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Smelting of polymetallic nodules in electric furnace – results from laboratory tests

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What are polymetalic sea nodules?

The promising resource of non-ferrous metals, which has particular industrial value, due to the high level of metals concentration such as: Ni, Cu, Co, Mo, Mn, Ti, V and REE.

Cu, Ni, Co, Fe, Mn

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The tests of polymetallic nodules thermal reduction have been performed in two stages:

Stage 1 – „crucible” reduction tests performed in the sylit resistance furnace (m=500g)

Stage 2 – Tests performed in the laboratory electric furnace (m=25 kg)

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Material tested

Material for testing constitute oceanic nodules from the Clarion-Clipperton area. Nodules were kindly delivered by the Interoceanmetal Joint Organization.

The chemical composition of oceanic nodules and the humidity are presented below.

Mn	Cu	Ni	Co	Fe	Mg	Zn	Pb	Al	Na	K	Ca	Si	O
%													
27,5	1,19	1,29	0,17	5,48	1,70	0,16	0,03	2,31	1,84	0,85	1,84	5,94	31,6

Run	Humidity	Average
	%	
1	15,58	15,68
2	15,63	
3	15,84	

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Stage 1

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Test methodology

In the laboratory-crucible tests of thermal reduction process of oceanic nodules the following technological additives were used:

- Coke with the particle size distribution below 1,02 mm, which contained: 1,5% S; 3,5% SiO_2; 0,9% CaO,
- Sand with content of (%): 85,4 SiO_2, 9,5 Al_2O_3, 3,5 CaO,
- Technical calcium oxide with min. 96% of CaO,
- Crude iron (pellets) with the granulation from 5 to 10 mm and 91% Fe content,
- Pyrite with particle size distribution below 1,02 mm and chemical content (%): 44,8 Fe; 37,9 S.

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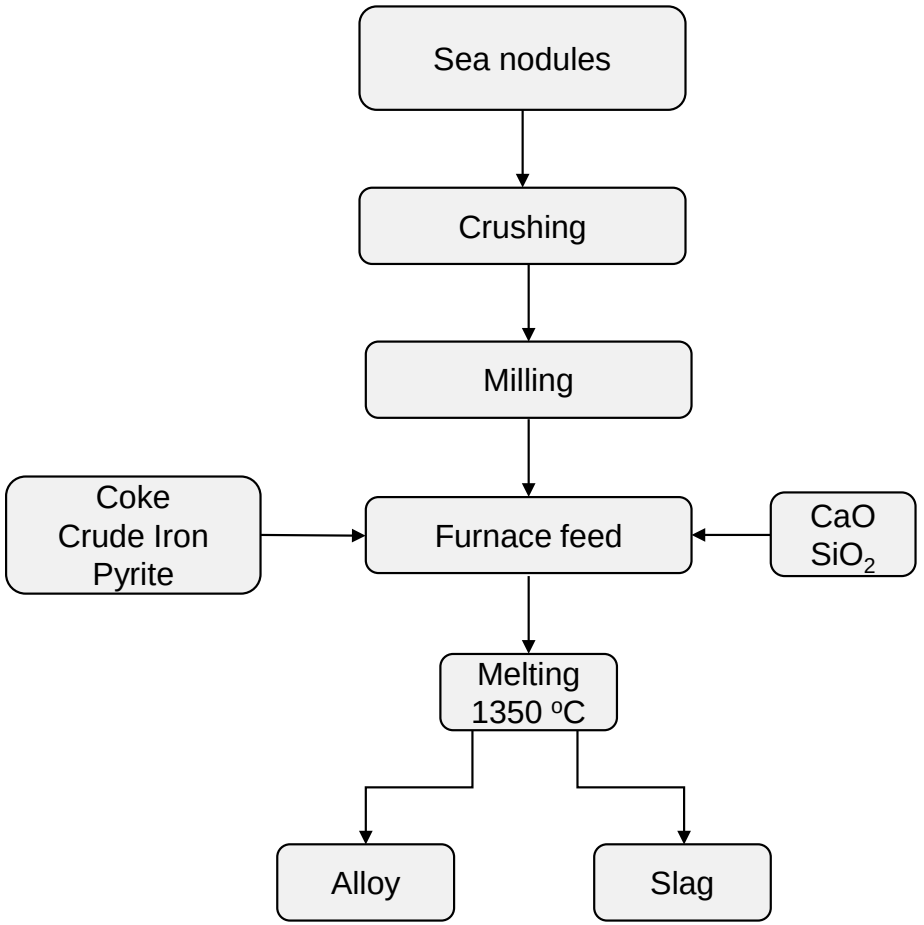
Test methodology

