Improving the dry magnetic separation of BOF-slag by applying an innovative pre-treatment process

Iron recovery, Slow-Cooling, Crystallite Structure, Microwave-Treatment, Intergranular Cracks, Grinding

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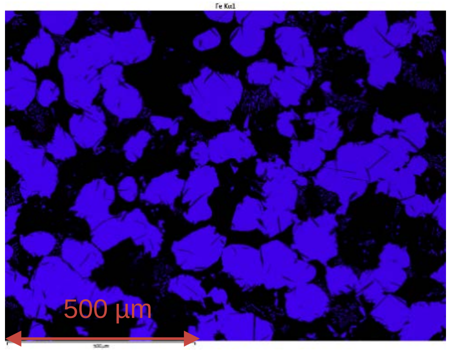
Motivation and Process Concept

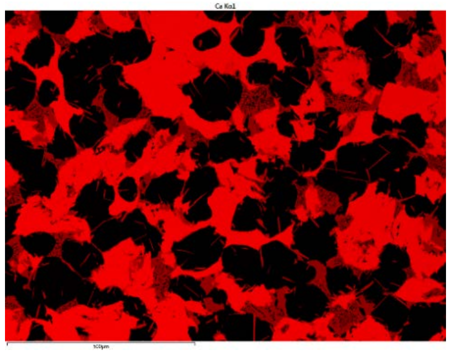
- <u>Motivation:</u>
  - 8 Mt of BOF-slag produced in EU in 2018*
  - Only 15.3% of BOF-slag recycled internally* → **limitation due to P-content**
  - Fe-content ~ 20%
  - Move towards a circular economy
  - → RFCS Project SLAGREUS

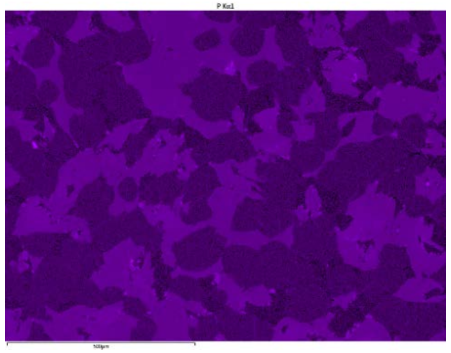
- <u>Process Concept:</u>
  - Separation into Fe-rich/P-poor fraction and a Ca-/P-rich fraction
  - Fe-rich (Oxides, Ferrites) → fine ore substitute in sinter plant
  - Ca-/P-rich → external use as reactive cement additive, raw meal additive or fertilizer

