Investigation of a Novel Concept for Carbothermic Reduction of Alumina

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Many technological concepts for an alternative aluminium production process have been developed during the last century, because the still utilized Hall-Héroult process is one of the most energy and CO2 intensive industrial processes. However no basic approach was able to prevail in industrial scale. The most promising alternative process is still the carbothermic reduction of alumina, which has been investigated by several companies and researchers. The greatest challenges are the extensive aluminium volatilization occurring at high reaction temperatures, the complicated back-reaction and carbide formation mechanisms as well as critical reactor design issues.

The aim of this investigation is the optimization of a novel technology proposed for the high temperature carbothermic reduction of alumina in a labscale electric arc furnace (EAF) under protective gas over the gaseous phase.

Work done for Al-Generation over the gaseous phase can be divided into 5 sections:

- Rebuilding of the furnace
- Pre-service testing and start-up
- First experiments
- Chemical analysis of the products
- Optimization and modification of the furnace

The work on the optimization of the high temperature carbothermic reduction of alumina at the framework of the European Project "ENEXAL" had to face primarily 3 challenges regarding the development of the experimental setup:

i) The thermal conditions at the interior of the EAF.
ii) The isolation of the interior of the EAF from the environment.
iii) The flow conditions of the gases at the interior of the EAF.

All the aforementioned challenges were examined thoroughly and the optimum conditions were determined via experimental results. Analyzed samples of the condensed material have shown that it is possible to generate a condensate consisting of nearly pure aluminium, with small amounts of Al_2OC, Al_4C_3 and minor traces of Al_4O_4C.

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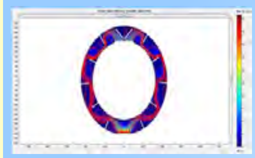
Motivation

- Conventional Hall-Héroult process is one of the most energy and CO_2 intensive processes
- No alternative aluminium production process was able to prevail in industrial scale
- The most promising alternative is the carbothermic reduction of alumina in an EAF, which is characterized by high flexibility and power density as well as providing the required process temperatures
- A thermodynamic calculation indicates that the aluminium comproportionation reaction is preventing the complete alumina reduction in the liquid phase and leading to vapour losses
  ($T = 2250°C$; $Al_2O_{3(l)} + 5Al_{(l)} = 3Al_2O_{(g)} + Al_{(g)}$)

→ Suppression of liquid metal formation → Suppression of $Al_2O_{(g)}$ formation → higher alumina reduction yields → processing above 2500 °C → decreasing oxygen content of the system

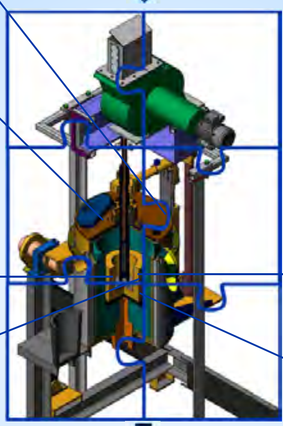
Al generation over the gaseous phase under protective gas

Process development



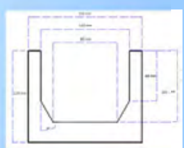
- New water cooled copper condenser
  - Design and calculation of the optimal parameter and conditions using CFD
  - Very fast cooling of the gaseous aluminium to avoid back reactions

- Feeding through rotary valve and hollow electrode



General Data:

- Power supply 25 kW
- Ar is used as protective gas
- Alumina + Carbon were pelletized in stoichiometric ratio ($Al_2O_3 + 3C$)
- Feeding speed was optimized
- Average duration of an experiment: 40 min preheating, 30 min experiment



- Optimization of the flow conditions of the gases at the interior of the EAF
  - 4 different gas inlets
  - Gas flow can be adjusted with the graphite base for rapid and homogeneous transition of the gaseous components to the condenser

- A special graphite felt for thermal isolation
  - Low thermal conductivity
  - High temperature resistance
  - High strength of shape
- Conical crucible design
  - Focusing to feed the initial material close to the arc

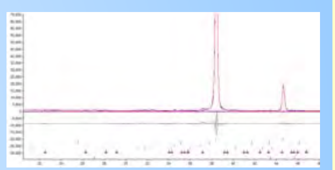
Results

Condensed Aluminium

- Fast and clean physical vapour deposition
- Successive optimization of the specific parts led to increasing Al contents in the condensed material

Progress in metal content

SEM Analysis



- After realization of the aforementioned processing and optimization steps: high amount of Al, no corundum, no graphite, no cubic Al_2O_3, minimal amounts of Al_2OC and Al_4C_3, traces of Al_4O_4C

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Successful generation of Al in a 25 kW lab-scale EAF ✓

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