The tests were performed according to the following procedure:

- 500 g of nodules with the relevant amount of reducer and technological additives were mixed and put into the crucible,
- Crucible was placed in the sylite furnace, where smelting was performed,
- After furnace was heated to the temperature 1350°C the sample was hold in for 2; 3 or 4 hours,
- When smelting time was completed the crucible was taken out from the furnace and left for cooling,
- After cooling the crucible was smashed in order to separate the products of the process,
- The obtained products where weighted and sampled for chemical analysis.



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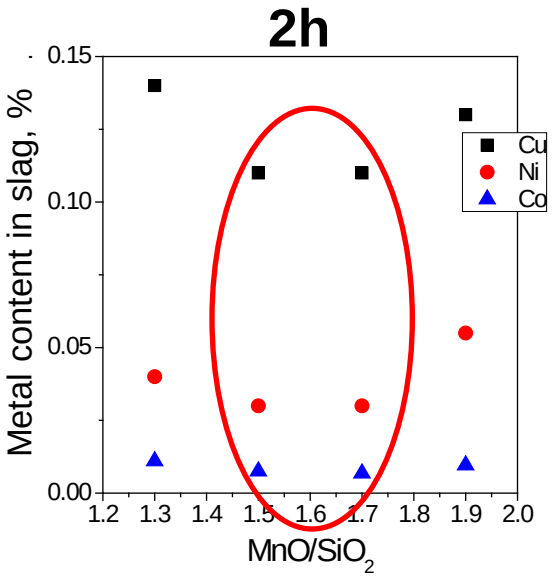
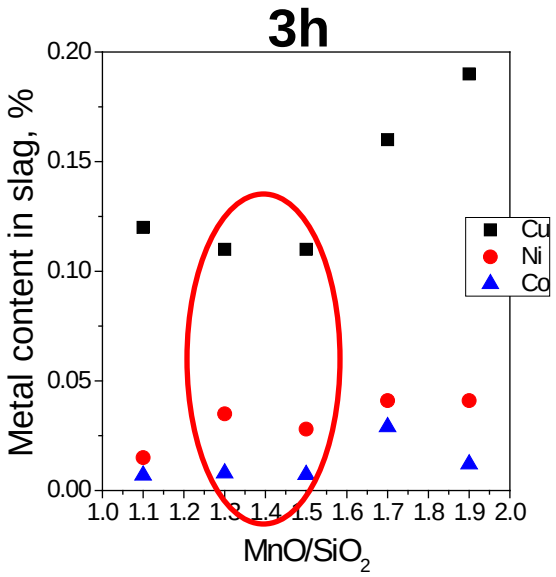
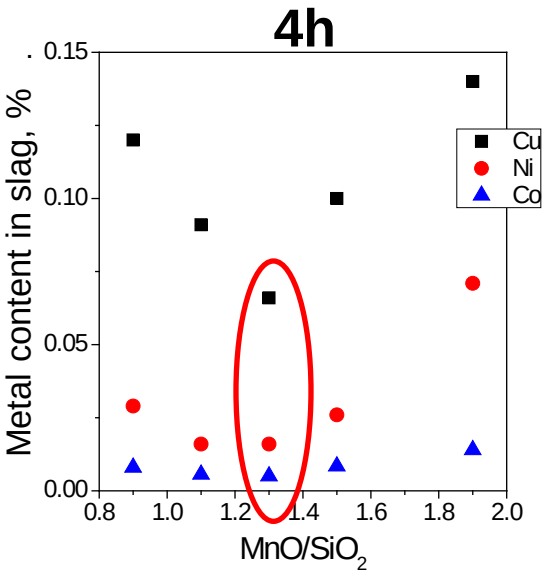
The selection of optimal ratio MnO/SiO_2

After analysis of results, showed on the pictures below, it can be noticed, that for the reduction time 2h the highest reduction level of Cu, Ni and Co was obtained at MnO/SiO_2=1,5÷1,7; whereas for the reduction times 3 and 4h the ratio was respectively 1,3÷1,5 and 1,3. On the basis of obtained results it was concluded that the most optimal ratio of MnO/SiO2 is 1,5.