*https://www.euroslag.com/products/statistics/statistics-2018/

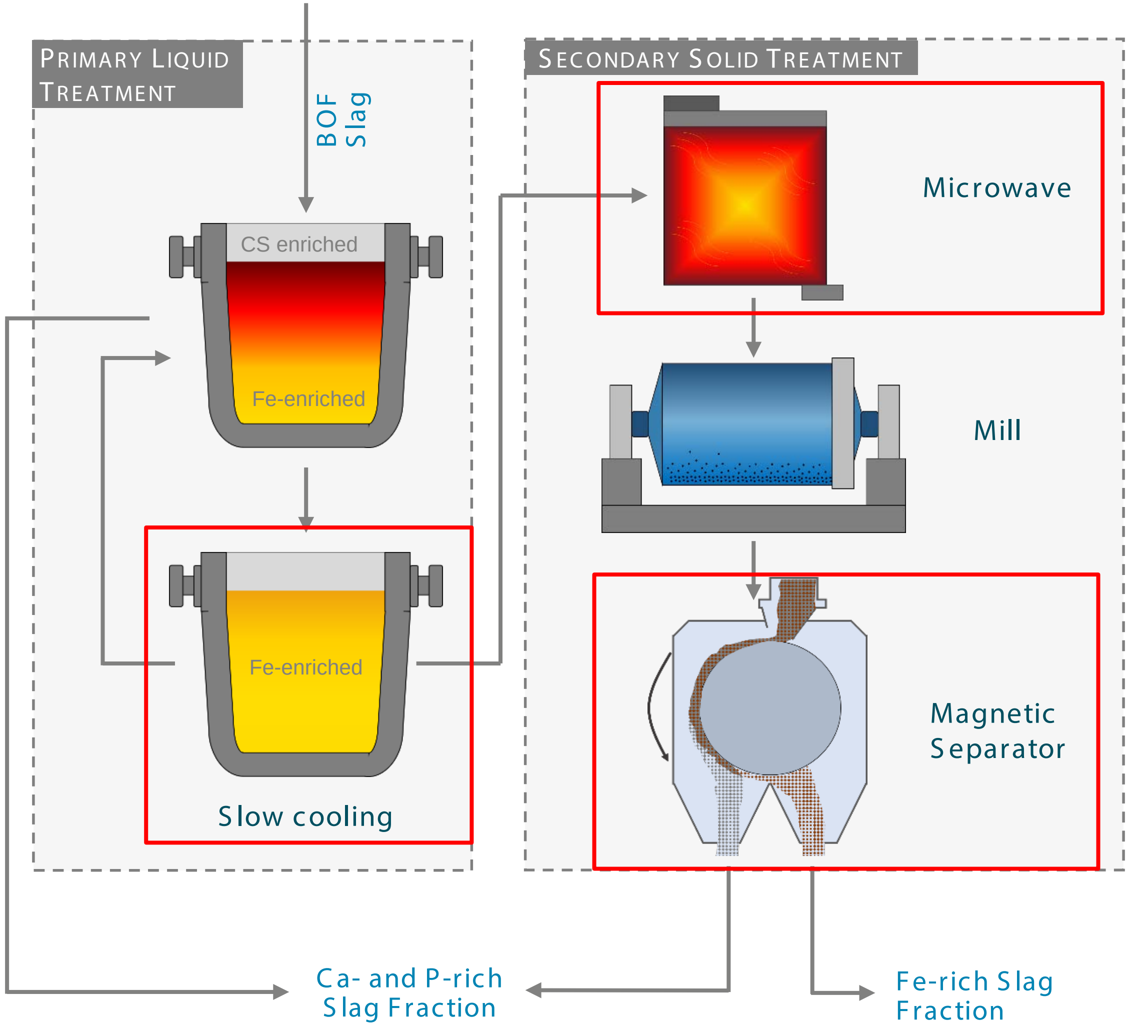


Fluorescence: Fe Kα1


Ca Kα1


P Kα1

SLAGREUS Process Concept



SLAGREUS BOF-slag recycling process concept

1. Primary Liquid Treatment:
    1. Segregation of Ca-/P-rich fraction in liquid state → reduce need for secondary treatment
    2. Slow cooling of remaining Fe-rich fraction → large crystal grains facilitate secondary treatment

2. Secondary Solid Treatment of Fe-rich fraction
    1. Microwave pre-treatment → intergranular cracks
    2. Grinding → liberate mineral phases
    3. Magnetic separation → obtain +Fe/-P fraction and +Ca/+P fraction

Primary Liquid Treatment

Slag Yard Compartment Test:

Slag Mixing

O_2-Injection + Slow Cooling

Slag Pot Test:

Slag Mixing

O_2-Injection

Slow Cooling

Self insulating properties for slow cooling

Enlarged crystal grain size

	Reference standard BOF slag	Overblown in converter + slow cooling	Liquid oxidation + slow cooling in slag yard	Liquid oxidation + slow cooling in slag pot
Q3(100µm) [wt.%]	100.0	17.5	53.8	57.1
Fe-content [wt.%]	24.4	40.5	23.8	20.1

