

## BR05 - Iron Source from Bauxite Residues by Using Microwave Technology

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### Abstract

Bauxite residue (BR) is an iron-bearing resource with Fe<sub>2</sub>O<sub>3</sub> content higher than 40%, as in the case of MYTILINEOS Aluminium of Greece plant. Given that iron ores and commercial iron concentrates have significantly higher iron oxide contents, utilizing BR in the established iron producing technologies is non-competitive. Microwave roasting technology is a very promising technology to transform and enrich the iron in BR. A new microwave system (ALFER) was specifically developed to enrich and transform iron into competitive valuable products. A microwave BR roasting pilot for continuous operation was installed at MYTILINEOS in the frame of the RemovAl project. A monitoring and control system, including microwave power reflectometry, pyrometry and other complementary sensors, was used to control the parameters of the process. The parameters of mass flow, temperature of the reaction, residence time, power consumption, and gases liberated were evaluated to extract the different intermediated products. The level of enrichment of the different obtained intermediate iron products was also compared with the measured energy consumption and the estimated cost to evaluate the benefits of the process. Results showed that the technology is a promising solution for BR treatment for valorisation as an iron-bearing source.

**Keywords:** Bauxite residue, Iron extraction, microwave, energy efficiency, circular economy.

### 1. Introduction

The utilization of the microwave roasting process has emerged as a promising technology in mineral processing. Compared to conventional heat treatment methods, this approach offers distinct advantages, including significantly faster reaction times and potentially lower energy consumption [1]. These advantages are attributed to the interaction between the material and the electromagnetic field generated during the process.

Materials can be categorized into three groups based on their dielectric properties: absorbers, insulators, and conductors. Absorbers readily couple with microwave energy, leading to instant heat generation inside the material rather than heating the surface slowly and conducting it inward [2]. Thus, microwave heating presents promising opportunities for reducing energy consumption in intensive metallurgical processes [3].

Due to these significant advantages, several microwave-based processes have been developed in mineral processing and extractive metallurgy over the past few decades [1,4-6]. Microwave treatment has shown promise in recovering iron from bauxite residue (BR), which is the solid waste produced during alumina production from bauxite ores [7]. As iron comprises a substantial portion of BR, numerous studies have focused on iron recovery using pyrometallurgical processes.

These processes can be broadly categorized into two groups: solid-state reductive roasting followed by magnetic separation [8], and reductive smelting using various furnaces [9]. However, these approaches have their drawbacks, leading researchers to explore innovative methods for iron recovery from BR. Presently, the microwave process stands as an innovative and promising technology in the field of mineral processing.

The aim of this work is to present a new microwave system (ALFER) developed by CEINNMAT for the enrichment and transformation of iron as a competitive valuable product and the results obtained after its installation at the MYTILINEOS plant, in collaboration with NTUA, in the frame of the RemovAL project.

## 2. Procurement, Manufacturing and Plant Development

The procurement stage was performed on CEINNMAT premises. Some of the components were the following:

- Maritime container to install the plant.
- Feeding system
- Close circuit cooling system.
- Extraction gas circuit.
- Microwave system.

The electric cabinet was also designed and assembled with the fundamental elements, such as energy monitoring of plant and microwave, general switch, PLC and other ancillary elements (Figure 1).



**Figure 1. Electrical cabinet.**

A gas circuit chamber was also designed and instructed, using two versions for different conditions, assuring a controlled atmosphere during the pilot trials. The pilot plant was built in a single 20-foot-high-cube container of maritime standard size, enabling pilot

mobility and easy sea transport from Spain to Greece. The pilot was constructed with three sub-spaces: operation, electrical components, and supplementary components, with the feeder at the container's top. The container was modified per precise engineering while preserving maritime certification. (Figure 2).