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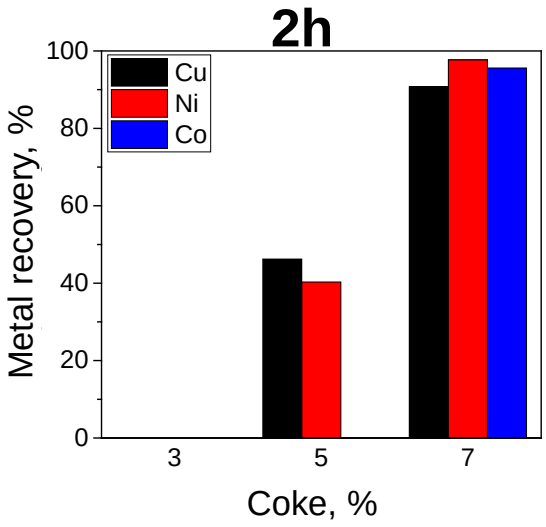
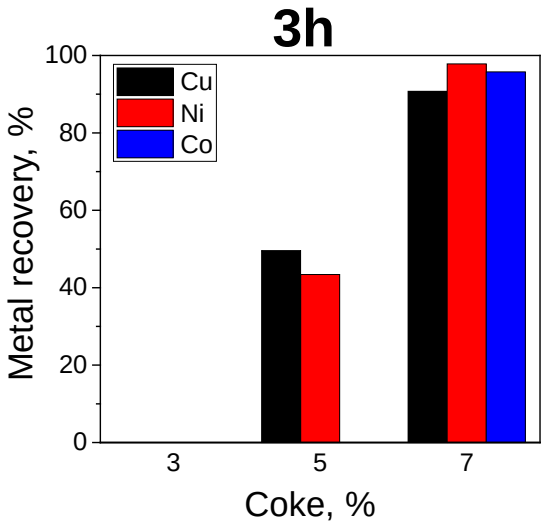
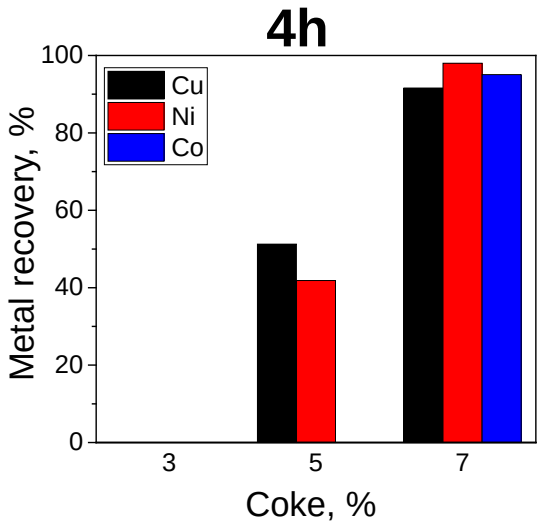
The results of reduction of oceanic nodules (with coke) – MnO/SiO_2=1,5