Microwave Treatment – Setup

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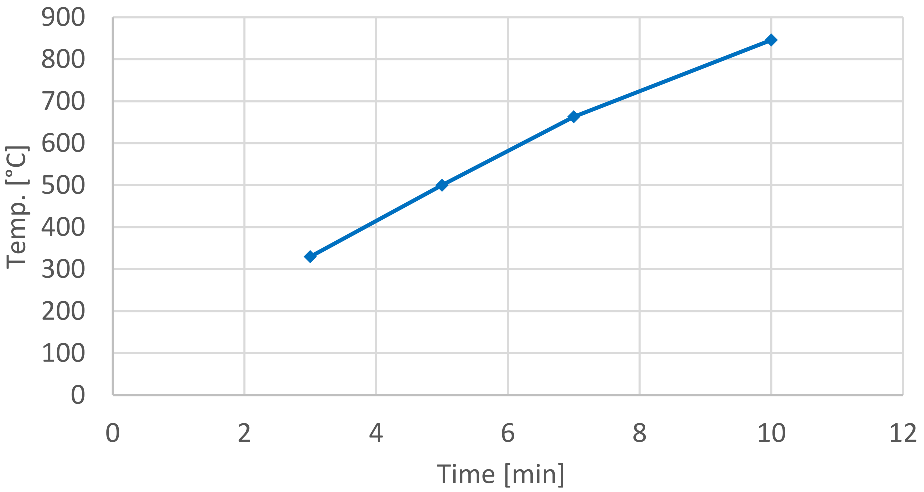
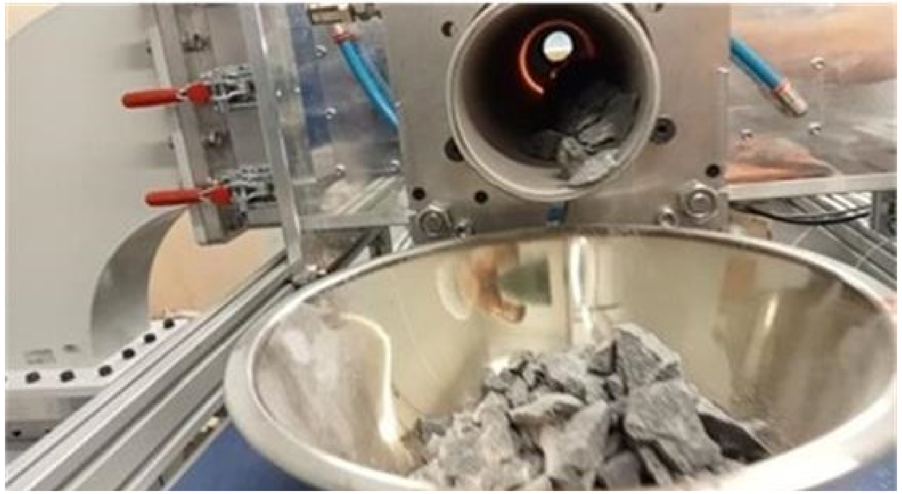
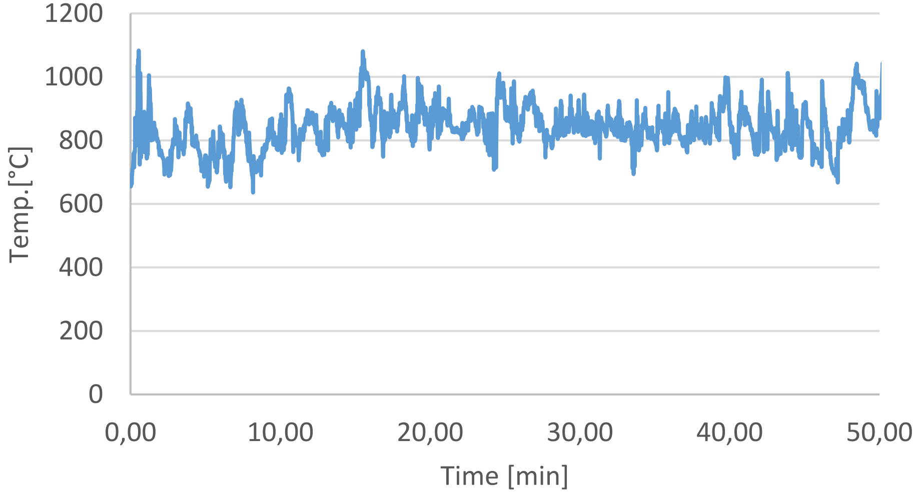
Alumina refractory block



Batch operation: Multimode 4 kW 2.45 GHz. Max. batch size: 1.2 kg





Continuous operation: Resonance cavity max. 30 kW 915 MHz. Throughput: 5 – 10 kg/h*

*https://ceinnmat.com/

Microwave Treatment – Effect

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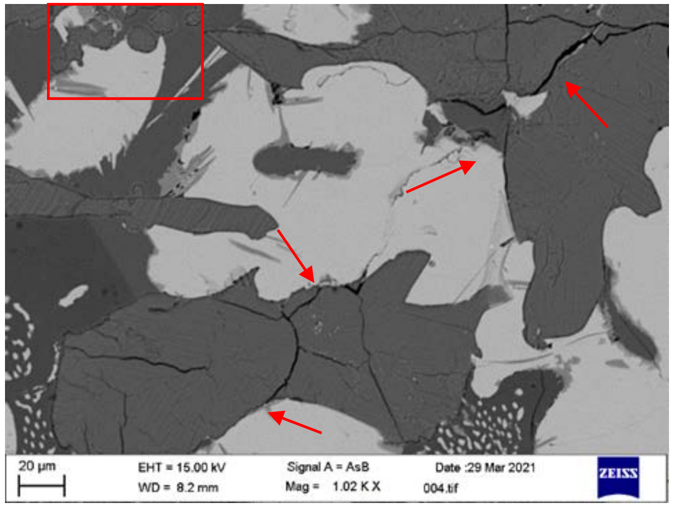
Dysfunctional Parameters	Adapted Parameters
Ionisation	Rapid heating of Fe-phases
Arcs + plasma	Thermal shock

Surface melting



Intergranular crack formation

	Untreated	Irradiated 4 kW 10 min
Grindability Wi [kWH/t]	23.4	19.9
Liberation [%] (mass fraction of particles $FeO_x \geq 80\%$)	20.2	36.4
Magnetisation [%] (SATMAGAN)	0.4	2.0

+ Solid-State Oxidation

Dry Magnetic Separation (Lab Scale)

