# 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 collimated light beam. The light then passes through the zone that one seeks to study. Variations in refractive index caused by density gradients in the fluid distort the collimated light beam. The beam of light then passes through another parabolic mirror or lens to redirect the light to a focal point. In the color-Schlieren method, a stripe-filter composed of bands of different colors is placed at said focal point. Henceforth, the light which is originally deflected by the density gradients will be directed towards different colored stripes when it hits the filter. For this reason, the resulting image will have different gradients of color that are directly dependent on the density gradients in the area of study. The filter can be set horizontally or vertically, depending on the direction of the gradients that we want to observe. A camera, or white screen is then placed behind the filter to capture the image.

The higher the gradient of the refractive index, the more the light is deflected. The highest observable gradient is limited by the actual dimensions of the experimental setup given that, above a certain threshold, the light beam may not reach the final image if it was diverted outside the range of the second mirror, or outside the range of the filter itself. Under such scenario, the area of the image will appear as black.

Figures 1 and 2 illustrate, respectively, an actual image and a schematic of the Schlieren setup developed by the GRIPS (Research Group for Process and System Engineering) that was used in the current experiments. In both images, item (1) represents the light source, (2) and (3) the mirrors, (4) the observed environment, (5) the filter and (6) is the camera. The distance between the light (1) source and the mirror (2) is 155 cm.


**Figure 1. Experimental setup.**

The green line from Figure 2 represents a light ray which is not deflected, passing through the middle of the filter without being offset. The red dotted line represents a deflected beam of light, not passing through the center of the filter and, therefore, changing color but arriving at the same image point on the camera.

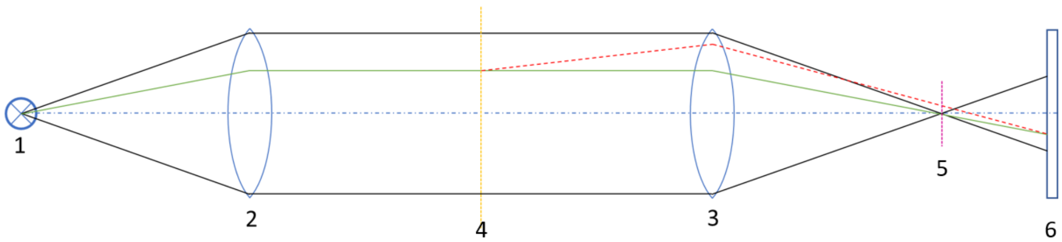


**Figure 2. Representation of the possible light paths during a Schlieren experiment.**

Figure 3 illustrates a type of filter used to modify the color of the light beam.

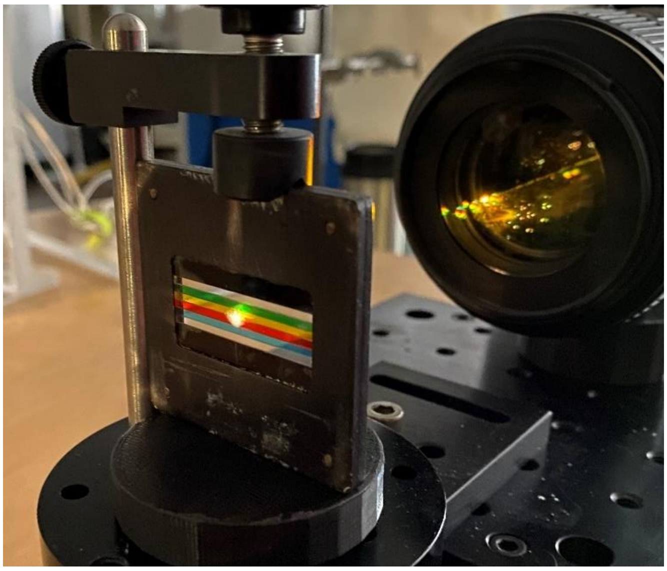

**Figure 3. Filter used during the Schlieren experiments (positioned horizontally) – refer to item (5) in both Figures 1 and 2.**

### 2.2. Specifics of the Experimental Setup

The samples used for the experiments are from Himalayan – also called pink – salt blocks. The original salt piece was cut first into cylinders of 47 mm in diameter and 27 mm in thickness, as shown on Figure 4. A hole of 4 mm diameter is also present in the middle of the sample for its support. A camera stand with rack and pinion was used to gently lower the samples into the water, in such a way that mechanical disturbances are minimized.

For some of the experiments, a small hole was made at half the radius and at half the height to insert a thermocouple in the sample. For experiments with cooled samples, the block is immersed directly in liquid nitrogen until the temperature of the thermocouple has stabilized around - 180 °C. For heated samples, they were put in an oven at 100 °C for several hours.