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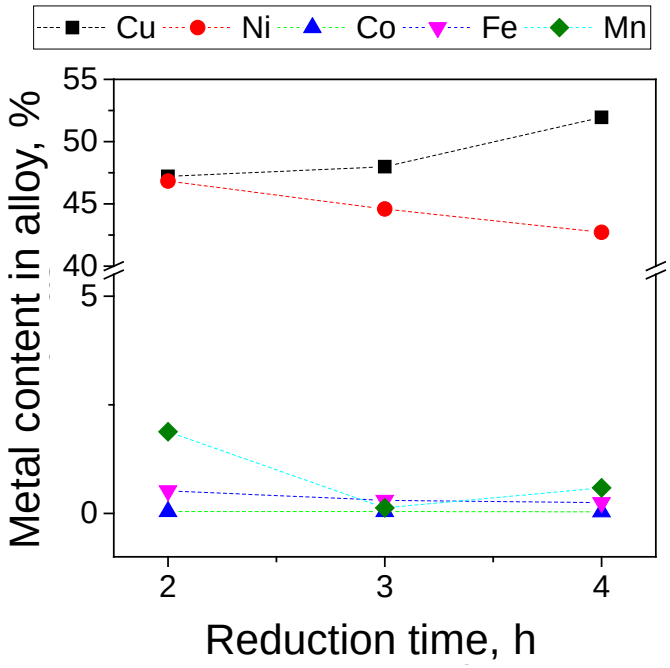
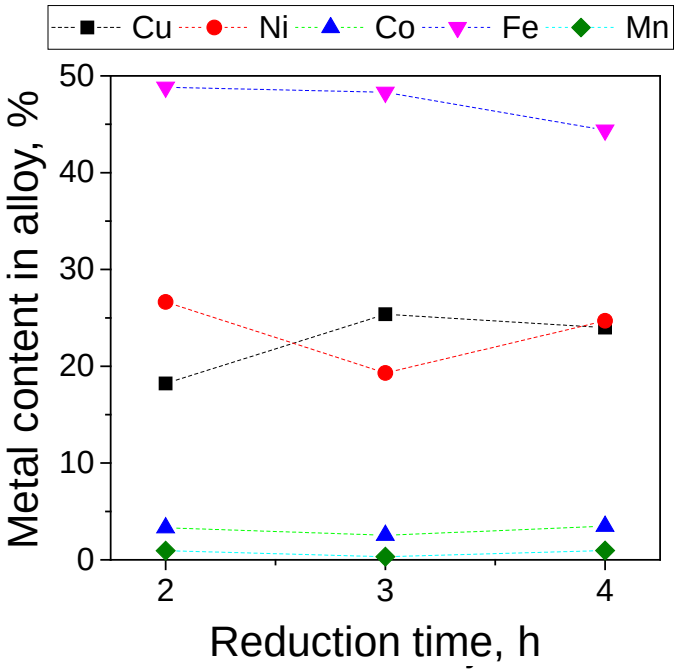
The results of reduction of oceanic nodules (with coke) – MnO/SiO_2=1,5

5% C



7% C



• Pb • Al • Zn • Cu • Ag

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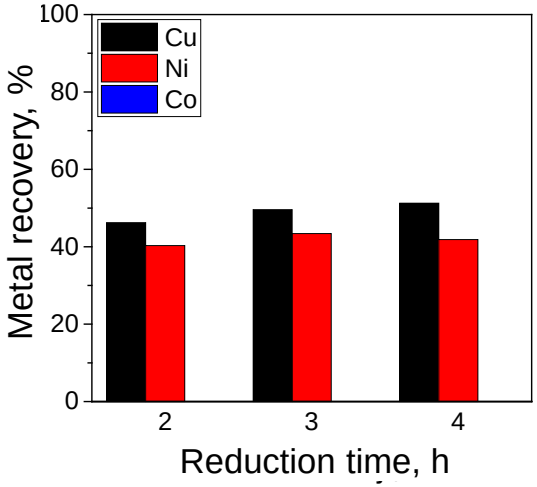
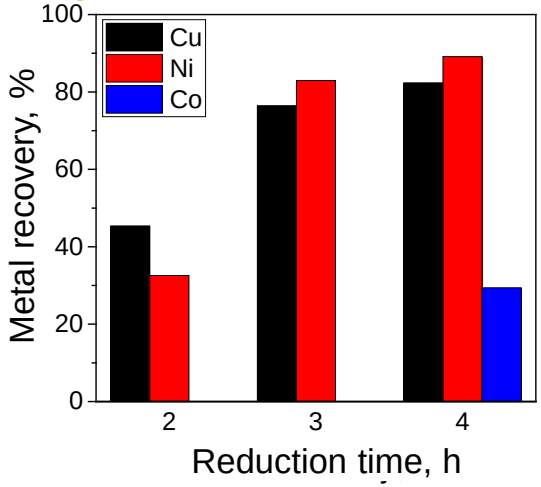
Results of reduction of oceanic nodules – MnO/SiO_2=1,5