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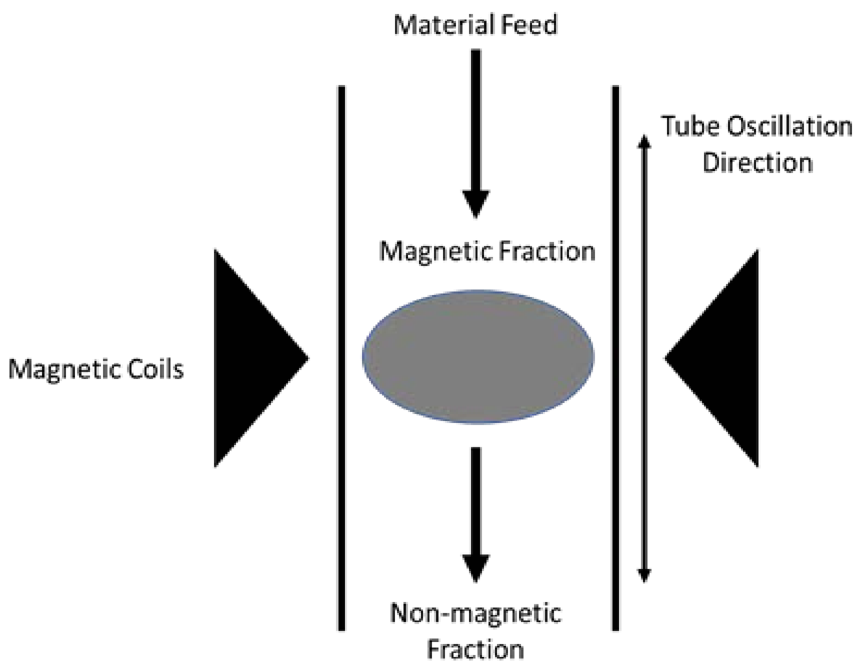
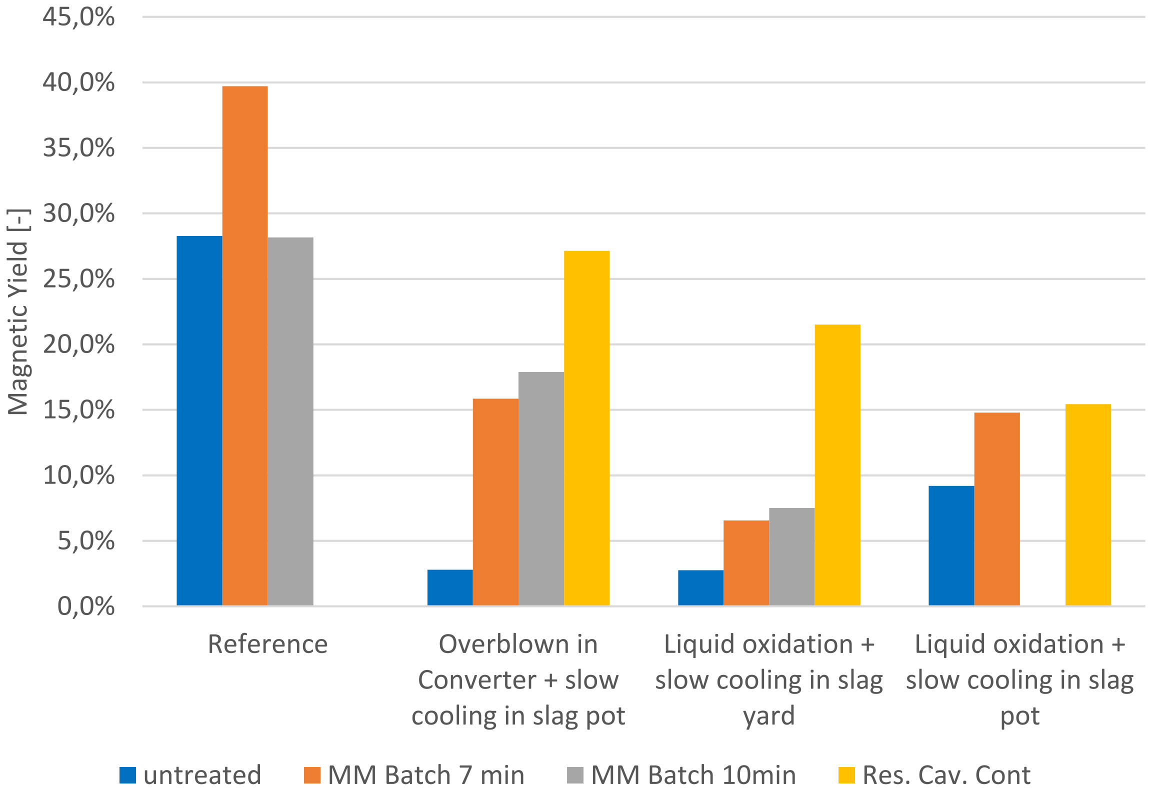