**Figure 4. Salt sample used in the analog system setup.**

## 2.3. Description of a Typical Schlieren Image

While not directly related to the process of aluminum electrolysis, Figure 5 is used to describe the typical observations that can be obtained with Schlieren imagery. It illustrates a previously heated metal cylinder placed in the ambient air to cool. The filter is placed vertically.

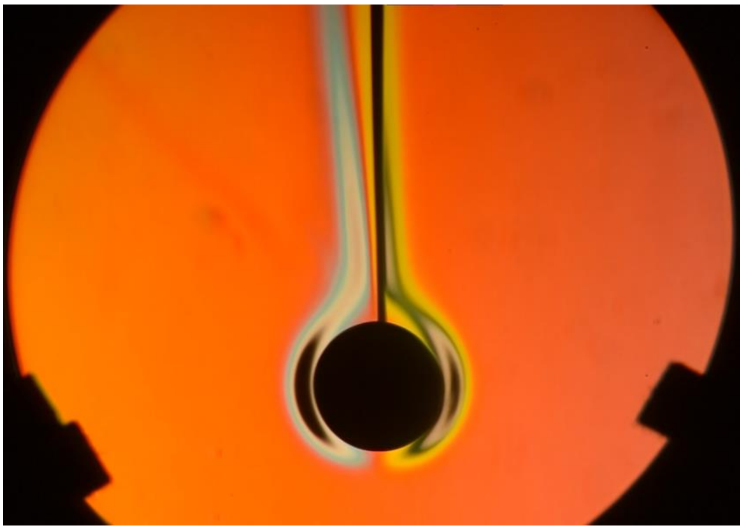

**Figure 5. Schlieren image of natural convection around a heated cylinder.**

The background in Figure 5 is red because the undeflected light beam passes through the red band of the filter. Given that the light doesn't pass through the metallic cylinder, it is depicted as a black disc. The vertical black band above the sample is the metal rod that supports it.

There is an updraft on each side of the cylinder. A given color is equivalent to a refractive index gradient and, consequently, to both a density and a temperature gradient. The flux is therefore a large band that includes the two colors and it is possible to estimate the temperature gradient using the width of the colored zone. The boundary layer on the two sides is also clearly visible. The black area in between the colored layers is due to an important refraction of the light as it reached the maximum deflection beyond the capability of the current experimental setup. The flow is similar, but the colors are different on each side because the light is reflected in opposite ways, so the rays do not arrive on the same band at the filter.

# 3. Results

## 3.1 Understanding the Behavior of Fluid Exposed to a Concentration Gradient

In the first experiment, a block of salt was placed on the surface of the water, half submerged. The block and the water are both at room temperature, around 20 °C. Therefore, any observation of natural convection is unrelated to temperature and exclusively associated to the concentration gradient. Special consideration was taken to make sure that no movement in the water was caused by temperature differences between the experimental setup and its surroundings.

Increasing the salt content in the water increases the density of the liquid. This variation in density generates a downward movement. The flow created is beneficial for the dissolution process because it allows water with a lower salt concentration to come in contact with the salt block.

Placing the sample at front of an inhomogeneous background, the refraction of light is visible to the naked eye, as illustrated on Figure 6. It is possible to observe that change caused by varying refraction index appears to widen the thickness of the black vertical lines observed directly underneath the block of salt.

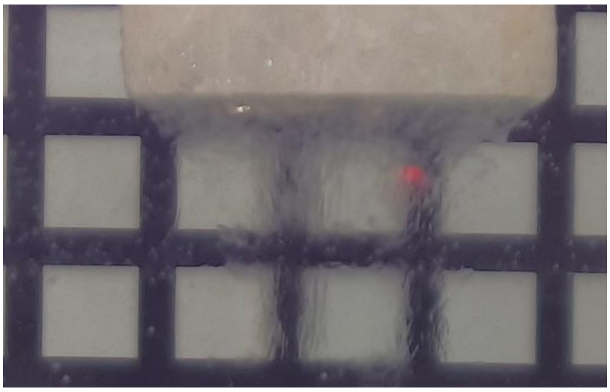

**Figure 6. Visual observation of the salt dissolution causing important refraction.**

By using color-Schlieren imagery, the perturbation becomes even more apparent. On Figure 7, the arrows represent the direction of flow. The refraction of the light is so pronounced that the deflected light beams do not reach the camera. For this reason, the flow caused by the concentration gradients tends to appear black like the salt block, making it difficult to see the dissolution at the edge of the sample.