**Figure 2. High-cube container during the adaptation process for installing the Microwave Pilot Plant.**

The installation covers the following systems and subsystems:

- Feeding system: Feeder, dosser elements, connections, and level sensing.
- Off-gas circuit: expansion chamber, flow regulation, piping, sensing, and gas filtering.
- Water cooling circuit: chiller, water piping, sensors of temperature in several points, pressure and flow rate.
- Microwave system: generator, microwave reactor, waveguides, sensors.
- Electrical supply, for the general system.
- Structural elements and envelope of some elements, including the microwave kiln.
- Crane: crane chain to move heavy elements in the operation place

After the installation of components, it was tested, validating the functionality, and verifying the parameters of calibration of each one, such as water pressure, airflow, air aspiration, rotary parameters, microwave parameters, safety, and security indicators. After validation, the packaging and lashing of all the components were done, and the container was fixed and shipped to MYTILINEOS, Aluminium of Greece plant.

### **3. Demo Site at MYTILINEOS: Commissioning and Operation**

The pilot plant was placed on site and unpackaged. The electrical supply was connected to the electrical cabinet, and the compressed air was to the air circuit. No other supply was required for the operation of the pilot plant.

All the components were verified, and the functionality was validated. Once the plant was validated and fully operative, the control room was installed next to the container. This allows it to work in normal conditions with the independence of the climatic conditions in the external site (Figure 3).



Figure 3. Installed Microwave Pilot Plant in MYTILINEOS.

The ALFER system is a microwave rotary kiln in continuous flow with flow rate flexibility up to 40 kg/h. When the process is in a steady state, samples from the output are taken and stored to assess the quality of the product at the current conditions. All the generated data from the process was stored for later analysis, but also data were provided during operation in the control panel to monitor in real-time the activities of the system (Figure 4).

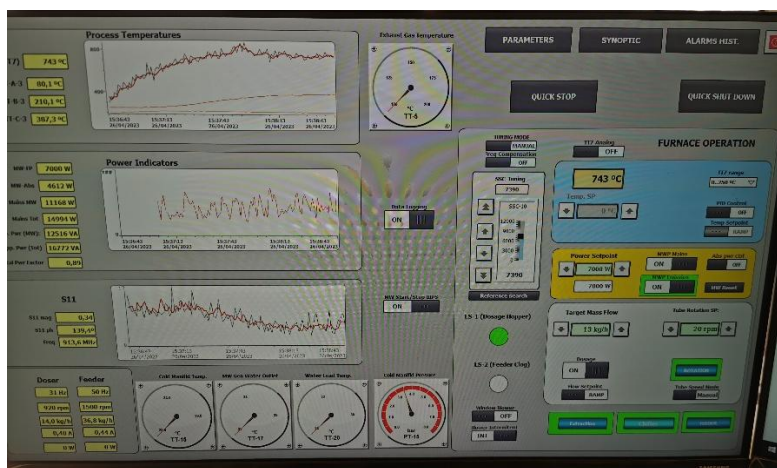


Figure 4. Real-Time parameters window.

The following data are stored during a process record:

- Microwave power parameters.
- Power consumption of the plant.
- Power consumption of key components.
- Temperature of the processed material and temperature of the system
- Mass flow rate parameters.

Other values are calculated based on the previous data:

- Microwave energy consumption per processed mass (kWh/t)
- Total energy consumption per processed mass (kWh/t)
- Effective energy absorbed by the material (kWh/t)
- Total Microwave performance (% from the ratio, energy absorption/microwave consumption)
- Global performance (% from the ratio, energy absorption / total consumption)

In addition, other auxiliary monitoring values were also recorded to check the system performance:

- Water cooling temperature
- Tube hot end support temperature – output bearing thermocouple temperature.

#### 4. Pilot Trials

The trials were carried out by CEINNMAT with the assistance of MYTILINEOS, providing support in all the requirements in the infrastructure and raw materials, with the collaboration of NTUA.