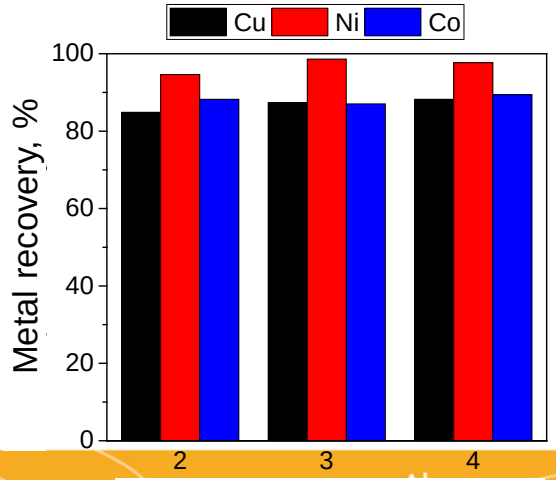
5% C



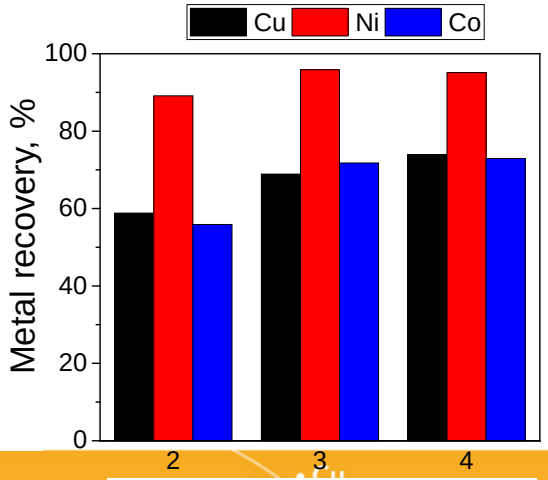
5% C + 5% CaO



5% C + 5% Fe



5% C + 5% FeS_2



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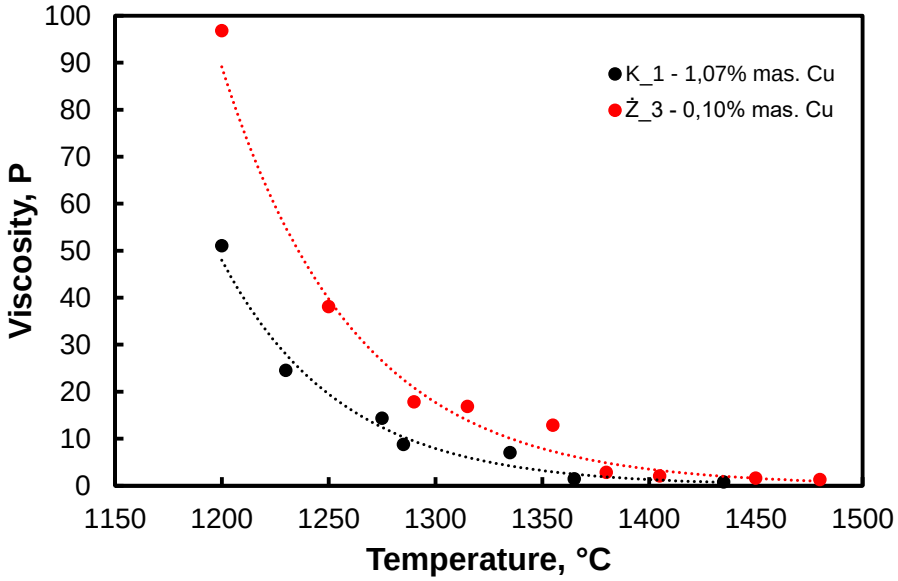
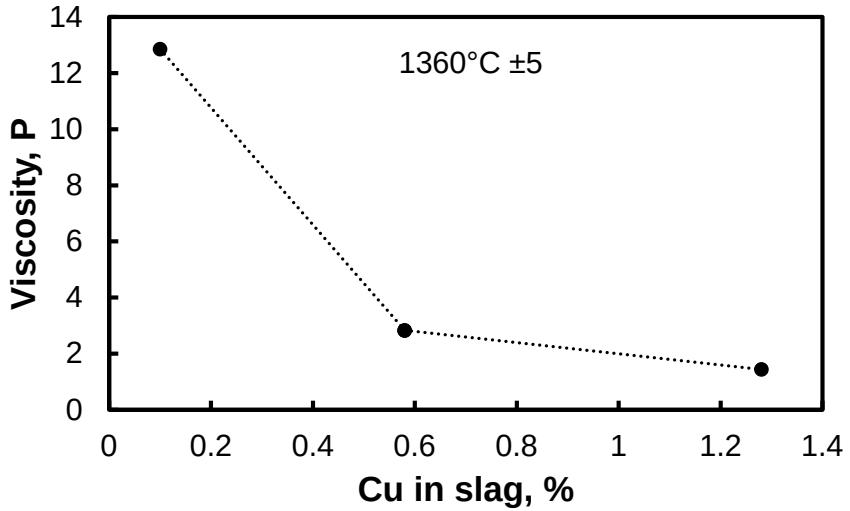
Viscosity measurment results