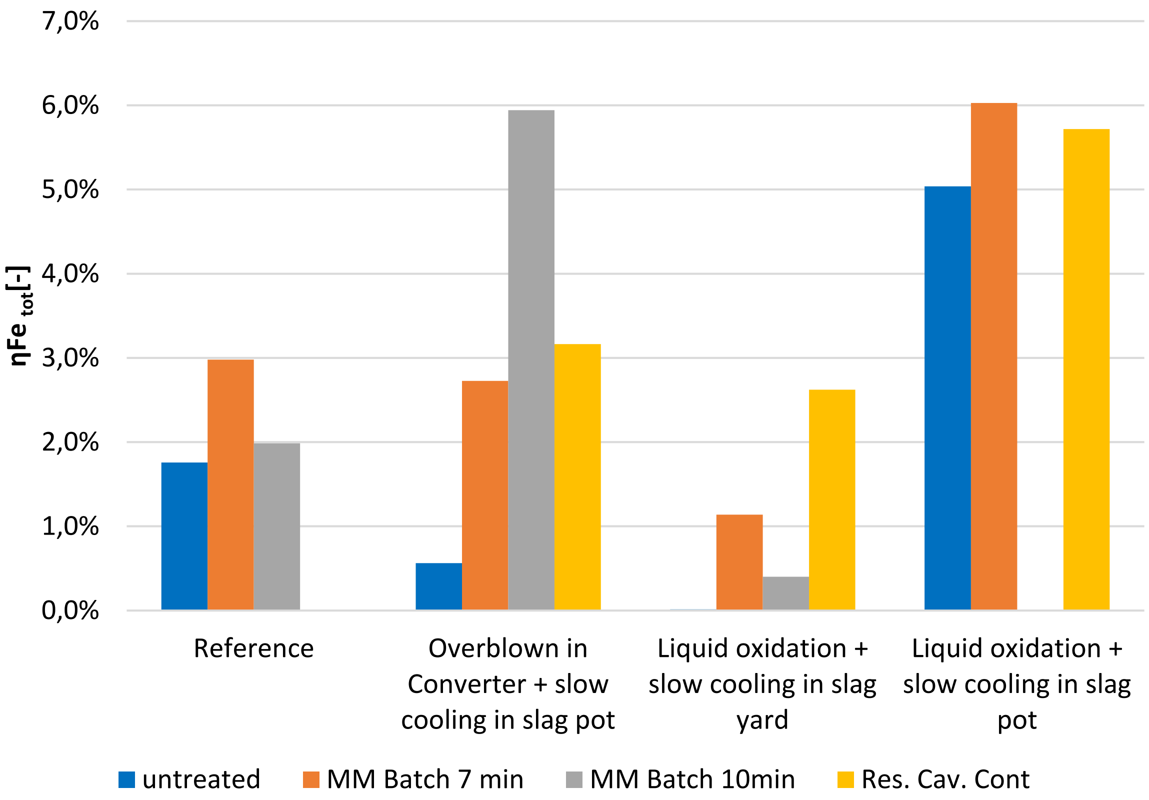
Davis tube (max 1.4 T) used for dry magnetic separation.

