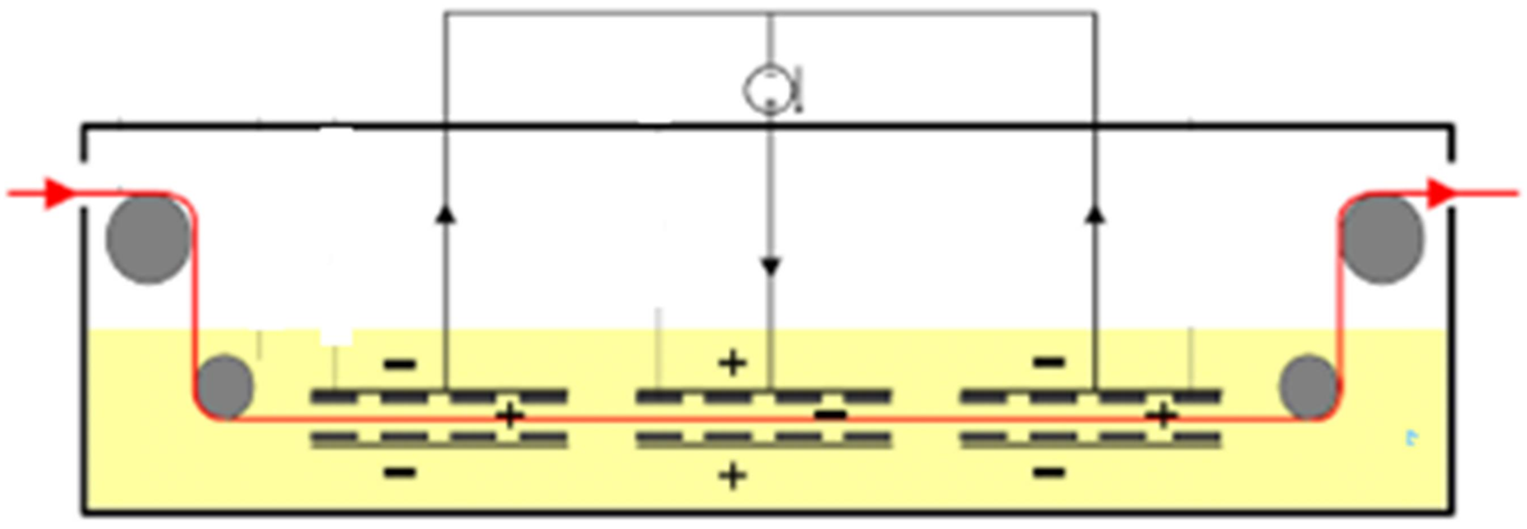

Figure 1. ***Industrial electrolytic pickling*** cell

Computational Methods: A reliable, flexible and robust ***3D model*** has been made for ***simulating*** the steel strip electrochemical ***pickling***. This process is modeled like a ***multiphysics system*** for the ***current control***.