Bauxite residue (BR), metallurgical coke and sodium carbonate were available for the tests. Several combinations were done during the trials. (Table 1)

**Table 1. Tests were performed, and main mineral phases were obtained.**

Test Code	Description	Iron phases
BR wet	Nuggets and sticky	Some magnetite
BR dry	No agglomeration, critical stability	Some magnetite
BR: C low	No agglomeration, poor stability	Magnetite rich
BR: C	Nuggets	
BR:C: N.411 Wet	Nugget formation. The sample started with high moisture content.	
BR:C: N.411 Dry	Nugget formation. Sample pre-dried with the microwave.	Iron and wüstite
BR: C.73	Partial agglomeration creating nuggets	Iron and wüstite
BR:C.11.a	Formation of granulation with good control of the process	Wüstite and iron
BR:C.11.b	Formation of granulation and pellets	Iron, some wüstite

Trials were performed at 15 kg/h for comparison, modifying other parameters, i.e. microwave power and airflow, accordingly. Processing parameters were recorded in the database by the control software and stored. Samples were collected at different temperatures to identify the iron transformation. Samples collected were analyzed by CEINNMAT for control of the process and NTUA for more detailed identification. (Figure 5). Also, some magnetic separations tests were performed in NTUA in order to evaluate the iron recovery from this process.



**Figure 5. The material in the rotary tube during operation and produced material.**

5. Results

Figure 6 depicts the transformation of the iron oxides to metallic iron as the temperature increases during the pilot trials. Several levels of intensification of the process from 850 °C (i1 of Figure 6) reaching 1100 °C (i8 of Figure 6).

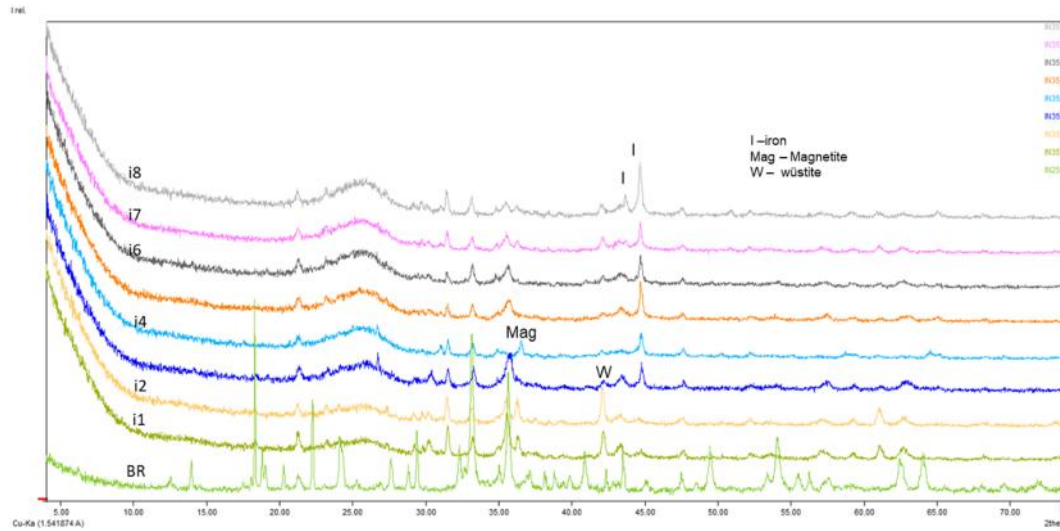


Figure 6. X-ray diffraction of the sequence of temperature tests with eight levels of intensification.

Considering the energy efficiency of the system, it varied from 600 kWh/t when magnetite was the final product to 1400 kWh/t when granulation containing the metallic iron was formed. Following the microwave reduction process, on two of the sinters, magnetic separations tests were performed: the first one was a mixture of BR and Metallurgical coke and the second one had the prior ingredients as well as Na<sub>2</sub>CO<sub>3</sub>. As can be seen in the following XRD mineralogical characterizations (Figure 7), in the first sinter, the transformation of the iron oxides to metallic iron is obvious, with some unreduced oxides remaining. Also, the formation of Hercynite (FeAl<sub>2</sub>O<sub>4</sub>) is apparent and predicted as no fluxes were used to prevent its formation [10]. On the second sinter, although metallic iron has not been formed due to the lower temperature achieved and the lower retention time, because of the use of Na<sub>2</sub>CO<sub>3</sub> as a flux, the formation of Hercynite was avoided and aluminium formed a Sodium aluminium silicate instead.

