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MATERIALS RECOVERY FROM RESIDUES OF INTEGRATED STEEL MAKING: EXPERIMENTAL INVESTIGATION ON BRIQUETTES PRODUCTION

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Framework

- Introduction
- The aim of the study
- Experimentation plan
    - Identification and quantification of the residues to be recovered;
    - Residue characterisation;
    - Mixture design;
    - Pilot scale briquetting test;
    - Mechanical strength tests;
- Results and discussion
- Conclusions
- References

Introduction

Introduction

On the concept of Circular Economy

- The circular economy is based on the capacity of an economic system, defined as circular, to self-generate (i) by using renewable sources and (ii) optimizing production processes (Bilitewski, 2012).
- One of the world's greatest examples of CIRCULAR ECONOMY ORIENTED SYSTEM is the integrated steel making process (Annunziata Branca et al., 2014).

Introduction

The integrated steel making process

- The ILVA Steelworks in Taranto (Apulia Region, Southern Italy) is one of the largest steel factories currently active in Europe for steel production, territorial extension (15 km^2) and plant complexity (e.g. n.4 blast furnaces, n.2 steel shops, n.2 hot rolling mills, n.1 galvanizing mills).
- The recovery of residues from the production process and their subsequent re-use inside the production cycle itself represents an exciting challenge, which can have strong economic and environmental implications.

The aim of the study

- In this context, the aim of this study was:

  - to verify the feasibility of recovering and reusing residues from the steel production process of ILVA.

In detail, some representative residues of the steel process were tested in order to produce briquettes to be re-introduced as a ferrous source in the Converters during the transformation process of hot metal into steel.

Experimental plan
and materials and methods

Experimental plan

Identification, quantification and chemical characterization of the residues to be recovered

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Mixture design

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Materials and mixture preparation

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Full scale briquetting test

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Mechanical strength tests

↓

Identification of the best mixture

Materials and methods

Identification and quantification of the residues to be recovered

Production residue[(a)]	Fe $_{tot}$ content (%)	Amount (ton/y)
Slag from BOF (Basic Oxygen Furnace) converters (steel shop n.2)	30,70	490.000
Sludge from OG gas cleaning (steel shop n.2)	73,00	26.000
Dust from dedusting system of Stock-house Blast Furnace 1 (BF n.1)	50,23	4.305
Dust from dedusting system of Stock-house Blast Furnace 2 (BF n.2)	48,50	
Dust from dedusting system of Stock-house Blast Furnace 4 (BF n. 4)	46,69	

- The selected residues were characterized by large amounts of iron, as shown in Table.
- A residues total production of 520.305 tonnes per year was observed.
- The largest fraction was BOF slag with a share of 94.2%. The total iron content was variable in the range of 30.7-73.0%.

