**Light Metals 2015**
*Edited by: Margaret Hyland*
*TMS (The Minerals, Metals & Materials Society), 2015*

# ROTARY FLUX INJECTOR (RFI): RECENT DEVELOPMENT TOWARDS AN AUTONOMOUS TECHNOLOGY

Francis Breton[1], André Larouche[1], Peter Waite[1]
Pascal Côté[2]

[1]Rio Tinto Alcan, Arvida Research and Development Centre,
P.O. Box 1250, Jonquière, QC, G7S 4K8, Canada

[2] STAS Inc., 1846, rue Outardes
Chicoutimi, QC, G7H 1H1, Canada

Keywords: Metal treatment, automation, furnace preparation

## Abstract

Since its introduction to the aluminum industry in 1998, the Rotary Flux Injection technology has been implemented in cast houses worldwide for replacing chlorine for metal treatment in furnaces. Using a rotary impeller to inject salt into furnaces maximizes shearing and reduces the concentration of alkali/alkaline earth impurities as well as the non-metallic inclusion content in the melt. This equipment also provides efficient mixing of molten aluminum to eliminate thermal gradients and to improve the alloying ingredient dissolution and homogenization.

In an effort to reduce the overall furnace cycle time, improvements to the RFI technology have been implemented throughout the last decade. Recently a new rotor as been design using mathematical modeling, labs scale and plant trials in order to improve the alkali removal rate as well as the mixing of the molten metal. In order to capture the full potential of the RFI, the concept of autonomy is also introduced. This paper presents progress in improving the performance of the RFI and the concept of autonomy that will require minimum human intervention.

## Introduction

The RFI is a cast house technology with a proven capability to not only remove alkali/alkaline earth impurities effectively, but also to stir the metal and assist in alloying[1,2]. These two features of molten metal processing in the cast house furnace are essential for the production of value-added products.

In situations where a significant reduction of impurities such as alkali or alkaline earth removal is required, it is sometimes necessary to increase the duration of the RFI treatment. In addition, for highly charged alloys, longer manual stirring is occasionally done to ensure complete dissolution of the alloying elements (that may have accumulated at the bottom of the furnace). These additional actions result in a protracted batch preparation cycle time, which can become the process bottleneck, negatively affecting cast house productivity.

Considering that impurity levels and alloy compositions can vary from batch-to-batch, it can be appreciated that the fluxing and batching practices must be adapted to the specific furnace processing needs. As such, operator intervention and decision-making are often required to ensure that the batch is successfully completed in a timely fashion.

With the objective of reducing the furnace preparation cycle time, maximizing asset utilization and generally reducing process variation, a strategy of an autonomous RFI, combining performance improvements with intelligent process automation, has been instigated. This paper describes recent work done on this subject.

## The Rotary Flux Injector

Over the years, the RFI technology (Figure 1) has been continuously improved. Besides the progressive evolution related to process performance, such as impeller design and flux chemistry optimization, the equipment design has also evolved due to user's feedback and operational reviews. The RFI has reached a well-established maturity in terms of machine configurations, ease of operation, maintainability and, not least, safety. With over a hundred and thirty units operating throughout the world, the technology is fully proven and is now widely recognized in the industry as an efficient solution for molten metal treatment in the furnace.

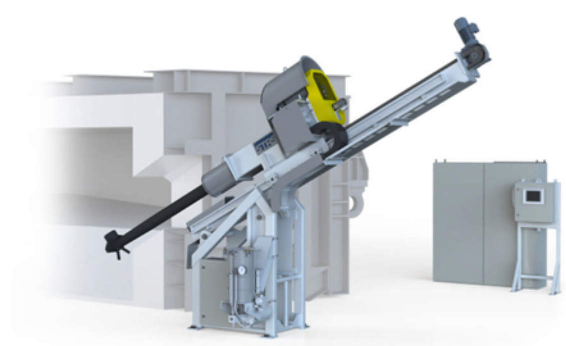


Figure 1: RFI in a typical configuration

However, to track and even anticipate industry requirements, a considerable development effort has been sustained in order to keep the technology at the cutting edge of the industry needs. This is especially true with respect to integrated controls and IT capabilities and keeping abreast of the rapid changes in this field. Today, RFIs integrate by design the latest in terms of safety integration, as well as up-to-date communication paths and networking capabilities. This opens the door to new opportunities and novel approaches for cast house integration, featuring links with Manufacturing Execution Systems (MES) and autonomous operation.

## Improved Fluxing and Homogenization Performance: The New Hybrid Rotor

The main objective of the RFI technology is to eliminate the alkali impurities from the molten aluminum. Moreover, many foundries also use the graphite rotor as a mechanical stirrer to break temperature gradients in the furnace and to aid in dissolution of the alloying ingredients. An improved alkali removal rate coupled with better mixing would significantly reduce the impact of RFI metal processing on the furnace cycle time.