Table 2 presents the chemical analysis of the two sinters. There is unreacted metallurgical coke in both sinters, which was expected since there was an excess of it during the mixing.

Table 2. Chemical Analysis of Sintors

MeOx	BR+MC	BR+MC+ Na <sub>2</sub> CO <sub>3</sub>
Fe <sub>2</sub> O <sub>3</sub>	37.51	37.48
Al <sub>2</sub> O <sub>3</sub>	16.32	15.32
CaO	10.53	9.25
TiO <sub>2</sub>	4.41	4.38
SiO <sub>2</sub>	13.46	8.89
Na <sub>2</sub> O	3.27	12.33
C	10.26	8.32

During the magnetic separation experiments, an iron recovery of around 82% was achieved, for the first sinter (BR and Metallurgical coke) and around 80% recovery for the second sinter (BR, Metallurgical coke and Na<sub>2</sub>CO<sub>3</sub>), as seen in Figure 8. The difference can be attributed to the

formation of metallic iron on the 1<sup>st</sup> sinter. Concerning the concentration of Fe on the magnetic concentrate, the BR+coke mix contains less iron than the second one due to the presence of Hercynite.

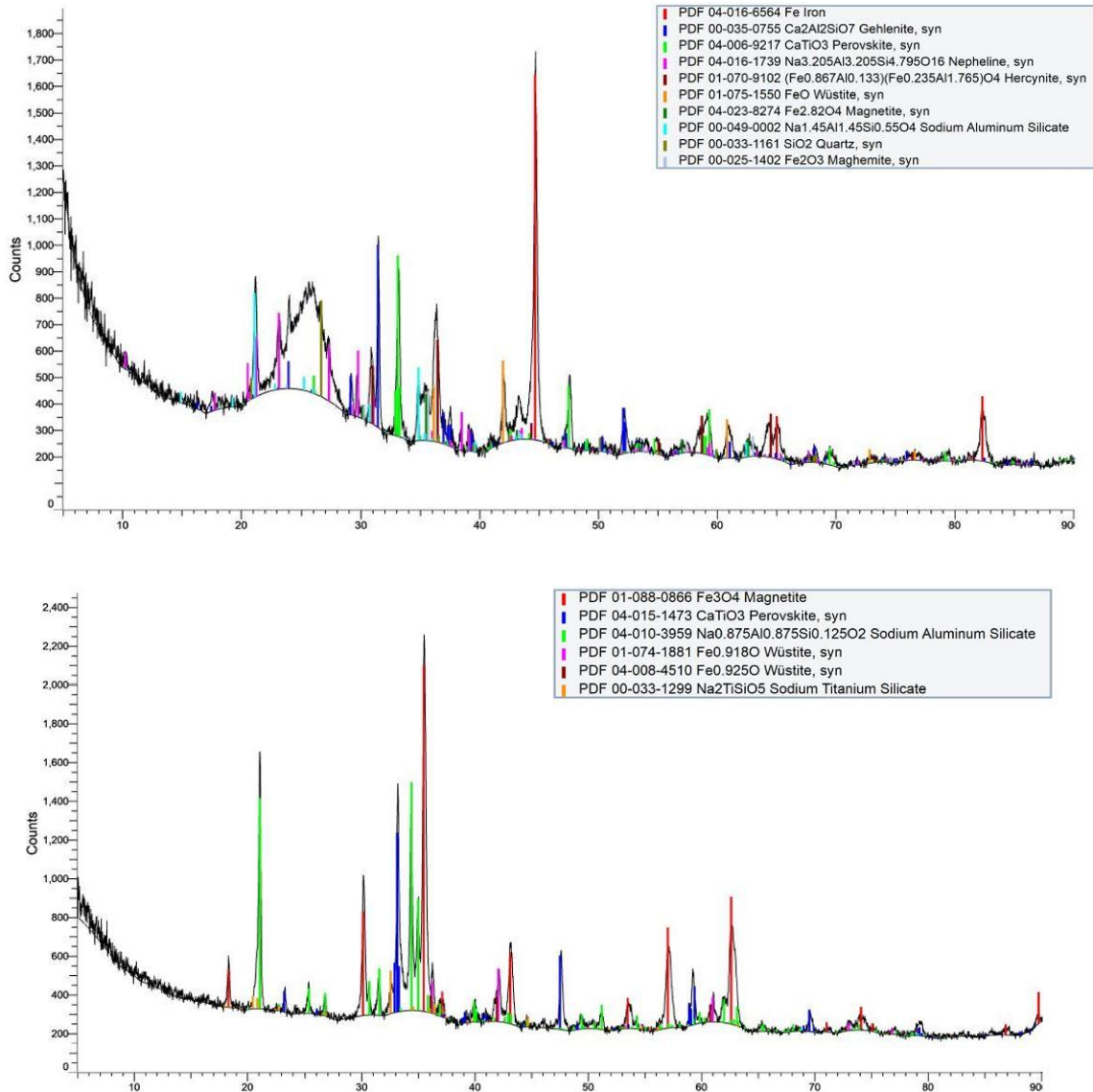