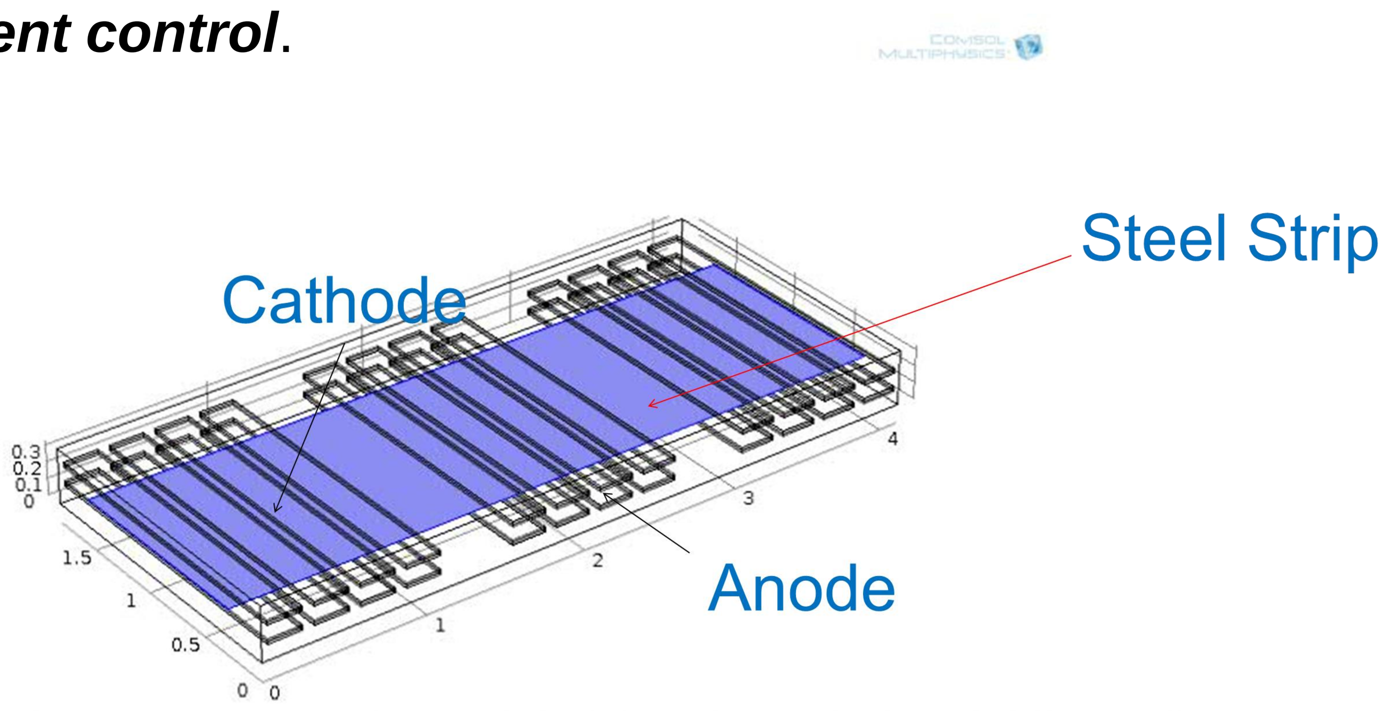

Figure 2. Geometric ***model*** of the ***electrolytic pickling*** cell

The physics of the problem is described by the following equations system:

$$\begin{cases} \nabla\cdot i_l = Q_l \quad (1.1) & i_l = -\sigma\,\nabla\,\Phi_l \quad (1.2) \\ \nabla\cdot i_s = Q_s \quad (2.1) & i_s = -\sigma\,\nabla\,\Phi_s \quad (2.2) \end{cases}$$

the equations system is completed by the next set:

• the boundary conditions of the current which develops on both the electrodes (Anode-Cathode) and the strip surfaces :

$$\boldsymbol{\eta_\Omega} = \boldsymbol{\eta}_a = \Phi_s - \Phi_l - E_{eq} \qquad (3.1)$$

$$i_k = i_0 \left[e^{\frac{\alpha k_a F\eta}{RT}} - e^{\frac{-\alpha k_c F\eta}{RT}} \right] \quad \forall\, k = 1, \ldots, N \qquad (3.2)$$

• the initial condition for the potential in the electrolyte, the electrodes and the steel strip:

$$\Phi_s = V_{s0} \quad (4.1) \qquad \Phi_l = V_{l0} \quad (4.2)$$

where the equations:

-1.1 and 2.1 are obtained by the combination of the mass conservation law with the Nernst-Plank's law and Faraday's one in the steady case and applied in the electrolyte, in the electrodes (Anode-Cathode) and in the steel strip

-1.2 and 2.2 represent the Ohm's law in differential form

-3.1 represents the secondary current distribution calculated according to the second Kirkoff's law of the equivalent electric circuit

-3.2 is the empirical Tafel's law for each ionic specie

- 4.1 and 4.2 are the initial potential values in the cell

Results: The obtained ***model*** allows to estimate, evaluate and verify the operating conditions of a cell dedicated to the industrial electrochemical ***pickling*** process. According to the logic of management of industrial plant, the total current is the "driving-control" variable. Then it is possible to evaluate:

- the potential distribution in the cell
- the current density distribution in the steel strip
- the geometric effect on the current density distribution
- the voltage-current characteristic curve.