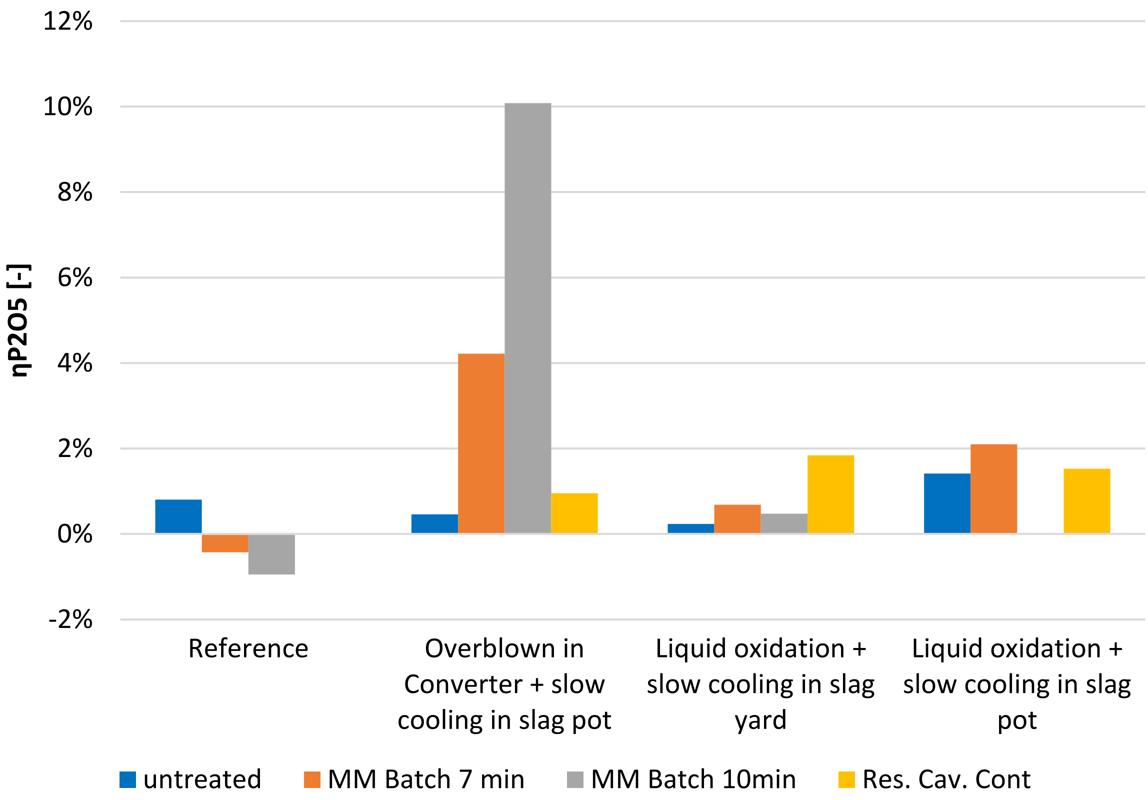


Agglomeration → Feed particle size range 56 µm to 100 µm

Increase in microwave irradiation duration/ intensity
→ Increase in magnetic yield of the dry magnetic separation (DMS)

Dry Magnetic Separation (Lab Scale)





Overall evaluation of separation → Separation degree η adapted from Luyken and Bierbrauer

$$\eta_i = \text{Recovery of resource} - \text{Recovery of byproduct}$$

Microwave irradiation → overall positive effect on η

Effect of Solid-State Oxidation on DMS

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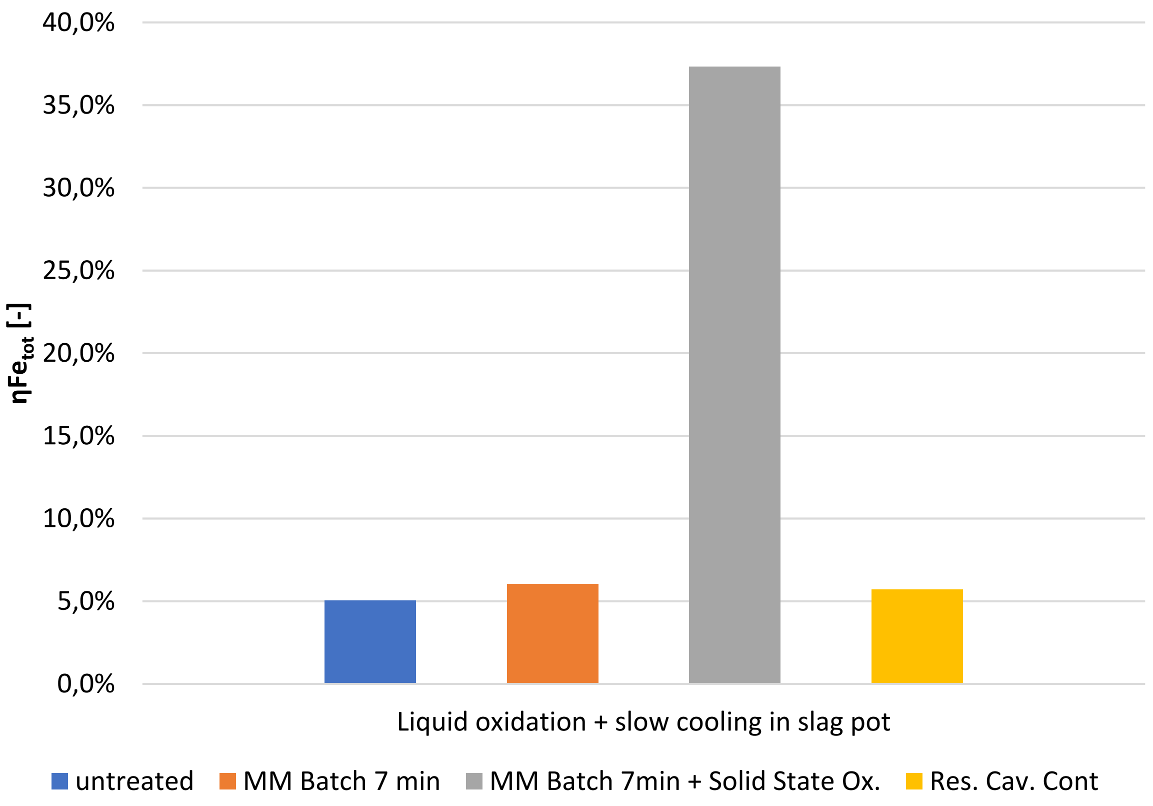
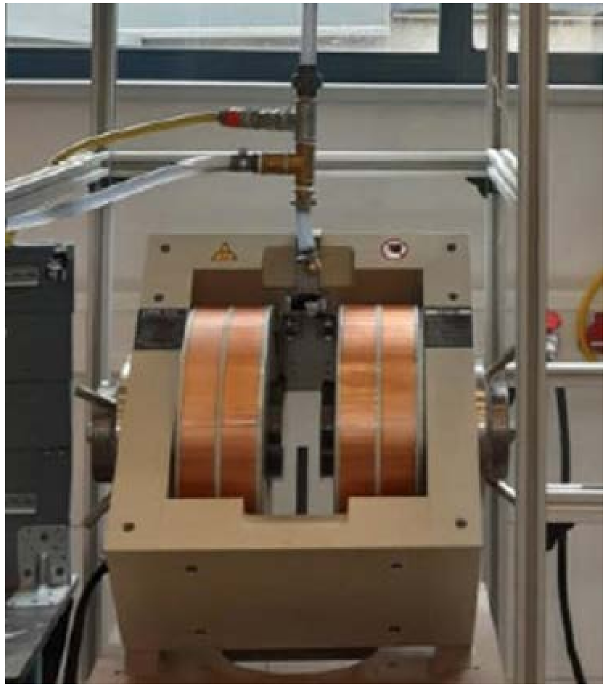
Sample Preparation:

