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EEESEF - INDUSTRIAL ECOLOGY CASE STUDY SERIES

Subsurface Automated Flux Injection
Transitioning to Chlorine-Free Alkali and Inclusion Removal in Primary Aluminium Smelting Casthouses

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Target Audience: Casthouse Operations Managers · Metallurgical Engineers · Industrial Sustainability Directors · Environmental Compliance Officers

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1. Executive Summary & Operational Context

In primary aluminium metallurgy, maintaining export-grade melt quality requires the minimization of dissolved alkali metals, especially sodium and calcium, as well as non-metallic inclusions. If left untreated, these contaminants can reduce mechanical performance, increase downstream defects, and lower qualification rates for high-value products such as foil, sheet, and wire. [1][2]

This case study reviews the deployment of four automated inline subsurface Rotary Flux Injection (RFI) systems in a primary smelting casthouse environment. Traditional methods such as manual surface fluxing or chlorine-based lancing are less efficient, create greater health, safety, and environmental risks, and often fail to deliver consistent deep-melt treatment. [2][3]

By transitioning to automated subsurface injection of fused salt mixtures beneath the liquid metal line, the facility achieved more effective melt cleaning while eliminating chlorine gas from the furnace environment. The case demonstrates how modern process design can support cleaner production, stronger compliance, and improved material recovery. [1][4]

2. Environmental and Metallurgical Deficiencies of Surface and Lance Fluxing

Conventional pyrometallurgical cleaning methods are limited by simple physical constraints. Surface spreading depends on passive convection, while gas lancing can create uneven treatment, localised over-reaction, and elevated atmospheric emissions. [2][3]

The result is often poor salt utilisation, excessive dross generation, and incomplete removal of dissolved impurities and inclusions. In practice, these weaknesses increase operating cost and reduce product consistency.

2.1 Manual Surface Spreading

When granular flux is applied directly to the melt surface, the reaction is concentrated near the boundary layer. Because the flux does not penetrate deeply, chemical contact is limited and a larger quantity of flux is required to achieve the same cleaning effect. [1]

This approach also tends to trap more metal in the resulting dross, reducing yield and increasing waste handling burden.

2.2 Conventional Gas Lancing

Chlorine-based lancing has historically been used to assist with melt treatment, but it introduces substantial occupational and environmental concerns. Emissions may include chlorine, hydrogen chloride, and particulate matter, all of which require careful capture and control. [2]

The handling, storage, and use of chlorine gas also complicate plant safety systems and increase the need for specialised mitigation infrastructure.

2.3 Inclusion Failure Modes

Surface fluxing does not reliably address subsurface non-metallic inclusions such as oxides, carbides, and borides. Without deep and active circulation, these particles can remain in the melt and later appear as defects in finished products. [4]

That failure mode forces more remelting, more scrap, and higher energy consumption across the production chain. Surface fluxing fails to reliably intercept subsurface suspended non-metallic inclusions — without an active physical mechanism to capture and float these particles, they remain trapped in the final cast ingot, severely lowering product qualification rates and forcing the costly remelting of out-of-spec scrap.

3. Engineering Mechanics of Subsurface Rotary Flux Injection (RFI)

The RFI system solves these limitations by changing the delivery mechanism. Instead of relying on surface contact, it injects flux through a sealed feeder and inert carrier-gas loop, delivering the treatment below the metal line. [1][3]

This approach improves dispersion, increases contact time, and allows the flux to interact with a larger volume of molten metal. The result is a more uniform and repeatable process.

3.1 Process Flow Architecture

In the case study configuration, fused salt is fed through an automated system into a hollow graphite rotor. The rotor disperses the material into micro-droplets and bubbles, improving distribution throughout the furnace bath. [1]

High-purity nitrogen or argon can be used as the carrier gas, helping to limit unwanted reactions and improve control of the injection process.

