SIMULATION OF INDUSTRIAL ELECTROCHEMICAL PROCESSES

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1. Introduction

Although advanced numerical methods exist and have been applied with great success in a broad range of engineering domains (hydrodynamics, aerodynamics, structural mechanics, heat transfer, etc…), the use of these methods for electrochemical plating applications remains rather limited. One of the main reasons is the complexity of the physical, chemical and electrical phenomena governing electrochemical reactor behavior. In general, a complex interplay of the following phenomena takes place: electrochemical electrode kinetics, electrolyte hydrodynamics, ionic mass transport, gas evolution, and heat generation in the bulk and at the electrode-electrolyte interfaces.

From an engineering and industrial point of view however, the main focus is on the current density and layer thickness distribution, which principally depend upon the following phenomena:

- ohmic drop in the electrolyte solution;
- cathodic polarisation and plating efficiency;
- anodic polarisation;
- reactor configuration including anode positioning, screens and current thieves;
- workpiece shape and dimensions;
- selective insulation of workpiece surfaces;
- number and position of workpieces on a rack;
- total current injected and anode + workpiece contacting method.

The modeling approach that takes into account these phenomena is commonly denoted as the 'potential model'. In order to produce reliable simulation results, the physico-chemical input parameters (polarisation behavior, plating efficiency and electrolyte conductivity) need to be defined carefully for the electrolyte being used, at a given operating temperature.

The potential model (PM) is based on the assumption that the concentration gradients in the bulk of the electrolyte can be neglected, and that concentration gradients on the electrodes, due to the electrochemical reactions can be correctly obtained from lab scale experiments. From daily industrial practice it is known that one has to assure a sufficient agitation and refreshment of the electrolyte. One also should avoid gas accumulation and large temperature variations.

2. Simulation technology

All simulation based on the potential model shown here are performed using Elsyca PlatingMaster a commercial software tool developed by Elsyca based on technology of the Vrije Universiteit Brussel and the Von Karman Institute.

It contains a state of the art unstructured grid generation tool, which is able to take movements of bodies and or boundaries into account. This is achieved by a strong integration into the CAD kernel of Solidworks.

The Laplace equation governing the electrical potential is dicretized using the finite element method, using a Newton-Raphson approach to tackle the non-linear boundary conditions. The resulting system of equations is solved using SAMG.

The next sections show different industrial examples of modeling of electrodeposition processes.

The first three examples are based on the potential model:

1. Optimization of chromium plating on shaft of an oil pump
2. Simulation of copper plating on printed circuit boards
3. Simulation of nickel plating of door handles on a rack

The fourth and final case investigates the deposition of copper and tin on a lead frame in a reel-to-reel process, employing simulations based on the multi-ion model and shows the additional information that can be obtained from using the (much) more complex model.

3. Optimisation plating cell configuration for oil shaft

In this section, the potential model is used to design a dedicated reactor for the selective chromium plating of an oil pump shaft. The current density and layer thickness distribution are evaluated for each step in the reactor design process. In a first step, the workpiece is partly insulated (taped), in order to redirect the current to the surfaces that will be subject to wear and corrosion in the normal mechanical operation conditions of the pump. The blue areas in the left picture of figure 2 show the areas that need to be plated.

A tubular reactor with cylindrical anode mesh is used. In the next steps, the anodes are redesigned, abandoning the concept of a single faraway anode mesh for multiple anode