1. Grinding
2. Separation of 56-100µm fraction
3. Annealing for 1h at 900°C under ambient air



→Magnetic separation with variable settings now possible → optimisation
→Increase of η_{Fe} by factor 6
→Increase of η_{P2O5} from 2.1% to 11.1%

Dry Magnetic Separation (Pilot Scale)



Air Stream Matrix Separator*

Low Intensity Magnetic Drum Separator (LIMS)*

η_{Fe} [%]	Davis Tube	Air Stream Matrix Separator	LIMS
Liquid oxidation and slow cooled in slag yard Irradiated in Resonance Cavity	2.62	7.33	0.25
Slow cooling in slag pot Oxidated	37.34	11.72	12.60

*Montanuniversität Leoben Lehrstuhl für Aufbereitung und Veredelung

Conclusion and Outlook

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Crystal grain size and shape	Set boundaries for subsequent treatment steps
Solid-state oxidation	Facilitates separation process
Intergranular cracks	Increased liberation at a given particle size

Outlook:

- Can solid state oxidation be done using waste heat?
- Is it possible to tune high power microwave treatment to achieve homogenous thermal shock?
- Can the produced slag fractions be utilised in the sinter plant (Fe-rich) and cement/fertilizer production (Ca-rich)?

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Dry Magnetic Separation (Lab Scale)

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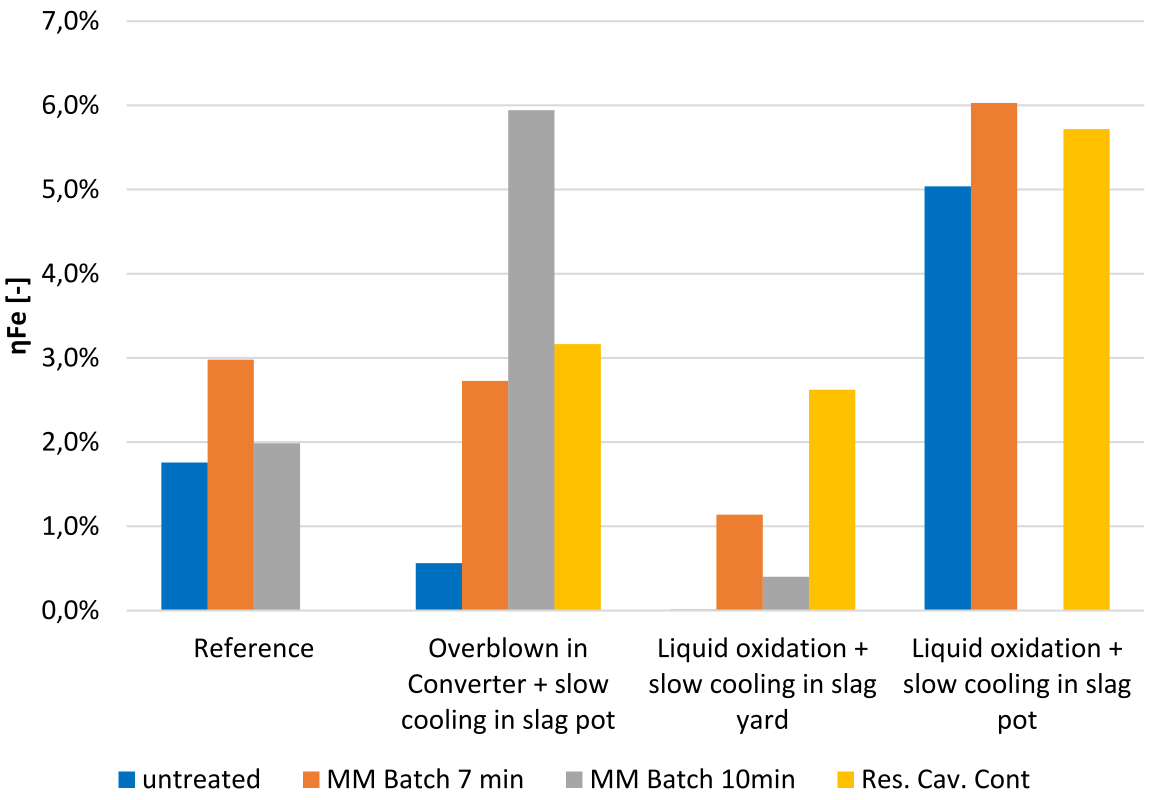