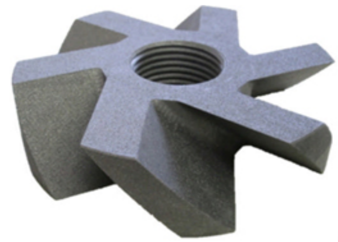
To reach the desired level of improvement , a two-stage approach was used. First a 3D steady-state model of the fluid flow induced by the RFI in a furnace was developed using Ansys/CFX software[3]. This model calculates the velocity, pressure and turbulence field in the vicinity of the blades and in the furnace. Assumption that the salt and inert gas do not play a role in the molten aluminum flow was used, avoiding the complexity and long simulation time associated with multi-phase flow. No removal kinetic sub-model was included in the CFD model. As the removal kinetic is complex to model, a lab-scaled furnace (scale: 1/20) was used to verify the relative metallurgical performance of the new impellers evolving from the 3D modeling.

The 3D fluid flow model was used to simulate the two impeller types currently used in the industry to study their mixing and shearing characteristics.

The pitched-blade impeller design presented in Figure 2a generates an axial metal flow, as shown in Figure 3a, that favors mixing. This type of rotor generates high metal velocity at the furnace floor and is very efficient to assist the dissolution of alloying ingredients such as iron and manganese that tend to accumulate on the furnace floor upon bulk or powder addition. Mechanical stirring with forklifts and cast iron blades is normally needed to completely dissolve these alloying ingredients. The use of this type of RFI impeller substantially limits or eliminates the need of subsequent mechanical stirring with forklifts.

The Super High Shear (SHS) impeller presented in Figure 3b generates a radial metal flow, as shown in Figure 3b, which favors the shearing of the injected gas and fluxing salts. The increased shearing effect improves the alkali removal rates, thus reducing the required fluxing period.

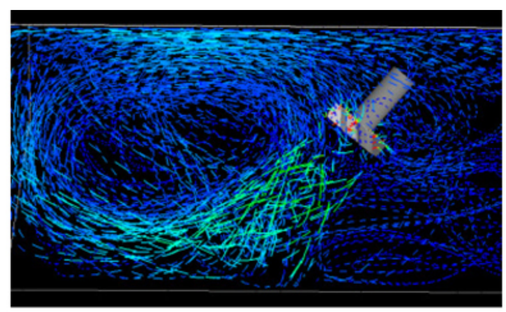
The challenge of improved RFI performance is to design an impeller that combines both higher mixing for dissolution of alloying ingredient and higher shearing rate for short fluxing duration. An innovative “Hybrid” rotor design is proposed in order to optimize the resulting metal flow patterns.



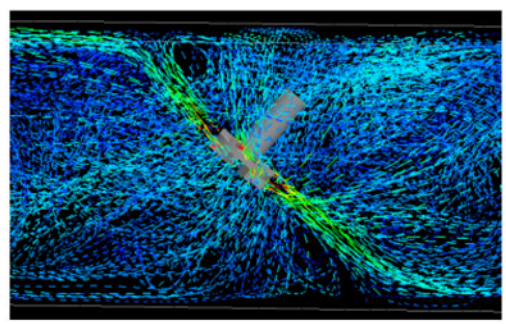
(a)

(b)

Figure 2 - RFI impeller designs :
a) Pitched-blade b) Super high shear



(a)



(b)

Figure 3 – Streamlines induced by RFI :
a) Pitched-blade axial flow b) Super high shear radial flow

The radial flow component is essential to maintain efficient gas / salt shearing and alkali removal rates, while an axial metal flow guarantees furnace mixing and satisfactory dissolution of the alloy ingredients. The hybrid rotor design results in an umbrella shaped flow, as illustrated in Figure 4. This flow geometry provides a radial metal flow component sufficient to force the injected gas and fluxing salt through the impeller blades, thus providing the required shearing action. Moreover, an axially oriented metal flow component is generated in a direction below and away from the impeller. The metal flow pattern illustrated in Figure 4 shows that the velocity at the bottom of the furnace is higher compared with super high shear. Upon contact with the furnace floor, the liquid aluminum will interact with any accumulated alloy ingredients, thus assisting their dissolution. In addition, the umbrella shaped metal flow reduces the surface turbulence of the melt, which can in-turn reduce dross generation when compared to the super high shear impeller.

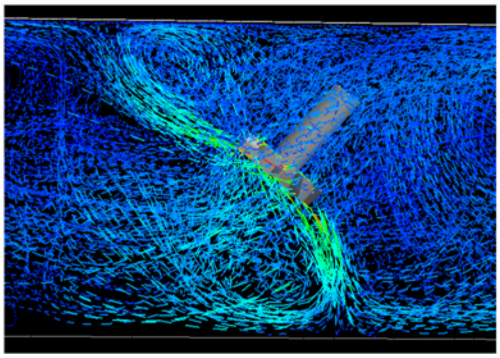


Figure 4: Streamlines induced by the hybrid rotor design

Industrial trials were carried out in three distinct cast houses to validate the computer simulation results. Horizontal disks for Optical Emission Spectroscopy (OES) analysis were taken before and during the RFI treatment, at regular intervals, to measure the alkali removal kinetics and the dissolution rates of the alloying ingredients. As the major alkali present in a primary metal is sodium, its removal kinetics was used as a measure of the shearing performance. Alloy dissolution and alloy recovery rates were used as a measure of the mixing parameter. In the same plant, 10 casts were performed with the SHS impeller and 14 casts, with the new hybrid impeller. The sodium removal kinetics is presented in Figure 5. A typical Mn dissolution curve for a 3XXX series alloy is presented in Figure 6.