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Conclusions – Stage 1

1. In the case of thermal reduction of oceanic nodules the optimal ratio of MnO/SiO_2 is 1,5.
2. The highest level of recovery of Cu, Ni and Co was obtained with the addition of 7% coke, and was respectively: 91; 97 i 95%, regardless the reduction time in the range between 2 to 4h.
3. The addition of 5% of crude iron allows to achieve the high level of recovery of Cu, Ni and Co with the decreased content of coke (5%), and after 3h of reduction it was found at the level of 87; 98 i 87% respectively.
4. Along with the increase of the recovery level increases the iron content in the reduced alloy.

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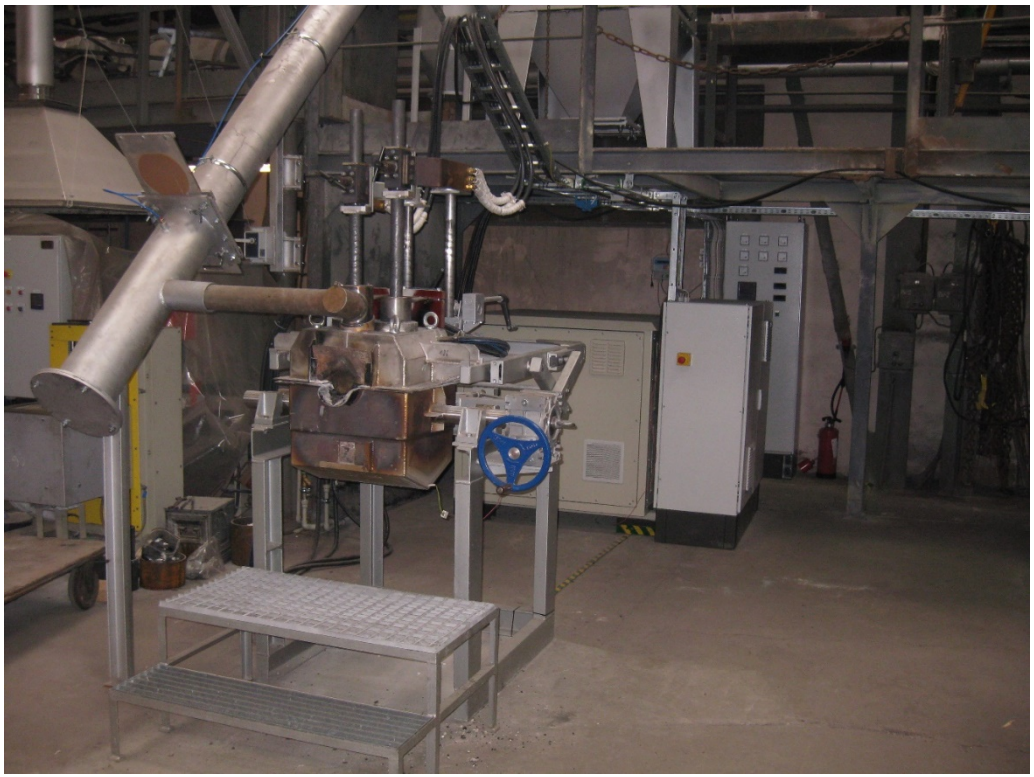
Stage 2 - laboratory tests in electric furnace



Power – 80kVA

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Stage 2

In the laboratory tests of reduction process of polymetallic sea nodules in the electric furnace the following technological additives were used:

- Coke in the amount of 7 to 10%,
- Silica (SiO_2) – Mn/SiO_2=1,5
- Limestone ($CaCO_3$) – 10%,
- Pig iron (pellets) – 5%,