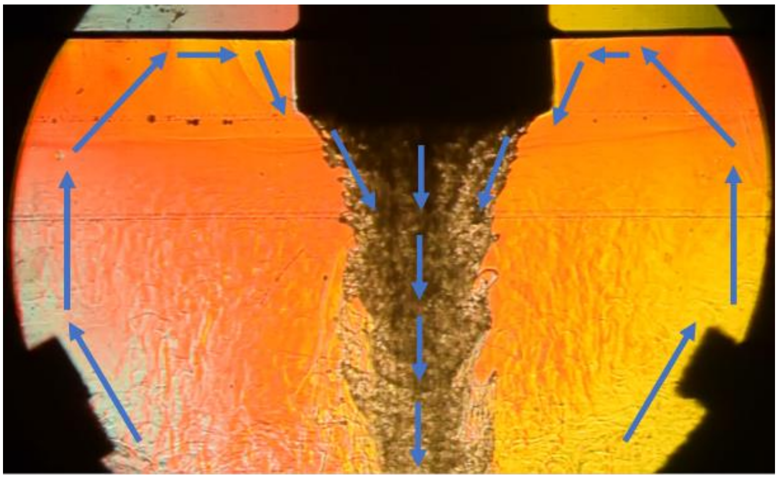

**Figure 7. Schlieren image of salt dissolution (sample at room temperature).**

However, by modifying the filter setup using knife-edge techniques, it is possible to add more flexibility to the detection range of the measurements. This method improves the visualization of the flow in the vicinity of the salt block and, consequently, of the salt dissolution boundary layer.

The distinction between the salt block and the liquid flow becomes clearly visible on the left side of Figure 8. The salt dissolution boundary layer is approximately 1.3 mm wide. It is possible to observe that this thin layer moves along the sample surface all the way to the bottom of the sample until it mixes with the bottom-part downward flow moving further from the sample and diffusing through the water.

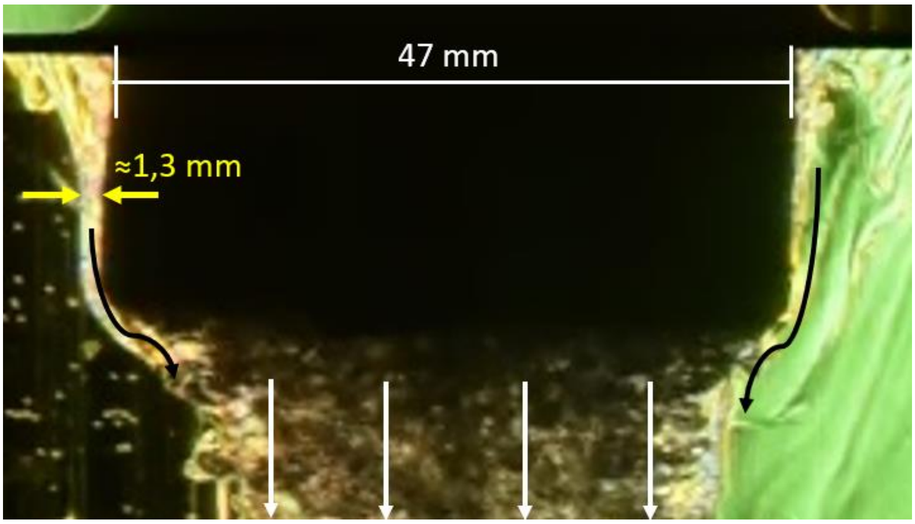


**Figure 8. Schlieren image of salt dissolution (boundary layer).**

During the experiments, it was possible to observe the disintegration of the samples on numerous occasions. In such cases, very small parts of the salt block broke off and quickly fell to the bottom, leaving a trail of salt water visible in the picture – see Figure 9. The trail disappeared quickly, remaining visible in the image for about three seconds.