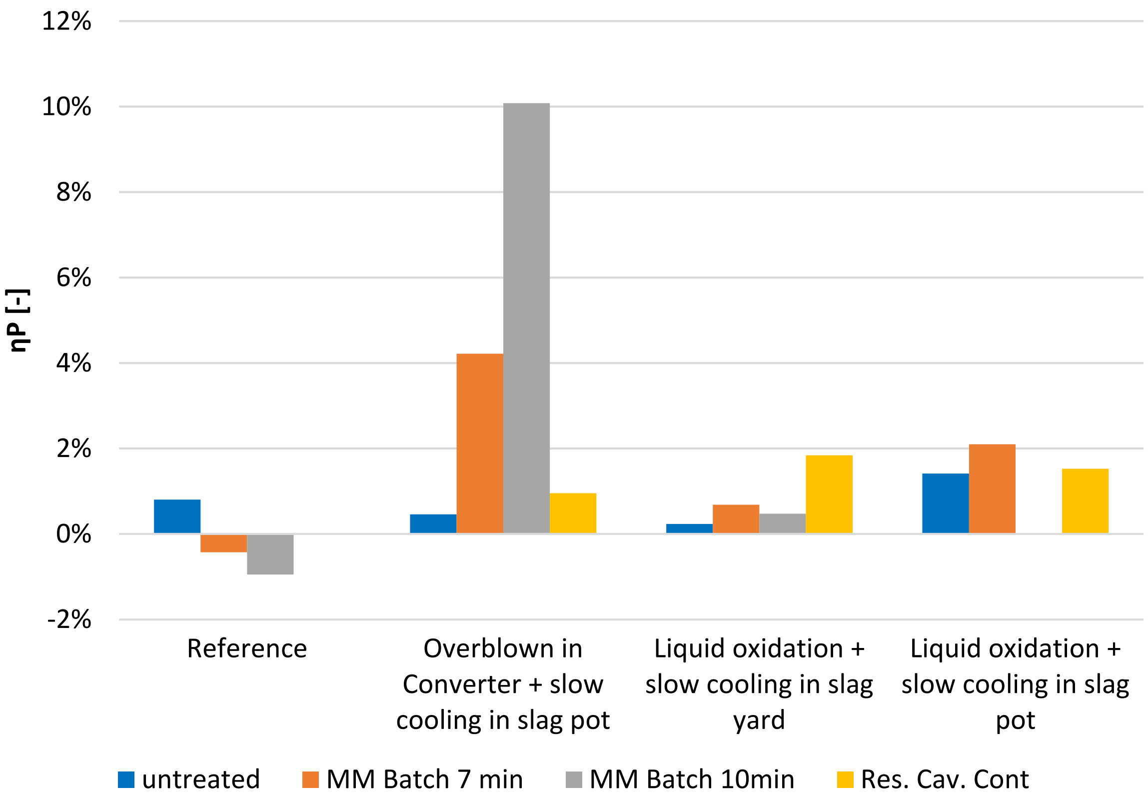

Overall evaluation of separation → Separation degree η adapted from Luyken and Bierbrauer

$$\eta_i = \frac{\left(w_{i,Magnetic} - w_{i,Feed}\right) \cdot \left(w_{i,Feed} - w_{i,NonMag}\right)}{w_{i,Feed} \cdot \left(1 - w_{i,Feed}\right) \cdot \left(w_{i,Magnetic} - w_{i,NonMag}\right)}$$

Reference → untreated

	CaO (%)	Fe (%)	P2O5 (%)	w [-]
Feed	38,39	24,92	1,01	
Conc.	37,45	26,09	0,98	0,28
Tailings	38,76	24,47	1,02	0,72

Slag Pot → untreated

	CaO (%)	Fe (%)	P2O5 (%)	w [-]
Feed	40,64	19,22	1,05	
Conc.	35,69	27,72	0,89	0,09
Tailings	41,14	18,36	1,07	0,91

Slag Pot → MM

	CaO (%)	Fe (%)	P2O5 (%)	w [-]
Feed	41,65	20,00	1,10	
Conc.	36,914	26,514	0,944	0,15
Tailings	42,473	18,864	1,125	0,85

Slag Pot → MM → Ox

	CaO (%)	Fe (%)	P2O5 (%)	w [-]
Feed	40,37	22,58	1,04	
Conc.	31,39	34,45	0,83	0,55
Tailings	51,33	8,08	1,30	0,45