Materials and methods

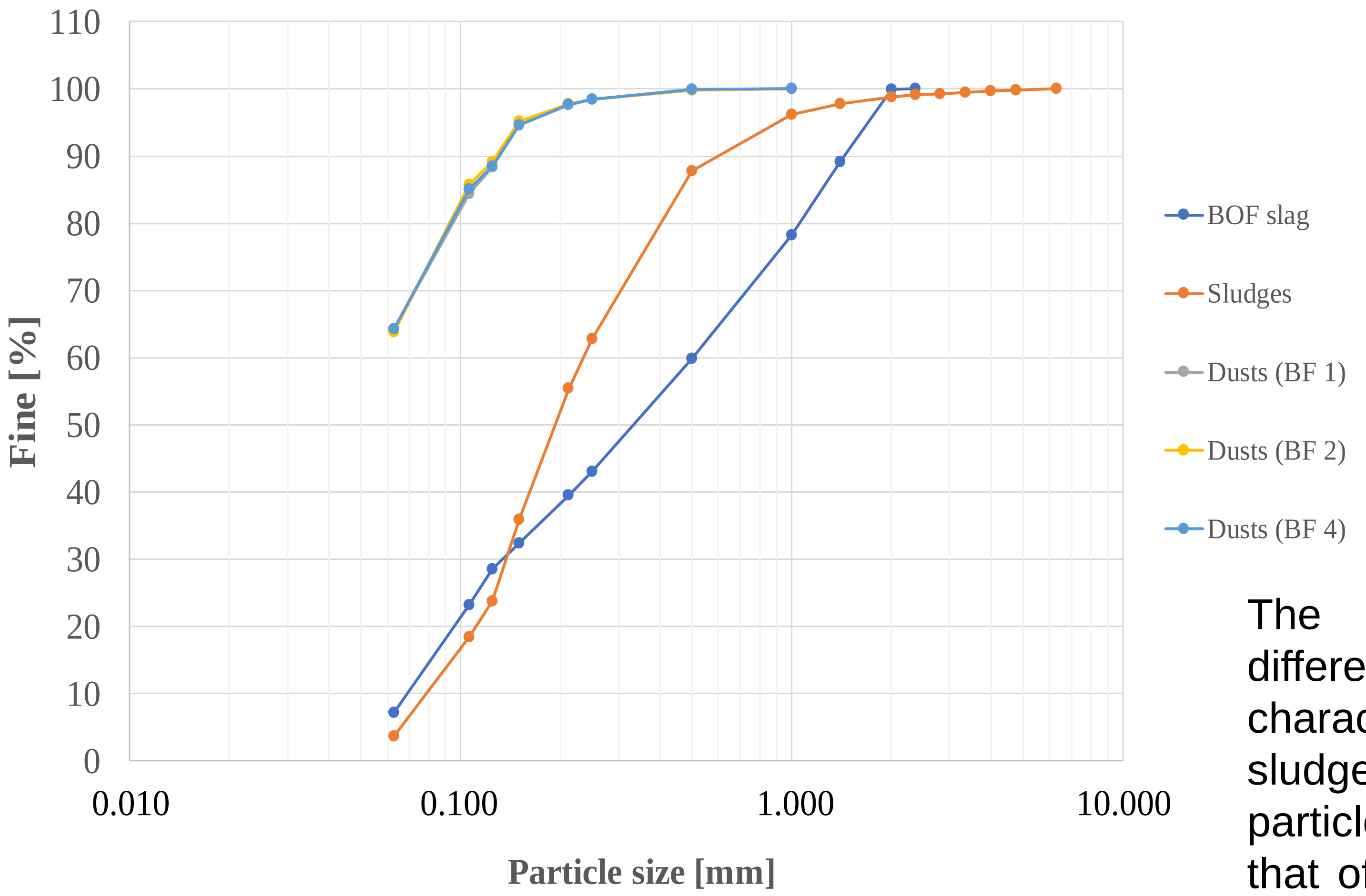
Characterization of the residues to be recovered

Parameter	Residues characterization (%)				
	Slag from BOF converters (steel shop n.2)	Sludge from gas OG cleaning (steel shop n.2)	Stock-house BF 1 dust	Stock-house BF 2 dust	Stock-house BF 4 dust
Moisture	0.51	12.20	0.30	0.20	0.50
Fe_{tot}	30.70	73.00	50.23	48.50	46.69
FeO	28.55	54.92	2.76	2.23	2.00
Fe metal	0.89	12.81	0.50	0.50	0.39
Fe_2O_3	10.90	11.62	68.04	66.16	63.98
SiO_2	12.31	2.26	6.62	6.51	6.06
Al_2O_3	1.29	0.35	1.42	1.44	1.74
CaO	32.72	7.59	11.62	10.08	8.28
C	0.03	5.81	3.84	8.68	12.58
MgO	6.29	2.83	2.02	1.80	1.39
MnO_2	1.73	0.42	0.24	0.22	0.22
P_2O_5	1.57	0.22	0.14	0.14	0.14
TiO_2	0.32	0.10	0.09	0.10	0.12
S	0.08	0.07	0.11	0.14	0.09

- BOF slag and dust had a limited moisture content, varying in a narrow range (0.2-0.51%). On the other hand, the moisture content of the sludge averaged was 12.2%, in line with a dewatered sludge (Metcalf & Eddy, 2003);
- Among all fractions, sludge from OG gas cleaning (steel shop n.2) showed the highest value of the total iron content, equal to 73%.

Materials and methods

Characterization of the residues to be recovered



The residues had different particle size characteristics, dust and sludge had a finer particle size compared to that of the slag, and the dust curves were overlapped.