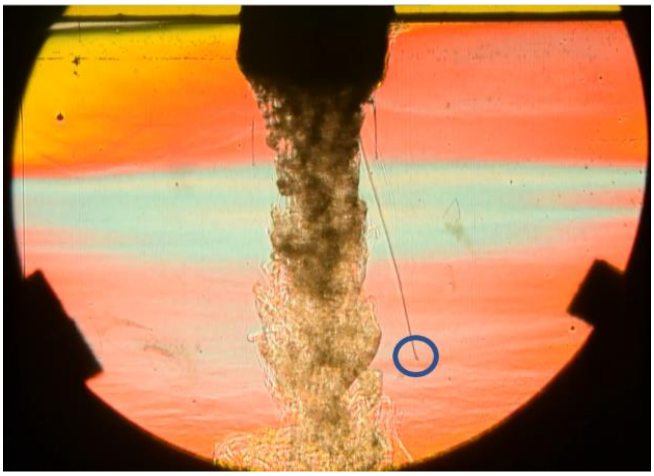

**Figure 9. Schlieren imagery during salt dissolution with disintegration of small particles.**

### 3.2 Understanding the Thermal Behavior and the Influence of a Frozen Layer

When injecting alumina into cryolitic bath, a raft is formed because the alumina is colder than the bath's solidification temperature. As such, a layer of solidified bath, *i.e.*, a raft, is formed and prevents the recently added $Al_2O_3$ from falling to the bottom of the tank. To reproduce this phenomenon, the salt block is cooled with liquid nitrogen to approximately - 180 °C, before being half immersed in water at a temperature of approximately 20 °C. As depicted in Figure 10, a layer of ice is created around the sample that hinders the dissolution, similarly to the phenomenon occurring in an alumina raft.

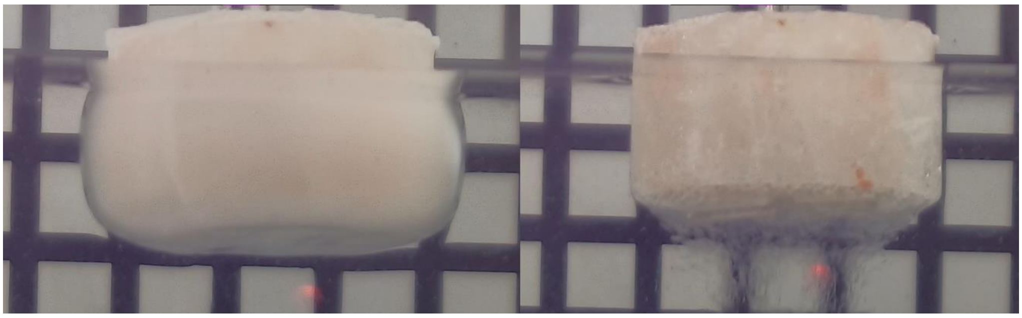

**Figure 10. Formation of the ice layer around a sample pre-cooled in liquid nitrogen. Left: ice layer surrounding cold sample. Right: salt dissolution after melting of ice layer (analogous to Figure 7).**

The layer of ice prevents the salt from dissolving in the water. The ice must first melt to allow the block to come into contact with liquid water and begin its dissolution. Once the block has warmed up and the layer of ice has disappeared, the dissolution conditions are similar to the previous case (Figure 7).

The temperature difference generates a flow with similar directions to the one generated by the dissolution of the salt. The flow is descending but the effect on the water density is less important as it barely deforms the visual observation of the black grid. Using schlieren imagery, a color gradient is visible in the liquid flow underneath the sample, highlighting that the refraction of light caused by the temperature gradient is weaker than the one caused by the dissolution.

Figure 11 shows the evolution of the heat and mass transfer over time. The top left image was taken at the instant of injection: the ice layer is still very thin because it has not had time to form and there is no dissolution. The top right image is taken when the layer of ice is the thickest and the heat flux is at its peak. The bottom left image shows the beginning of the dissolution, which starts from below because the sides are still frozen. In this case, we clearly see the mix of the two phenomena (colored flux caused by thermal and black flux caused by concentration). The last (bottom right) image is taken when the salt block and the water are at a uniform temperature. At this point, the dissolution is the same as in the previous case (Figure 7). The layer of ice therefore delays the onset of dissolution and generates natural convection caused by the heat flux in the liquid.

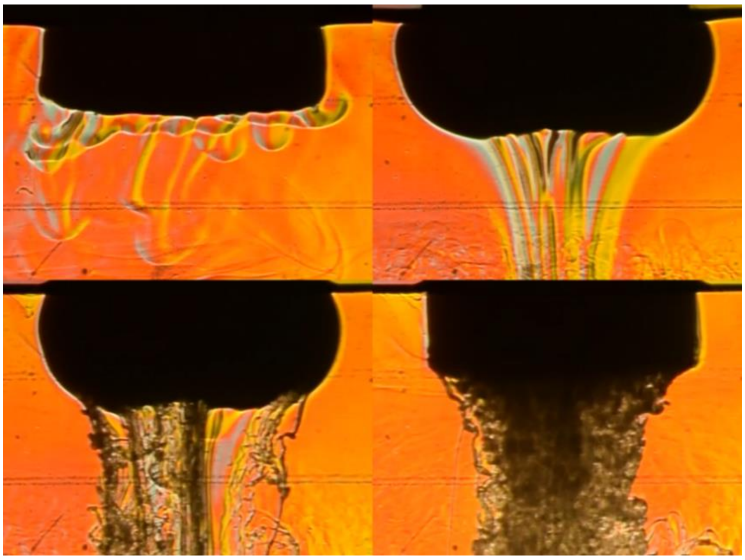

**Figure 11. Evolution of the mechanisms as the ice layer evolves around the sample. Top left: immediately after cooled sample injection, Top right: maximum ice thickness and maximum heat transfer, Bottom left: dissolution initiates from the bottom sample surface, Bottom right: salt dissolution after melting of ice layer (analogous to Figure 7).**

