Modelling and Design of a Forced Convection Network for Hall-Héroult Cells

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Abstract

Forced convection networks (FCN) are now commonly used in the aluminum reduction technology to increase the heat transfer from the sidewalls of the cells. This both cools down the potshell and increases the ledge thickness, potentially leading to additional amperage creep in the smelter. Proper design of a FCN requires a combination of modelling tools: a computational fluid dynamics (CFD) model to predict the air flow pattern and heat transfer coefficients on the shell, a thermal model to evaluate the ledge response inside the cell, and pressure loss calculations to design the pipe network. In this work, we present the approach that has been developed at Rio Tinto Aluminum to design and optimize the FCN configuration. The models are validated based on measurements taken in the potroom. Finally, a case study illustrates how the approach can be applied.

Keywords: Forced convection network; computational fluid dynamics; cell modelling.

1. Introduction

Most aluminum smelters are steadily increasing their line amperage. In order to maintain the cells' thermal balance, such increases often need to be accompanied by higher heat dissipation. This can be achieved in a variety of ways, for example by modifying the cathode design (eg. more conductive sidewalls) or operating parameters (eg. higher metal levels).

One of the most interesting options to increase heat dissipation is to install forced cooling around the cell. In 2001, Pechiney patented a forced convection network (FCN) [1]. Since then, most high productivity plants in Rio Tinto Aluminum (RTA) have been equipped with this type of system. A schematic representation is shown in Figure 1. FCNs are intended to cover the entire pot and to be operated continuously. They consist of a main pipe surrounding the cell, which is connected to a series of nozzles providing air cooling approximately at the level of the bath-metal interface. These systems are operated at relatively low pressures (a few kPa) to minimize energy requirements. The main pipe should be large enough to have small head losses compared to the nozzles in order to maintain as uniform a flow rate as possible around the pot.

A FCN also confers additional benefits beyond simply extracting heat: it cools down the sideshell, which could otherwise become too hot when highly conductive sidewalls are used; it can be designed to target known weak points with more intense cooling, thus improving cell robustness; and the flow rate can be adjusted as needed, for instance to offset seasonal variations or to compensate for periods at different intensities.

This paper aims to present how such systems are designed within RTA. We will begin by describing the modeling and calculations tools that have been developed, followed by a comparison with experiment measurements, and we will end with a case study showcasing how such tools can be applied in practice.

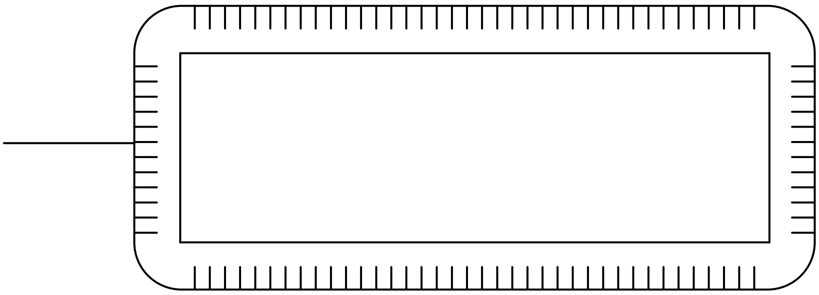

Figure 1. Forced convection network surrounding the electrolytic cell.

2. Modelling Approach

The three most important aspects to consider in the design of a FCN are the configuration of the nozzles, the impact on the thermal state of the cell, and the behavior of the pipe network. Our approach was to develop a separate model to study each of these components. This can lead to some back-and-forth, but offers the considerable advantage of making each model easy to manipulate and computationally inexpensive.

2.1 Nozzle configuration

Perhaps the most crucial step is to find a nozzle configuration that maximizes the heat transfer from the cell. Parameters of interest include the nozzle diameter, angle, distance from the shell, number per inter-cradle, as well as the position of the point of impact. Also relevant are the velocity and air temperature of the jet.

Several methods can be used. The simplest one is to rely on semi-empirical correlations. Jambunathan et al. [2] provides a good review of the available literature, and Martin [3] presents an easy-to-use correlation that predicts the heat transfer coefficients as a function of geometrical parameters and air flow rate. This approach can give a good first approximation of the performance that can be expected from the FCN. That being said, it’s also severely limited: it cannot account for several important aspects of the system, most notably the jet angle, the influence of the cradles or fins on the shell, the interactions between neighboring jets, the natural convection in the potroom, the large temperature gradient in the shell, and the exact nozzle geometry.

Another approach is to perform experimental parametric studies, either in a laboratory [4] or on a full-scale pot [5]. This is more reliable, but also time and resource intensive.

We have instead decided to rely on a computational fluid dynamics (CFD) model of the air jet and side shell. This allows us to account for all the relevant parameters, while still being able to rapidly test many different configurations. The basic geometry is shown in Figure 2. A half or a complete inter-cradle may be represented, depending on the exact configuration being studied. The model includes the nozzles, the air region surrounding the shell, as well as most of the cell’s lining. Both the air flow field and the conduction through the shell and lining material are explicitly calculated.

The air flow rate is imposed at the inlet of the nozzles. An additional inlet is present at the bottom of the air region, with an upward velocity corresponding to the natural convection measured in the potroom. The k-ε model of turbulence is used. Periodic boundary conditions are present on both sides of the inter-cradle. Radiation between all surfaces is included. On the solid side, the liquidus temperature is imposed on the ledge-liquid interface and on the top surface of the cathode. Adiabatic boundary conditions are used for all the other surfaces.

5. Further Developments

The tools presented thus far capture most of the physical phenomena relevant to the FCN. Still, there remains one important aspect that has not been considered. In an operating cell, the magnetically-induced metal flow leads to significant variation in the ledge thickness and shell temperature around the pot. Some zones are systematically warmer than others, and will be affected differently by the FCN.

To take this into account, the next step would therefore be to couple the previous calculations with our magneto-hydro-dynamic (MHD) model of the entire cell [6]. Such an approach would predict the FCN impact at every position around the pot, and might eventually lead to more sophisticated designs that aim to partially compensate for the disparity caused by the MHD forces.

6. Conclusion

A FCN is a technological option that can be used to increase cell intensity, robustness and operating range. To assist in its design, we have developed a combination of modelling and calculations tools, each focusing on a specific part of the system. The results of the models have been compared with experimental measurements, and show good agreement. We are now using this approach to optimize existing FCNs and design future ones.

7. References

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