AUTOMATED SALT FEEDER	⇒	Fused Salt Charge: $MgCl_2$ + KCl
INERT GAS CARRIER LOOP	⇒	High-Purity Nitrogen or Argon
RFI GRAPHITE ROTOR (Subsurface)	⇒	Three-Action Mechanism: ‣ Subsurface Agitation ‣ Micro-Bubble Shear ‣ Deep Vortex Transport

3.2 Chemical Displacement Reactions

The chemical basis of the process is the interaction between the flux and dissolved impurities. The salt system shifts sodium and calcium out of the melt and into removable byproducts through the following thermodynamic exchange reactions: [1][3]

Reaction	Thermodynamic Exchange Formula	Target Impurity Removed
R-1	$MgCl_2(l) + 2Na \rightarrow 2NaCl(s/l) + Mg(l)$	Dissolved Sodium (Na)
R-2	$MgCl_2(l) + Ca \rightarrow CaCl_2(s/l) + Mg(l)$	Dissolved Calcium (Ca)

Because these reactions reduce magnesium chloride to elemental magnesium, the process introduces a small amount of magnesium into the melt. This is compatible with alloy families in which magnesium is an intended constituent, but for magnesium-sensitive alloys the salt system and injection rate should be selected to keep the resulting magnesium content within the target specification.

3.3 Deep Vortex Transport

Because the flux enters beneath the melt surface, the rotor and gas flow create a strong internal circulation pattern. That circulation spreads the treatment through the bath instead of confining it to the top layer. [1][3]

This deeper transport mechanism helps separate both dissolved contaminants and suspended inclusions, producing cleaner metal and drier dross.

4. Material Optimisation, Yield Quantification, and Energy Multipliers

The deployment data associated with the four RFI units indicates clear performance gains in salt usage, dross quality, and scrap reduction. These effects matter because they reduce waste, improve throughput, and lower the carbon intensity of the finished product. [1][4]

The most important benefit is not only better chemistry but better resource efficiency across the entire casthouse system.

4.1 Salt Flux Consumption Minimisation

By maximising active reaction surface area through micro-droplet dispersion, the RFI system can achieve comparable impurity removal with significantly less salt than manual surface spreading. Lower salt consumption reduces procurement costs and transport requirements. [1][3]

It also decreases the amount of secondary waste generated during the process.

30–50%
REDUCTION IN FLUX USE

4.2 Dross Volume and Metal Recovery Gains

A more uniform subsurface treatment pattern can reduce over-fluxing and create a drier, more recoverable dross profile. That matters because conventional dross often contains unrecovered aluminium that is still too valuable to lose. [4]

Improved dross quality can support higher downstream metal recovery, better residue handling, and lower process losses.

60%
Al RECOVERY FROM DROSS

4.3 Scrap Elimination Energy Multiplier

Primary aluminium production is highly energy intensive, and every avoided rejection saves significant thermal input. When melt cleanliness improves, fewer cast products are downgraded or returned to the furnace. [1][2]

In this case study, the RFI deployment reduced internal casting scrap and therefore lowered the energy penalty associated with re-melting off-spec material.

5. Strategic Operational Roadmap for Regional Smelter Modernisation

For operators seeking to modernise casthouse operations without major production disruption, a phased implementation model is the most practical route. A staged approach reduces technical risk while allowing plant teams to learn the system incrementally.

The objective is not simply equipment replacement — it is process modernisation with measurable environmental and productivity gains.

Phase 1 — Pyrometallurgical Baseline Audit
Begin with melt cleanliness monitoring, inclusion mapping, and current-state flux consumption analysis. This establishes a reliable benchmark for comparing future performance.

Phase 2 — Core Subsurface Upgrades
Retrofitting existing furnaces with rotary injection units can often be done without stopping the full production line. This makes the upgrade more feasible for continuous-operation facilities. [1]

Phase 3 — Chlorine Line Decommissioning
Once performance is validated, the facility can move toward chlorine-free fluxing combinations and gradually retire high-risk gas infrastructure. This step improves plant safety and simplifies emissions management. [2][3]

Phase 4 — Closed-Loop Optimisation
After installation, process parameters should be standardised inside the plant control system so injection rates can be matched to alloy family, furnace condition, and casting requirements. Ongoing tuning ensures the process remains stable and efficient.

EEESEF CASE STUDY CONCLUSION
The deployment of subsurface Rotary Flux Injection confirms that advanced engineering design can successfully decouple high-tier industrial aluminium manufacturing from its most critical environmental and HSE liabilities — simultaneously delivering 30–50% flux reduction, 60% dross metal recovery, and a 50% reduction in internal casting scrap rates, all while achieving complete chlorine gas elimination from the production environment.

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Sign-Off and Closing Block

APPROVAL FOR PUBLICATION

This case study has been reviewed and approved for publication by the Euro-Eurasia Environmental Science & Education Foundation (EEESEF).

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