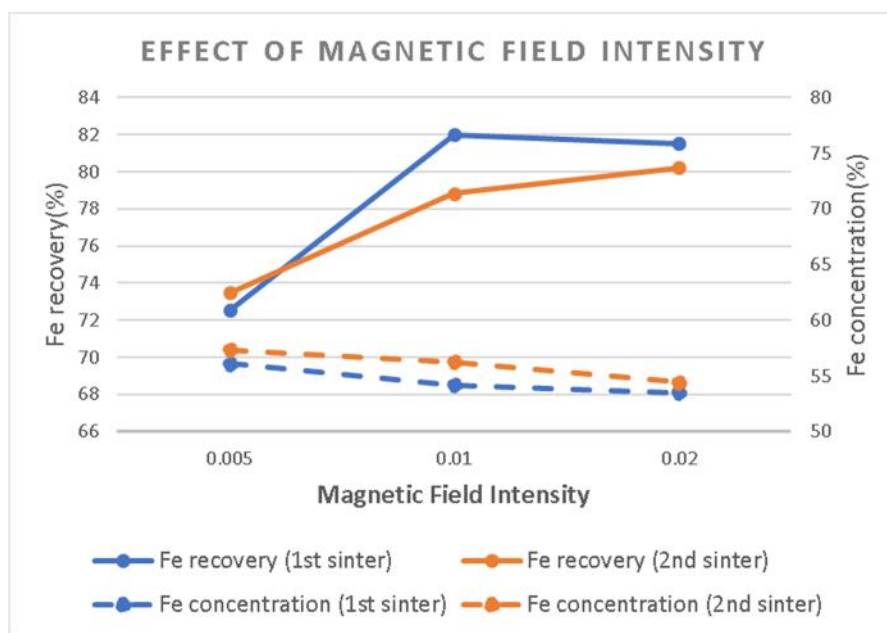


Figure 7. Mineralogical characterization of sinters, top: BR+M.C.; bottom: BR+MC+ Na<sub>2</sub>CO<sub>3</sub>

## 6. Conclusions

During this study, a Demo plant was manufactured by CEINNMAT and installed in MYTILINEOS in the frame of RemovAL project, performing pilot trials of BR microwave reduction through a continuous flow rotary kiln. The plant, with a capacity of processing 40 kg/h, was operating for the tests at 15 kg/h. The process using the microwave ALFER system for iron extraction from BR was validated and showed a robust process with the capacity to produce reduced iron forms, from magnetite to metallic iron. The sinters produced from the microwave reductive process were magnetically separated with an optimal Fe recovery of 82%. The capacity for improvement at the pilot level is significantly high, considering the optimization of each process.



**Figure 8. Magnetic separation of sinters.**

## 7. Acknowledgements

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