Materials and methods

Mixture design

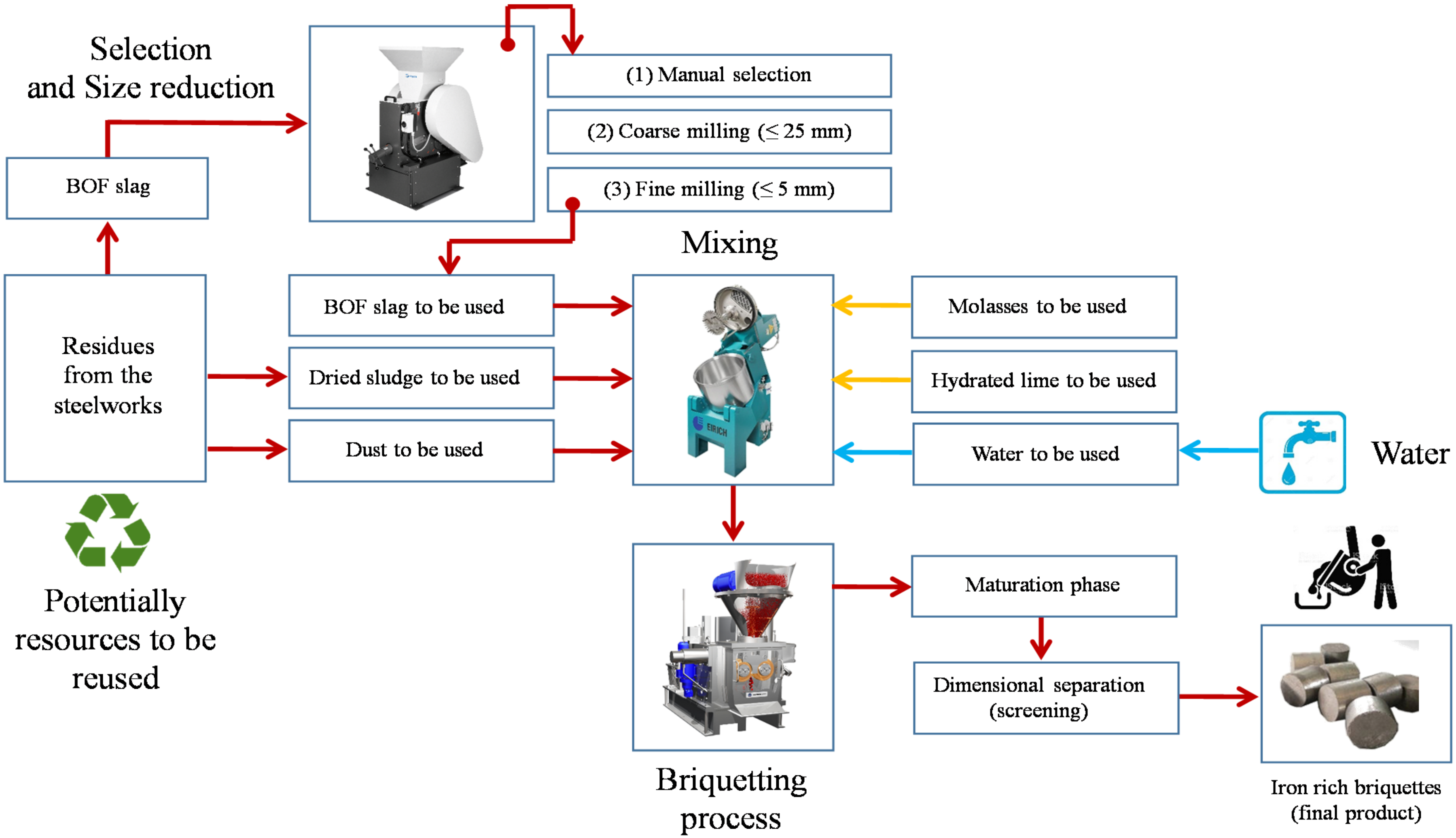
N.	Mixture composition [%]						
	BOF slag	Stock house dusts	BOF Sludges from steel shop 2[(a)]	Molasses	Water	Hydrated lime	Total
1	60.63	25.98	0.00	7.09	6.30	0.00	100.00
2	65.42	14.02	14.02	4.67	0.00	1.87	100.00
2b	62.50	13.39	13.39	8.04	0.00	2.68	100.00
3	61.95	0.00	26.55	6.19	3.54	1.77	100.00
3b	61.40	0.00	26.32	7.02	3.51	1.75	100.00
4	64.22	18.35	9.17	4.60	1.83	1.83	100.00
4b	63.64	18.18	9.09	5.45	1.82	1.82	100.00
4c	61.40	17.55	8.77	7.02	2.63	2.63	100.00