Process temperature: 1400÷1550 °C
Reduction time: 4 h

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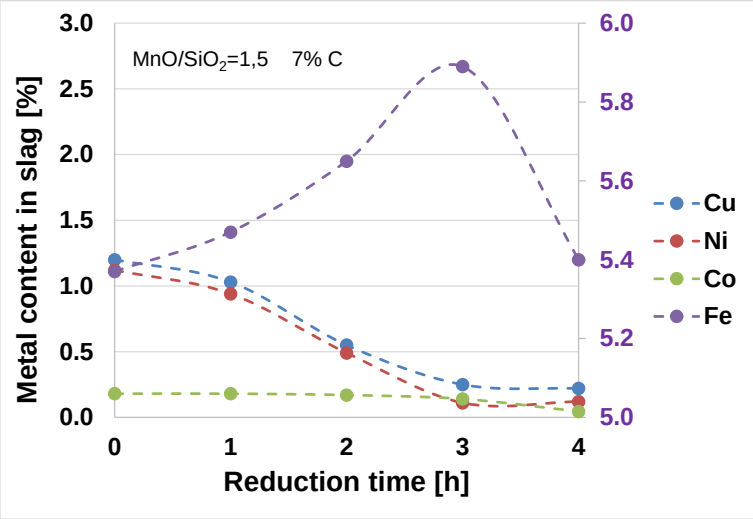

