Application of COMSOL Multiphysics in the Simulation of Magnesium Refining and Production

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Abstract

Magnesium (Mg) is the least dense engineering material, with an excellent stiffness-to-weight ratio. The wide spread use of magnesium as a structural and functional material is driving the development of new cost effective and environmentally friendly methods of primary magnesium production and recycling. Recently, magnesium has been refined from the magnesium-aluminum(Al) alloy by a novel refining process: dissolving magnesium and its oxide into a molten CaF2-MgF2 flux, followed by argon-assisted evaporation of dissolved magnesium and subsequently condensing the magnesium vapor [1]. In addition to refining, the production of magnesium by direct electrolysis of its oxide using the solid oxide membrane (SOM) process has been shown to be effective on a laboratory scale [2], [3]. In both refining and production processes, argon gas was used to stir the flux in order to improve the transport of magnesium vapor out of the flux. In the SOM electrolysis process, the stirring of the flux also improves the diffusion and convection of magnesium cations to the cathode. In this study, the flow behavior of the molten flux and its effect on the mass transport of magnesium were investigated by COMSOL multiphysics modeling. For the refining process, the flow behavior of the molten flux is driven by the argon gas stirring. The bubbly flow mode was utilized to simulate the flow behavior of the molten flux driven by argon gas stirring. The bubbly flow mode tracks the average phase concentration rather than each bubble in detail, and is therefore well suited to model the flow of the molten flux [4]. The mass transport of magnesium in the molten flux was simulated using COMSOL 3.5a and 4.2a. The mass transfer was then coupled with bubbly flow to simulate the magnesium mass transport in the molten flux. Figure 1 shows the flow profile of the molten flux with the argon gas flow rate of 5 cc/min. Figure 2 shows the magnesium concentration distribution in the flux after 10 minutes. The magnesium transport mainly follows the circular motion of the molten flux. For the SOM electrolysis process, the stirring of the flux was modeled using the bubbly flow mode in COMSOL 3.5a. Figure 3 shows the flow profile of the molten flux with the argon gas flow rate of 100 cc/min. As the flux has a small solubility for magnesium, it is advantageous to perform SOM electrolysis at reduced pressure. The flow behavior of the molten flux under reduced pressure stirred by argon gas will be investigated. The modeling successfully simulates and predicts the flow behavior of the molten flux and also the magnesium transport during the refining process. It was observed that since the flux is highly viscous magnesium transport is significantly higher near the stirring tube during SOM electrolysis. As a result it has been determined that the highest current efficiencies in SOM process are obtained when the stirring tube is used as the cathode.

Reference

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[2] U. B. Pal and A. C. Powell, "The use of solid-oxide-membrane technology for electrometallurgy," Journal of the Minerals, Metals and Materials, vol. 59, no. 5, pp. 44-49, 2007.
[3] Ajay Krishnan et al., "Solid oxide membrane process for magnesium production directly from magnesium oxide," Metallurgical and Materials Transactions B, vol. 36, no. 4, pp. 463-473, 2005.
[4] "Flow in a Bubble Column Reactor," COMSOL Model Gallery, http://www.comsol.com/showroom/gallery/2160/. .

Figures used in the abstract

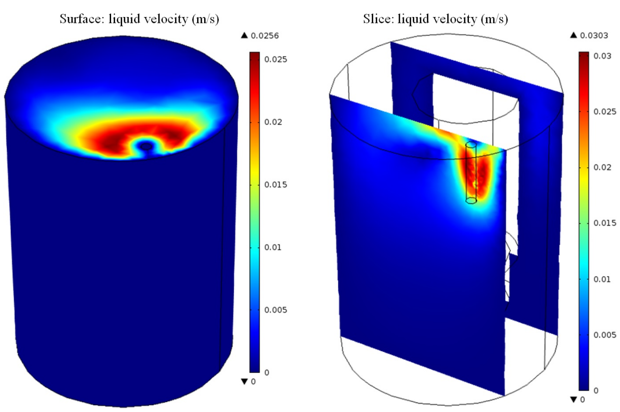

Figure 1: The molten flux flow profile (a) on the surface and (b) on the vertical slices during refining.

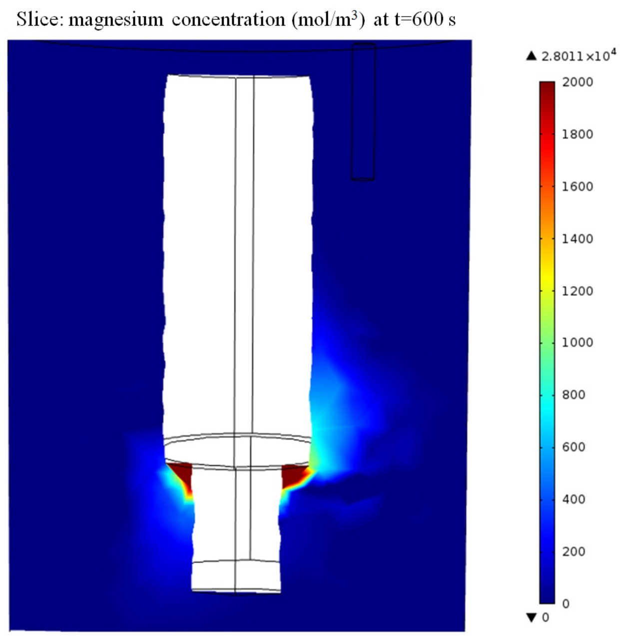

Figure 2: The magnesium distribution on the middle vertical slice after 10 minutes.

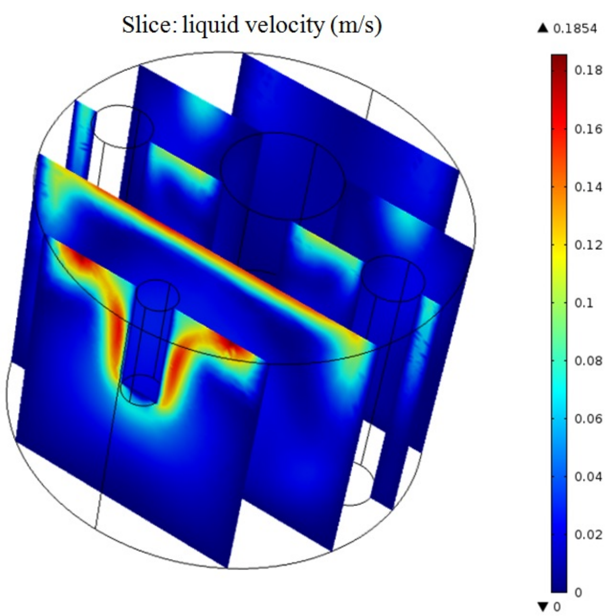

Figure 3: The molten flux flow profile on the vertical slices during SOM electrolysis.