### 3.3 Influence of Natural Convection in the Fluid

In the third set of experiments, a cooled block of salt was quickly placed at the bottom of the tank, one side touching the bottom. As it is immersed, a layer of ice develops all around and prevents the start of dissolution. However, the thermal effect of the cold block creates a boundary layer at the bottom of the tank quite similar to the effect of concentration (not illustrated). However, this effect is only temporary as the block heats up. Once the ice has melted, dissolution begins and the conditions are quite similar to the start of the experiment, as seen on the left side of Figure 12. It reveals that the specific flow occurring during this experiment is contained within the boundary layer of the block and the bottom of the tank.

Nonetheless, the effect of the dissolution becomes increasingly visible over time as it creates different layers of density within the fluid, as shown on the right side of Figure 12. Additionally, mass comparisons before and after the test demonstrated that the block dissolves well in water but more slowly than when it is at the surface of the water. By comparing the mass of two blocks that have been fully immersed in the water for 10 minutes (*i.e.*, one at the bottom and one atop), the block on the top surface of the water dissolves about 20 % faster. Therefore, it indicates that without forced convection of the fluid to disperse the salt water, the flow generated under these conditions is restrained to the boundary layer from the sample, and a film layer at the bottom of the tank which hinders the dissolution rate of the sample.

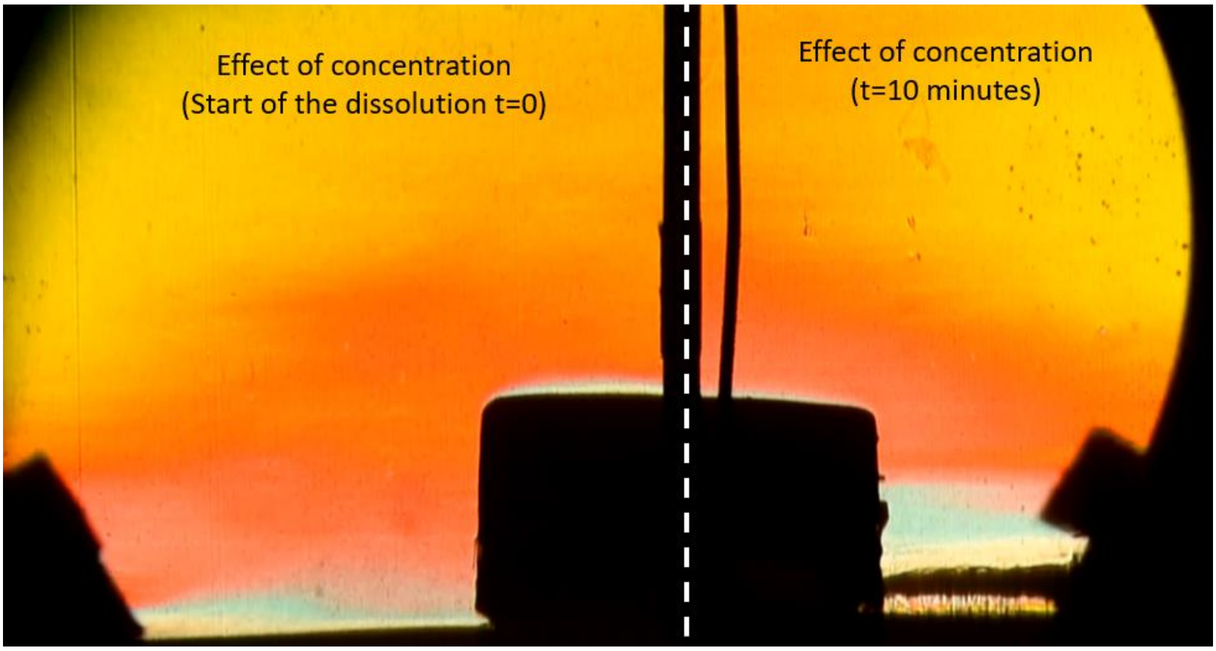


**Figure 12. Sample at the bottom of the tank. Left: at the start of the dissolution, Right: after 10 minutes of dissolution.**