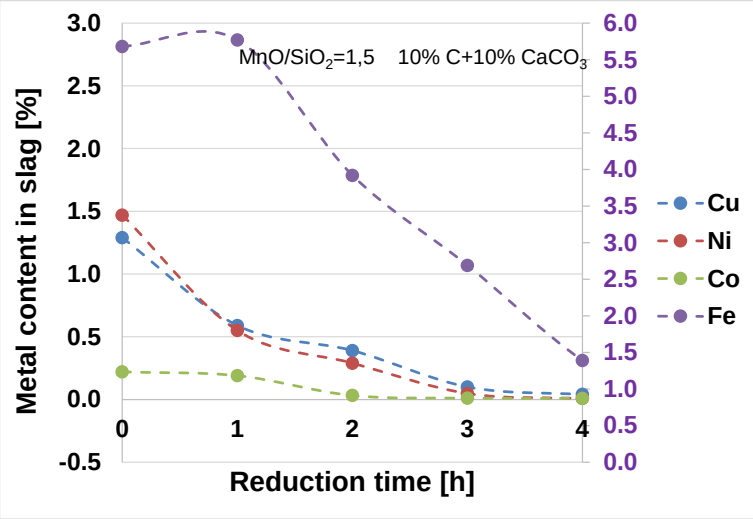

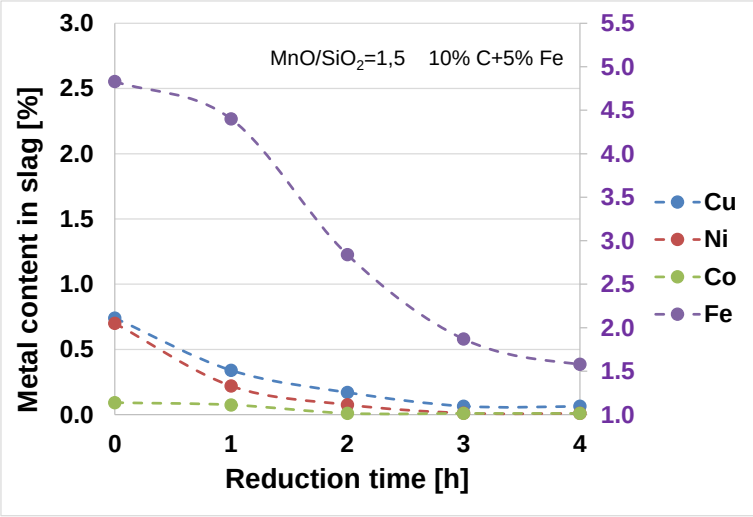

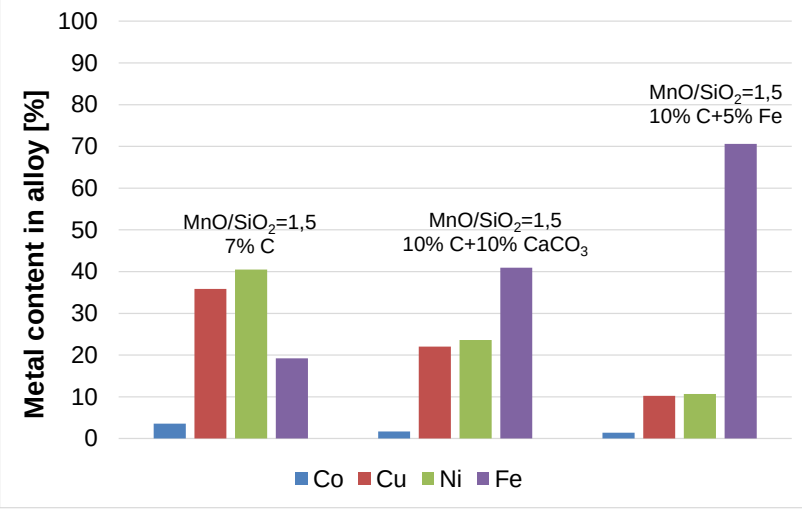

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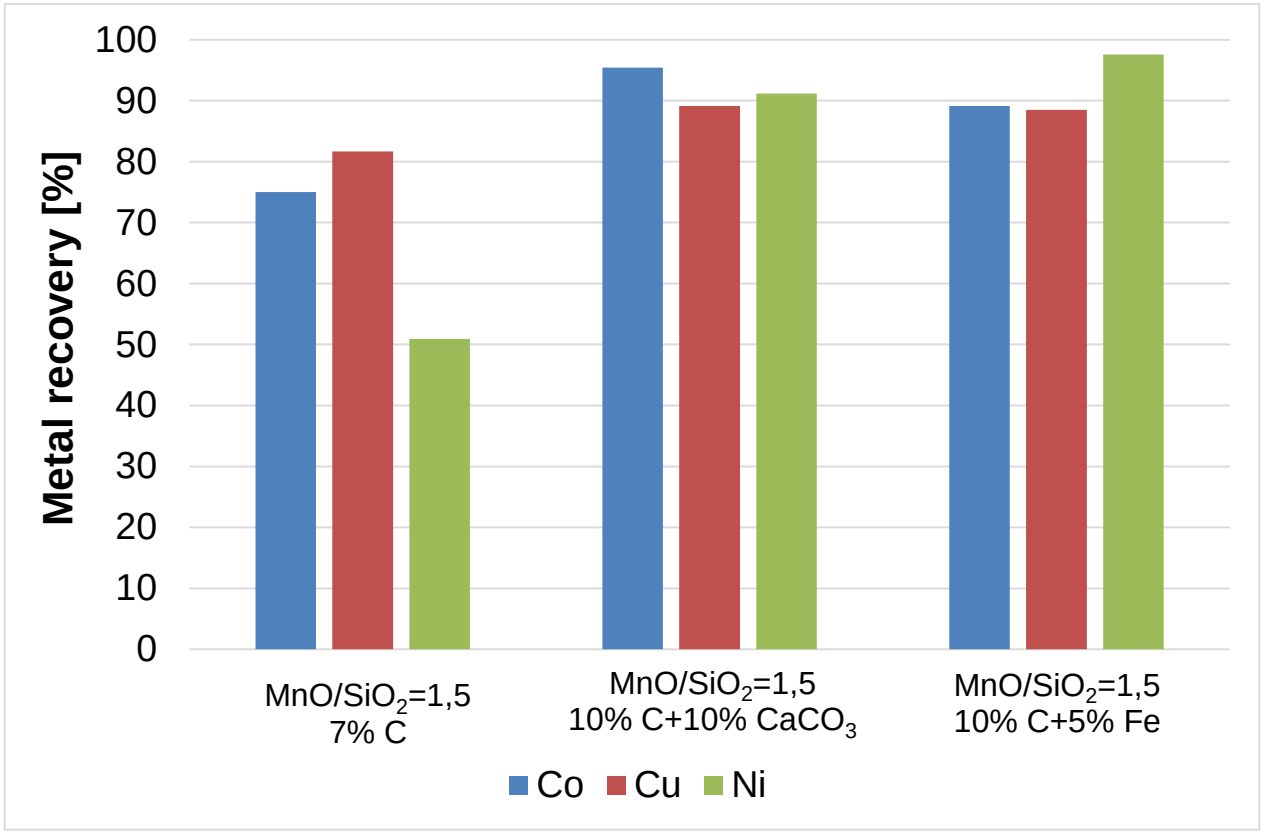
Metal recovery [%]
100
90
80
70
60
50
40
30
20
10
0
MnO/SiO2=1,5
7% C
MnO/SiO2=1,5
10% C+10% CaCO3
MnO/SiO2=1,5
10% C+5% Fe
Co
Cu
Ni

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Conclusions – Stage 2

1. The highest recovery level of Cu, Ni i Co from polymetallic sea nodules was obtained with the addition of 10% C + 10% $CaCO_3$ and 10% C + 5% Fe and was around 90%.

2. Along with the increase of recovery level of metals, increases the iron content in the reduced alloy.

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Thank you for your attention

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