Analysis of Turbulence of Aluminium and Molten Cryolite in the Aluminium Electrolysis Cell

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Abstract

The aluminium electrolysis cell used in Hall-Héroult process contains two stratified molten materials (aluminium and cryolite). These fluids are subjected to gravity, shear and high-intensity electromagnetic stresses. The two-fluid flow is important as it ensures distribution of alumina and heat throughout the cell; avoids depletion of reactants and local overheating. However, on the other hand, it is difficult to describe the flow of fluids at any time throughout the volume of the cell. The fluids are opaque, of high temperature and excessively aggressive and the cell is of complex geometry. It is very important to define the parameters that influence the flow of both fluids. In this article, a comparison is made to test different turbulence models to simulate the fluid flow in the cell. Different approaches using the Reynolds Averaged Navier-Stokes (RANS) and using the Large Eddy simulation (LES) method are compared. A simplified model of the electrolytic cell is considered for this purpose in order to investigate the transient fluctuations of the fluids velocity field in aluminium electrolysis cell.

Keywords: Aluminium electrolysis, two-phase flow, stratified fluids, magnetohydrodynamics of aluminium electrolysis cells, turbulence models.

1. Introduction

The Hall-Héroult process consists of the dissolution of alumina in an electrolytic bath. A high intensity electric current passes through the media resulting in the production of liquid aluminium which collects to the bottom of the cell. This reaction then produces a layer of molten aluminium at the bottom of cryolite bath at a temperature of around 960 °C [1]. On an industrial scale, this process is used in large cells, which can produce several tons of aluminium per day [2]. Liquid metal in the cell as well as the electrolytic bath where the different chemical reactions take place constitute a two-fluid system, in which, in addition to the chemical reactions, a certain number of thermo-solutal and magnetohydrodynamic phenomena occur [3]. The magnetic field is produced by the main current through which the cell is fed as well as the neighboring cells and magnetized steel parts [4]. The two fluids present in the cell are conductive to the electric current. Their movement within a magnetic field causes the induction of a non-negligible electric current and thus participates in the magnetism produced in and around the cell.

Fluid-flow of the bath is essential for the dispersion and the dissolution of the alumina and the distribution of the chemical species in the bath [4]. The chemical kinetics of the reactions is also influenced by the flow. The reaction rate is increased by the flow and the mixing caused by the velocity field achieves high reaction levels. The thermal balance of the cell is also influenced by the fluid flow [5]. However, the intensity of the flow must remain in a certain range to ensure stability of the cell. High velocity fields can alter the proper functioning in terms of safety and energy efficiency of the electrolysis process. The fluctuating instabilities of the fluids in the cell go along with the modification of the shape of the interface between the aluminium and the cryolitic bath. This deformation changes the local distance between the anodes and the surface of the aluminium layer and thus the current distribution [6]. This change in distribution will typically reduce the cells performance [7].

Controlling the flow of the fluids in the electrolysis cell is very important, although it is difficult to observe the different flow regimes during its operation. Thus, an approach is based on numerical simulations to predict the behavior of the two stratified fluids. The two fluids are subjected to a very high electrical current in the range of ~ 400 000 A and a magnetic field induced by the electric current of the range of 0.02 T [3].

Several studies are available in the literature on the flows in the electrolysis cell. Mathematical models are developed to investigate several impacts of velocity fields on its operation. The proposed models present flow simulations of the two fluids in three dimensions, where different physical phenomena are considered. Various works are carried out for the study of the generation of the bubbles in the electrolytic bath and the two-phase flow of the liquid and the gases [8-13]. Other studies have focused on the impact of flow on the dissolution of alumina in the bath [14]. The interface between the liquid aluminium and the electrolytic bath can be studied using 3D flow models [15, 16]. Simulations of the flow are also done in order to study and test the design of new cells [17-19] or for the study of its thermal balance [5, 20].

Mathematical modeling of 3D flows typically requires the use of turbulence models that take into account fluctuations in velocity over time and space. All the works cited above took into account a turbulence model in order to calculate the velocity field. However, very little information is available on the chosen model over another. In engineering, there are many different approaches for calculating turbulence for different applications [21]. The literature describes many case studies and validation scenarios of turbulence models in different applications, but very few are referring to the case of the electrolysis cell.

This work consists of the modeling of the flow of the fluids in the cell with a particular attention on the turbulence model to represent the velocity field fluctuations during electrolysis operations. The flow model is developed with the basic equations that govern the movement of fluids. Two approaches to represent turbulence are described and used in numerical simulations in order to compare the results. The two models to compare are Large Eddy Simulation (LES) and Reynolds Average Navier-Stokes (RANS). The comparison is made in order to see the viability of the two models to treat turbulence in the electrolysis cell. The hydrodynamic flow is modeled by using simplified conditions, but it is able to reproduce measured turbulence in the cell.

At the end, an attempt is made to compare the numerical results with some in-situ measurements made in an industrial electrolysis cell during its operation. The fluctuation of velocity over time was measured using the principle of drag force due to the flow of liquid aluminium around a body submerged in the aluminium layer.

2. Methods and Mathematical Model Description

The resolution of the equations governing the fluids is quite easily achievable according to numerical schemes available in the literature and such schemes are available in specialized CFD commercial codes. Large velocity fluctuations in the fluids are treated by the way of turbulence models in different industrial applications. Validation must be carried out in order to compare

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