8 mixture design have been defined;

The mixtures were characterized by slag between 60 and 70%, dusts and sludges between 10 and 30%

Materials and methods

Materials preparation



Materials and methods

Pilot-scale briquetting tests

- The briquetting test involved the use of the Kompaktor Hutt CS25 compacting machine, capable of using 5 kg of mix per single test;
- The briquettes obtained from each test were taken from the appropriate collection compartment, weighed on the Mettler Toledo SB S001 balance and then, in order to allow them to mature, placed in the electro-ventilated stove (Binder model FED-115) for 16 hours at a temperature of 105° C.


Materials and methods

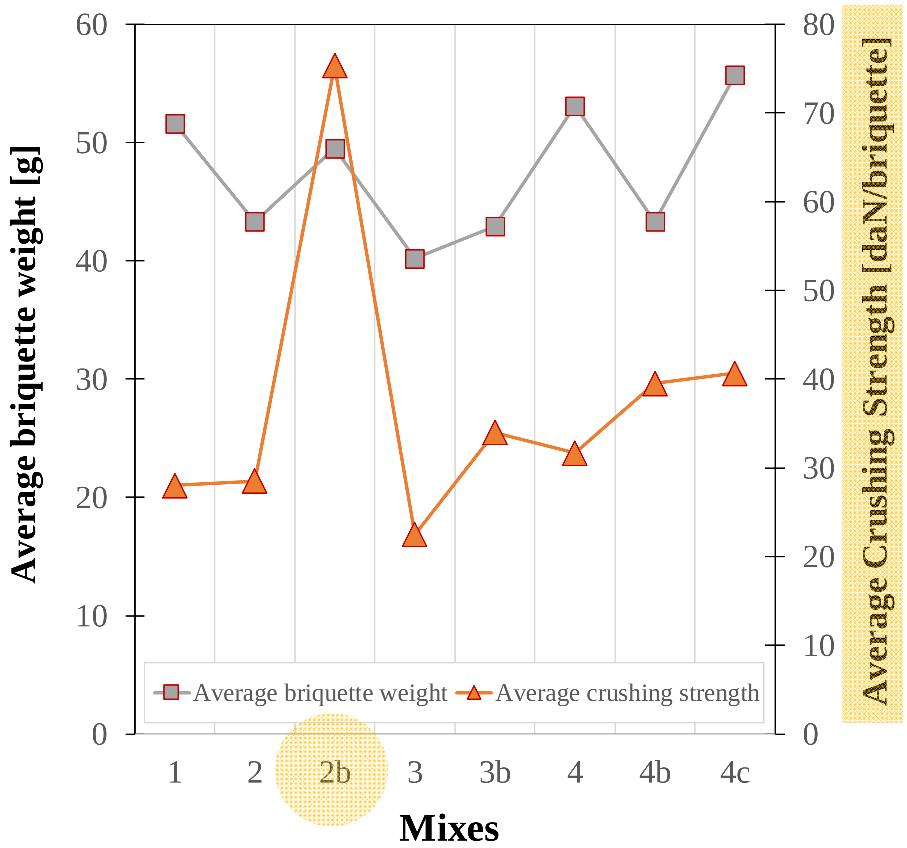
Mechanical strength tests

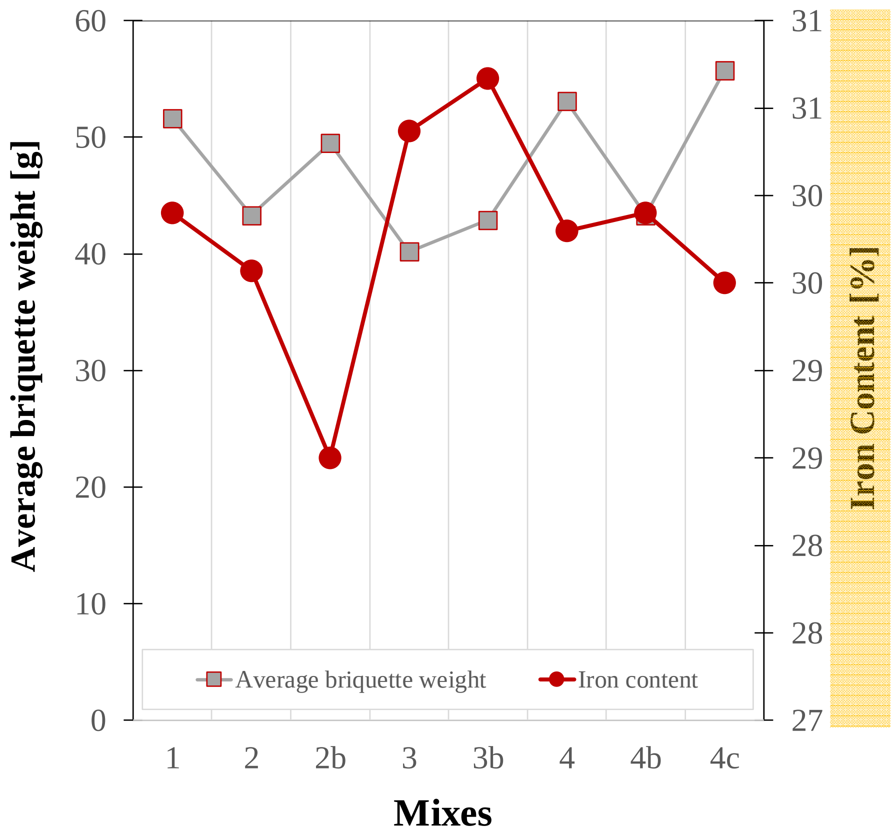
- For the purposes of this experimentation, a crushing test was carried out using experimental briquettes;
- As there was no specific technical standard for briquettes at international level, it was referred **to ISO 4700:2015** “Iron ore pellets for blast furnace and direct reduction feedstocks - Determination of crushing strength”;
- **The output of the test - the compressive strength or CS (Crushing Strength)** - was represented by the maximum load value recorded during the test;