### 3.4 Reproducing Visually the Dissolution of Alumina in a Cryolitic Bath

In the fourth experiment, the salt block is immersed in water after having been heated in an oven for a significant period of time at about 100 °C. During insertion, the sample reaches the bottom of the water tank with an internal temperature of 80 °C. This experiment was performed because the density of the cryolitic bath behave in clear opposition to the behavior of salt and water. As it increased in concentration, cryolitic bath decreases in density. Moreover, as the alumina is injected cooler than the bath, the forces created by the temperature difference generate a downward flow which ultimately generates two opposing flows in the alumina-cryolitic bath system. As described in Table 1, this scenario was used to reproduce opposite behavior with similitudes to what actually occurs in an electrolysis cell.

It was possible to reproduce these opposing flows in the salt water system by heating the salt sample, as described previously. In Figure 13, the image is reversed to help visualize the phenomenon in the same referential as if it was occurring in an electrolysis cell when the sample is floating at the upper surface of the cryolitic bath. The surface of the water is at the bottom of the image and the bottom of the tank is at the top.

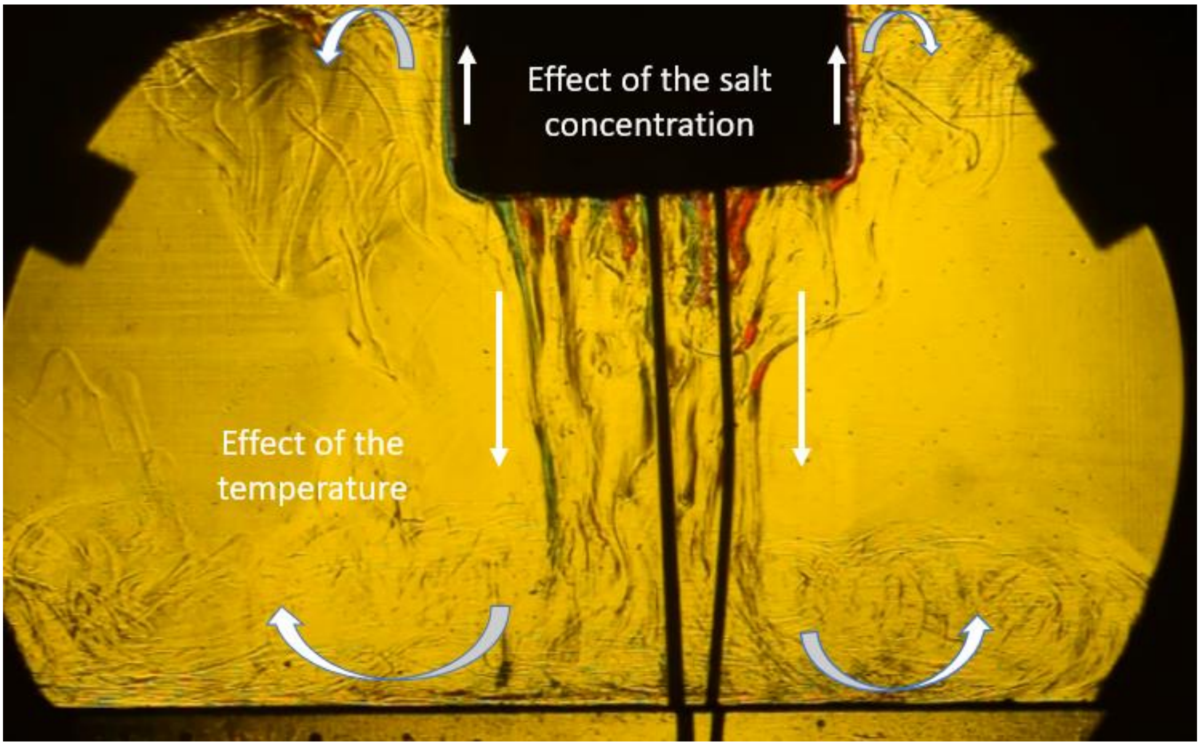


**Figure 13. Schlieren image reversed (heated sample placed at the bottom of the tank).**

As it was mentioned previously, in the salt-water system, the concentration has a more important impact on the density of the fluid than a change in temperature. In this particular case, as the forces generated will be in opposite directions, the movement of the fluid resulting from a change in its density will be directly dependent on sum of these opposing forces. Therefore, this indicates that any flow that is moving towards the bottom of Figure 13 can only carry a minimal “amount” of salt. Given that this “amount” is proportional to the temperature difference between the sample and the water, the quantity of salt dispersed in the tank towards the bottom is negligible and bound to reduce with time as the temperature reaches equilibrium.