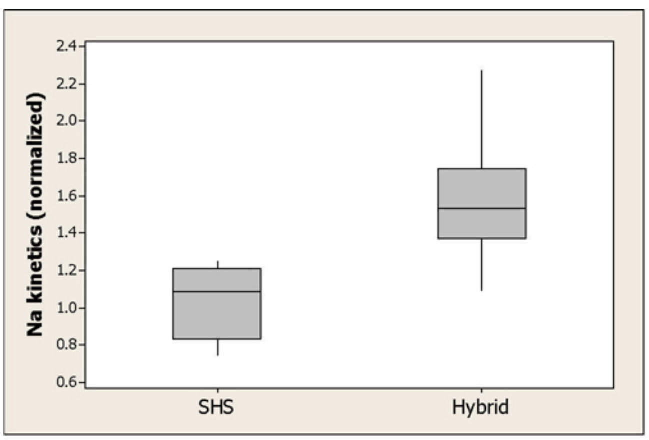



Figure 5: Na removal kinetics (normalized)

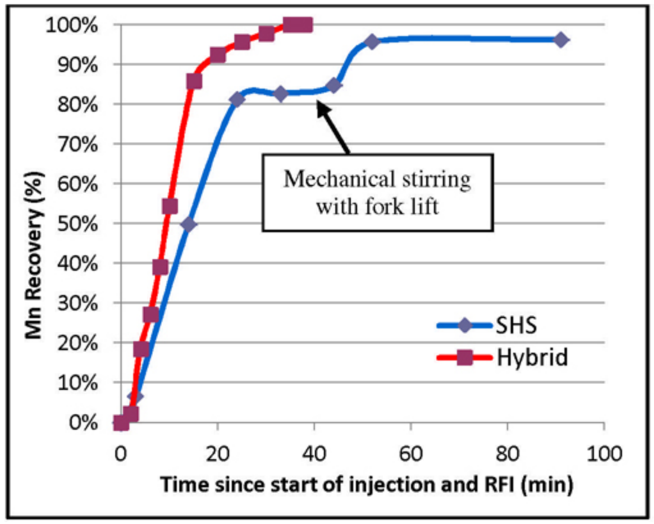



Figure 6: Mn dissolution kinetics

The new hybrid rotor improves the Na removal kinetics by 50%. This improvement allows a reduction of both the fluxing time and the flux salt consumption by 33%.

Figure 6 shows the Manganese recovery rate (actual composition/nominal composition) during the alloying addition and fluxing. As predicted by the simulation in Figure 4, due to the increased metal velocity at the furnace floor, the hybrid impeller improves the alloying ingredient dissolution. During the trials (red line), no additional mechanical stirring was needed with the hybrid impeller, while a mechanical stirring with a forklift was needed with the SHS impeller (blue line) to achieve a complete dissolution of the Mn.

This new patent-pending (US patent application no. 61/883,728) and design-patented (US design patent no. D713861) hybrid rotor significantly reduce the impact of alloying and fluxing on the overall furnace cycle time. In order to fully catch the potential of this improvement, the concept of RFI autonomy is introduced.

## Autonomous RFI

The RFI equipment can be used at multiple steps during the furnace preparation cycle. It has primarily been designed for metal fluxing for efficient alkali removal performance but, as presented in the previous sections, it is also very efficient to accelerate alloy preparation by assisting alloying ingredient dissolution.

In most cast houses, the RFI is started and stopped manually from a local control panel by the operator responsible of the furnace preparation.

Considering the multiple tasks that furnace operators have to perform during a furnace cycle, delay to operate the RFI at the required moment may happen, hence increasing the cycle time. The concept of autonomous RFI is to integrate the control of the operating sequence of the RFI in the Manufacturing Execution System (MES). The MES is used to control the start/stop of the RFI, as required by the cast house metal preparation sequence.

## Conclusion

The RFI is a well-established technology for efficient furnace metal preparation and treatment. The new hybrid rotor improves the performance for alloying ingredient dissolution and alkali removal. This improved performance was validated at industrial scale in several cast houses. Finally, the concept of autonomous RFI connected to the MES is introduced. These improvements can contribute to significant reduction of the furnace preparation cycle time thus improving the cast house productivity.

## Acknowledgments

The authors wish to thank Rio Tinto Alcan for permission to publish the present paper. Special thanks are given to Messrs. Joseph Langlais, Serge Munger, and other R&D technicians as well as plant personal at Rio Tinto Alcan, for their active contribution and feedback on this work.

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