- **This test involved n. 3 briquettes of each mixture**; for each briquette the CS index value was determined using the RB 1000 press.

Results and discussion

Results and discussion

Mechanical characterization of the briquettes





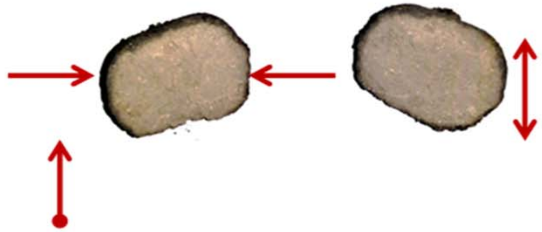
The 2b mixture, which had the best resistance to crushing, was the one with the highest percentage of molasses (8.04%), a high content of hydrated lime (2.68%) and no additional water (except for the water related to the humidity of the used materials).

Results and discussion

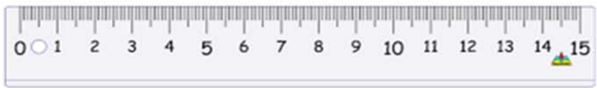
Consistency and geometry of the briquettes produced with the mixtures 2b and 3 after the crushing test.

Briquettes in the RB 1000 press rotary disc

4.30 cm long 3.00 cm high



Briquette produced with the 2b mixture after the compression test



2b mixture

Briquette produced with the 3 mixture after the compression test

3 mixture

- The test of resistance to crushing was carried out by applying an axial compression force to the briquettes that induced, as it increased, the sample breakage.
- **Details of the breaking mechanism.** The 2b mixture underwent breakage along the direction of the force applied (See the central photo); in fact, the two half of the briquette had very clean and regular separating surfaces.