This last case best illustrates what happens in an aluminum reduction pot. Although a reversed referential is necessary in the context of these experiment, it may be clearly seen that the dissolution and thermal-induced flows oppose each other, similar to what happens in actual smelting practice. In a real electrolysis cell, the alumina is floating on the top surface of the electrolyte. Therefore, the flow created by the dissolution rises and stagnates at the top surface while increasing the concentration in the vicinity of the alumina raft. However, the flow induced by the temperature difference will generate a downward flow towards the bath-metal interface.

## 3.5 Interpretation of the Results Applied for Aluminum Electrolysis

As we have seen, Schlieren imagery is a powerful tool to visualize the different effects induced by either thermal or concentration gradients. Prior to an in-depth comparison, the behavioral differences between the analogous experimental model and an electrolysis cell are summarized in Table 2.

**Table 2. Summary of the different considered parameters and the behavior of both salt-water and alumina-cryolitic bath systems.**

| Parameter | Behavior in salt-water system | Behavior in alumina-cryolitic bath system |
|---|---|---|
| Reduction of the local fluid temperature | Generates a downward flow proportional to the change in temperature | |
| Increase of the solute concentration in the fluid medium | Generates a downward flow proportional to the concentration gradient | Generates an upward flow proportional to the change in concentration |
| Influence of the frozen layer | Delays the start of dissolution | Delays the start of dissolution and prevents the alumina powder from spreading or falling to the bottom of the cell |
| Raft disintegration | Disintegration of very small fraction of the sample which contribute to the dissolution process | Disintegration of small-to-moderate fraction of the alumina rafts. Particles may contribute to the dissolution, or drop below the bath-metal interface |
| Forced convection in the fluid medium | None | Strong presence of external flow from difference sources (magnetohydrodynamics [MHD], process gas bubbles, alumina feedings, etc.) |

As it is shown in the above table, there are similarities and differences between the salt-water system and the alumina-cryolitic bath melts. However, it is possible to transpose the observations to the system of interest for aluminum electrolysis. It is important to take a step back and assess the information obtained from the experimental model and apply it properly in the field of aluminum electrolysis. To provide deeper insight while studying both systems, it is primordial to consider the respective level of magnitude with which the observed phenomena occur in the electrolysis cells, in comparison to what we have seen in the salt-water system.

To properly establish this comparison, it is necessary to define some hypotheses regarding the boundary conditions of the solid sample located in the liquid medium. The boundary conditions are considered because they compose the initial driving force of the mechanisms and represent the extremum values that should be reached under each respective scenario. The hypotheses used for the interpretation are listed below:

1) On concentration:
    a. Salt and water system: the concentration of salt in the water at the vicinity of the solid sample is similar to the saturation concentration of salt water at room temperature. According to [1], this concentration is approximately 25 wt%.
    b. $Al_2O_3$ and cryolitic bath system: the concentration of alumina in the cryolitic bath at the vicinity of the solid is equivalent to the saturation concentration of the bath for a respective set of conditions. According to Solheim [2], the saturation concentration is approximately 8.45 wt% at 965 °C, 5 wt% CaF2 and 11 wt% excess AlF3.
2) On temperature difference:
    a. Salt and water system:
        i. When cooled, the maximum temperature difference observed will be dependent on the minimal temperature of the water. As the initial water doesn't possess dissolved salt, its freezing temperature is 0 °C. It is unlikely that the water temperature drops much below that point as the

dissolution of the block will only start once the ice melted, which occurs once the block surface is at 0 °C;

ii. When pre-heated, the maximum temperature difference is dependent on the temperature of the sample just after insertion. This temperature is estimated to be 80 °C, creating a temperature difference of approximately 60 °C. However, this temperature difference is present only for a limited amount of time due to the transient nature of the phenomenon.

b. $Al_2O_3$ and cryolitic bath system:

i. When dissolution is not present in the sample, the considered liquidus temperature of the typical bath is 960 °C, generating only a 5 °C temperature difference;

ii. As the dissolution of alumina occurs, the liquidus temperature can decrease down to 933 °C, generating a temperature gradient of 32 °C.

### 3.5.1 Effect of the Frozen Layer and Raft Disintegration

In both systems, we can anticipate that a frozen layer will have similar overall effect, *i.e.*, that it will slow the dissolution process proportionally to the thickness of the layer formed, which is dependent on the initial temperature difference at immersion. However, it is important to note that fusion of frozen bath in the alumina-cryolitic bath system does not happen at a single temperature (*i.e.*, the eutectic point) such as it is with the ice-water fusion. The mechanics involved to anticipate the real start of the dissolution process from an alumina raft is far more complex and requires further studying, which cannot be accomplished with Schlieren imagery and the current setup.