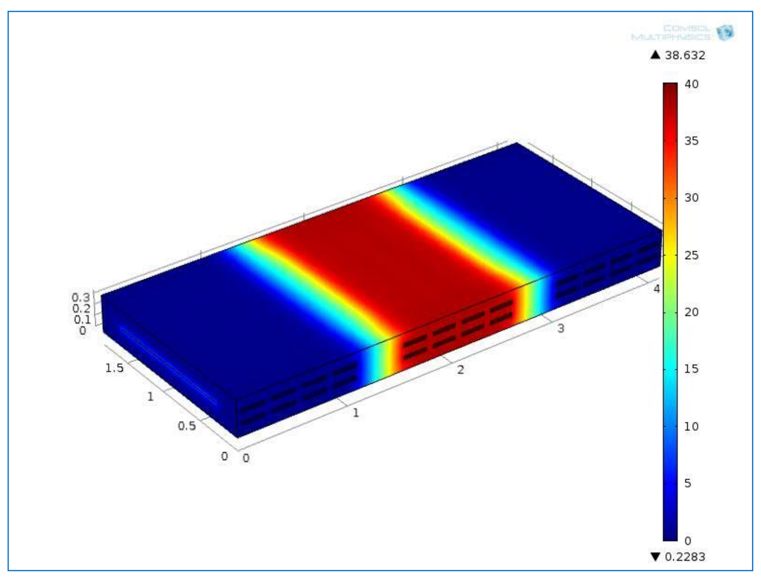

Figure 3. Initial potential distribution in the cell

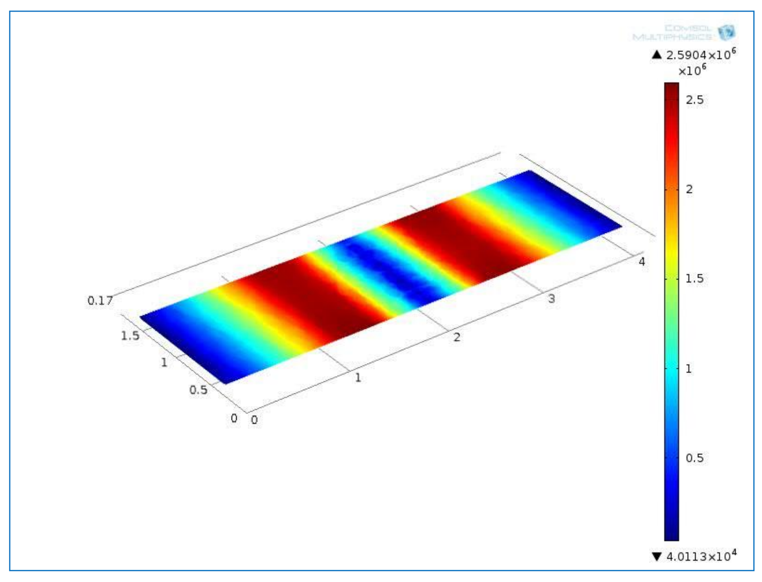

Figure 4. Steel strip current density distribution

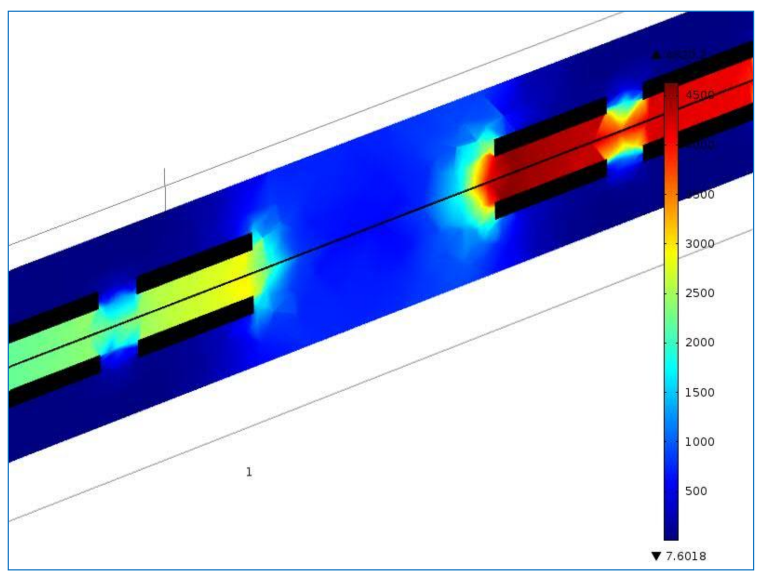

Figure 5. Geometry effect on the current density

I [A]	V [V]
6000	7.33
10000	10.38
14000	13.42

Table 1. Voltage-Current characteristic curve

Conclusions: The system is an excellent tool to use during feasibility study, plants analysis and design, testing and maintenance in the ***electrolytic pickling*** plant. The ***model*** results were compared and validated with real process data. Different ***pickling*** cells/plants will be ***simulated*** in the future. The system will be upgraded with additional physics (*e.g. electrolysis gas modelling), as well.*

References:

[1] U.Landau, "Determination of Laminar and Turbulent Mass Transport Rates in Flow Cells by the Limiting Current Technique", AIChE Symposium, Series 204, Vol.77,75-87. R.C. Alkire and T.Beek (1981)
[2] P.Cavallotti, L.Piracchini, "Manuale di Trattamenti e Finiture",Tecniche Nuove SpA, Milano(2003)
[3] N. Ipek ,M. Vynnycky and A. Cornell, "A Coupled Electrochemical and Hydrodynamical Two-Phase Model for the Electrolytic Pickling of Steel", Journal of The Electrochemical Society, 155 (4) P33-P43(2008)
[4] N. Ipek ,M. Vynnycky, "Supporting electrolyte asymptotics and the electrochemical pickling of steel", Proc. R. Soc. A 2009 465, 3771-3797 (2010)
[5] Comsol Multiphysics 4.3, "http://www.comsol.com/products/tutorials" (2012)