Experimental Study and Visualization of the Thermal and Dissolution Flux Using Schlieren Methods to Improve the Understanding of the Kinetics of Alumina Dissolution in Cryolitic Melts

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Abstract

The purpose of this study is to investigate and describe the dissolution and heat transfer mechanisms of a cooled solid in a liquid medium to properly establish a clear parallel with the alumina dissolution in the aluminum electrolysis process.

The Schlieren method was used to visualize the dissolution kinetics of a solid in a liquid medium. Blocks of salt were cooled with liquid nitrogen and subsequently immersed in liquid water. The experimental method used allows for the visualization of either small or important changes in the density of the water due to different temperature or salt concentration. Thus, it is possible to visualize the movement of the water by filming the inhomogeneities generated by the thermal and dissolution process. In addition, a secondary camera also films the sample with a grid background to directly show the dissolution by another method. This secondary camera is also used to confirm the presence of disintegration in the sample.

The results of the observations clearly show that a downdraft appears as the salted water sinks to the bottom of the tank. Small disintegration of the salt block is also noticeable where these small chunks come off and sink to the bottom of the tank leaving a trail that clearly shows their dissolution. Similar observations are also discussed regarding the effect of the temperature differences in the system.

With an adequate representation of the kinetics considered, this study can henceforth be used to improve the understanding of the electrolysis process while also serve as a tool that validates some physical aspects implemented in mathematical models used to reproduce the dissolution of alumina in cryolitic bath.

Keywords: Alumina dissolution, Alumina injection, Schlieren imagery, Thermal and dissolution flux.

1. Introduction

The aluminum industry faces numerous challenges due to the aggressive nature of the process in a high-temperature molten salt cell. Among those challenges and goals, improving the quality and stability of the process while reducing the cost associated to the production of the aluminum are corner stones of the optimization. In order to improve the process, an accurate understanding of the alumina injection phenomenon is of upmost importance, for it'll allow for mitigating (or even preventing) the negative effects of alumina gradients which lead to the formation of alumina sludge (too high local Al_2O_3 concentration) or the onset of anode effects (too low local Al_2O_3 concentration). Therefore, an optimization of the alumina dissolution kinetics may lead to better energy efficiency and lower greenhouse gas emissions.

Following the injection of alumina in the electrolytic bath, the overall dissolution process is complex and can be divided into different mechanisms, as follows: formation, coalescence and disintegration of raft, and the actual dissolution of the alumina-cryolitic bath mixture. In this paper, a laboratory experiment in an analogous setup was designed in order to precisely visualize how this phenomenon takes place and improve of the understanding of each step. Schlieren imagery technique was used for this experiment, which allows the visualization of the density gradients in a fluid medium. In this context, it was used to show the natural convection of the fluid generated by such density gradients induced by differences in concentration or temperature.

For the simple reason that filming the injection of alumina directly into a cryolitic bath is extremely complicated due to the high temperature and the nature of the fluid, an analogy was introduced using a solid salt block as the solute and water as the solvent.

Respectively, the experiment was split into four phases in order to properly understand the mechanics of either individual or combined phenomena. A brief description of the experiments and the studied phenomena are described in Table 1.

Table 1. Main purpose of each essay.

Test	Purpose
Sample at room temperature, half submerged at the surface of the water	The main goal of this test is to see the movements of the fluid induced by the dissolution of the salt, placed on the surface of the water without interference from the thermally induced flow
Sample cooled with liquid nitrogen, half submerged at the surface of the water	The key focus of this study is on the effect of a frozen, solid layer which is created around the sample and melts over time
Sample cooled with liquid nitrogen, fully submerged at the bottom of the tank	The purpose of this test is to visualize the movements of the fluid induced by the dissolution of the salt when the sample is at the bottom of the tank, which reduces the span of the salt diffusion. As a result, the concentration in the vicinity of the sample increases more rapidly
Sample heated in an oven, fully submerged at the bottom of the tank	The interest is in the flow induced by both temperature dissolution, two effects which oppose each other. This case is used to visualize a behavior similar to what occurs in the cryolitic bath

2. Methodology

2.1. Presentation of the Schlieren Imagery Technique

Schlieren imagery is an optical technique which allows the visualization of refractive index gradients in a fluid due to the change of density. As the density changes in a transient manner, natural convection becomes present in the fluid and it allows the visualization of the flow.

A Schlieren imagery installation, shown in Figures 1 and 2 is composed of a light source with a very narrow point or line-like source in the focus of a parabolic mirror (or lens) that forms a

Practically, this observation highlights that dissolution, in itself, is acting twice as an inhibitor for the dissolution rate of an alumina raft floating on the surface of the cryolite. First, as the concentration increases, the alumina concentration gradient decreases, therefore reducing the driving force leading to alumina dissolution – a well-known phenomenon in the industry. Secondly, while the alumina raft is floating, the cryolitic bath richer in alumina will try to remain at the top surface of the electrolyte, thus in the vicinity of the raft, which will be detrimental to the dissolution rate. This is in strong contrast to the salt-water system, where the dissolution process actually helps to mix the fluid and favors the dissolution process.

This highlight the importance of the horizontal and vertical forced flow around the floating alumina raft, which will truly be the main driver in the dissolution rate as it will help prevent the local Al_2O_3 concentration of the cryolitic bath from reaching the saturation point by continuously renewing the bath in the vicinity of the raft.

4. Conclusion

Schlieren imagery was used to visualize the natural convection of water generated by differences of salt concentration and temperature. The images were used to visualize and analyze the morphology of the flow of water to make an analogy to the alumina-electrolytic bath system, in order to better understand and improve the electrolysis process.

The analogy drawn between the experiments and the industrial conditions is adequate to understand the key drivers and their importance in the process. Electrolytic bath containing higher alumina concentration will stagnate on the surface of the bath, reducing the rate of dissolution. The natural convection induced by the alumina concentration and the temperature are not strong drivers in favor of the alumina dissolution either. However, the natural convection is beneficial to reduce the duration of the frozen layer as well as the time between injection and the start of the dissolution process. This confirms that stirring the bath is important to help dissolve the alumina.

A major difference found between the experiments and the operation of an industrial electrolysis cell relates to the movement of the liquids. In our experiments, the water was still, while it is known that the electrolysis cells are rich in convection from different sources (thermal, MHD, bubble agitation, etc.). It was highlighted by the Schlieren imagery experiments that limited natural convection can be generated by the different phenomena considered in this study.

However, it is believed that the forced convection from said different sources is most probably the dominant factor affecting the dissolution in an electrolysis cell. Further studies to understand the magnitude of the importance of forced convection would be required to efficiently complete the transposition between the salt-water and the alumina-cryolitic bath systems.

5. References

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