However, the current experimental setup did illustrate that the fusion of the ice was occurring first in the bottom of the sample due to the natural (thermally induced) convection, which increases the flow in this area of the sample. It is probable that similar behavior may be also observed for an alumina raft, if experimental conditions were similar (*i.e.*, without forced convection).

In this particular study, pieces of the salt block would dislodge randomly as the dissolution process occurred. Similar observations were also performed in the alumina-cryolitic bath system [3]. We could confirm with the Schlieren imagery that disintegrated parts of the block contribute to the dissolution process even if the vertical falling rate is very rapid.

### 3.5.2 Effect of Temperature

The effect of temperature changes in the fluid medium will generate a downward flow for both systems if the sample temperature drops below the solvent temperature. However, the changes in fluid viscosity and density induced by this temperature change will dictate the flow of the resulting natural convection.

Assuming different changes in temperature for the salt-water system and the alumina-cryolitic bath system, it is possible to estimate the range of variation of these parameters as listed in the Table 3. It indicates that the variation of physical properties caused by the thermal variations are coherent between both systems, *i.e.*, that both the density and viscosity increase as each respective liquid reduces its own temperature. However, the thermal effect on the change in viscosity for the salt-water system is almost an order of magnitude more significant that for the molten bath. The density change resulting from temperature variations is quite similar in both cases.

**Table 3. Effect of local fluid temperature on the density and viscosity for water and cryolite.**

| **Salt-water system (without dissolution, 0 wt%)** | | | **Alumina-cryolitic bath system (without dissolution, 3 wt%)** | | |
|---|---|---|---|---|---|
| Temperature (°C) | Density [1] (kg/m$^3$) | Viscosity [4-5] (mPa s) | Temperature (°C) | Density [3] (kg/m$^3$) | Viscosity [6] (mPa s) |
| 0 | 999.8 | 1.447 | 960 | 2075 | 2.326 |
| 20 | 998.2 | 1.002 | 965 | 2070 | 2.276 |
| 80 | 971.8 | 0.355 | - | | |
| **Salt-water system (near saturation, 25 wt%)** | | | **Alumina-cryolitic bath system (near saturation, 8.45 wt%)** | | |
| Temperature (°C) | Density [1] (kg/m$^3$) | Viscosity [4-5] (mPa s) | Temperature (°C) | Density [3] (kg/m$^3$) | Viscosity [6] (mPa s) |
| 0 | 1225 | 2.801 | 933 | 2048 | 2.902 |
| 20 | 1199 | 1.95 | 965 | 2023 | 2.556 |
| 80 | 1160 | 0.707 | - | | |

From these observations, we can anticipate that the natural convection in cryolitic bath induced by a temperature difference is more important than what we observed in our analogous experimental system. The reasoning backing this statement is that the density change will drive the natural convection, without being restrained as much by a significant change in the viscosity of the fluid in the cryolite than in the salt-water system.

Practically, this indicates that an alumina aggregate floating in an electrolysis cell will generate natural convection proportional to the difference in temperature between the raft and the cryolite. Such a flow will improve the heat transfer in the vicinity of the raft while slightly improving its dissolution rate as it forces new bath to come in close contact with the alumina raft.

#### 3.5.3 Effect of Density

Schlieren imagery observations clearly demonstrated that variations of fluid density caused by differences in concentration are dominant over those induced by a temperature difference in the salt-water system. Nonetheless, it is once again necessary to properly compare the physical properties presented in Table 3 for both systems to efficiently transpose the results to the alumina-cryolitic bath system.

It is possible to observe that, in our system of interest (alumina-cryolitic bath), the cryolite will be moving upward as the local density is reduced from 2070 to 2023 kg/m$^3$ (or a reduction of 2.25 %). This is in clear opposition to the flow observed in the salt-water system, induced by an increase of almost 20 % of local fluid density from 998.2 to 1199 kg/m$^3$. It is extremely important to pinpoint the magnitude of the density difference between both systems as it evolves from the initial concentration to saturation.

In an isothermal system, the density change in the alumina-cryolitic bath system is only - 2.5 %, while the salt-water system sees a difference of 20 %. When this is combined to the effect of the temperature change the differences is even more important (- 1 % for the alumina-cryolitic bath system versus + 22.7 % for the salt-water system). Consequently, the natural convection generated by the mass transfer in the alumina-cryolitic bath system will not be as important as what was observed in the salt-water system, even if the viscous effect appears to be less restrictive for the fluid flow.

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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