Results and discussion

Chemical characterization of the mixtures 2b after the crushing test

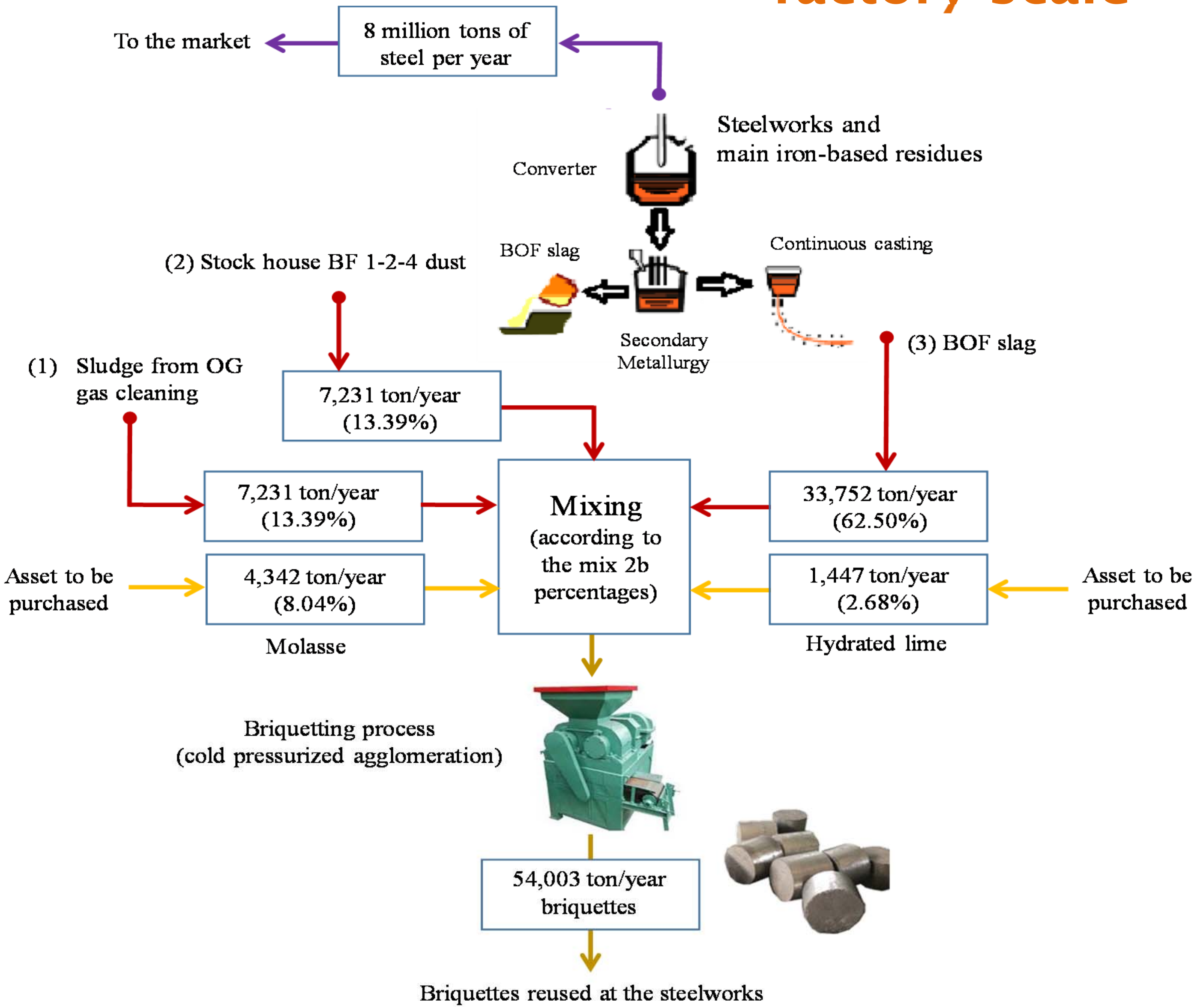
Parameter	Unit	Value
Antimony (Sb)	mg/kg	< 1.4
Arsenic (As)	mg/kg	< 1.4
Barium (Ba)	mg/kg	60
Beryllium (Be)	mg/kg	< 1.4
Cadmium (Cd)	mg/kg	< 1.4
Chromium VI (Cr VI)	mg/kg	< 0.10
Chromium as total (Cr tot)	mg/kg	500
Mercury (Hg)	mg/kg	< 0.14
Molybdenum (Mo)	mg/kg	< 1.4
Nickel (Ni)	mg/kg	9
Lead (Pb)	mg/kg	100
Copper (Cu)	mg/kg	11
Selenium (Se)	mg/kg	< 1.4
Thallium (Tl)	mg/kg	< 1.4
Tellurium (Te)	mg/kg	< 1.4
Vanadium (V)	mg/kg	360
Zinc (Zn)	mg/kg	400
Tin (Sn)	mg/kg	< 1.4
Cobalt (Co)	mg/kg	< 1.4

- **The chemical characterization of the briquettes produced with the 2b mixture confirmed the absence of metals in significant concentrations**, as already highlighted by the preliminary characterization of the individual residues constituting the mixture.
- This further strengthened the hypothesis of re-use within the production cycle

Results and discussion

Mass balance at factory scale

- **The results obtained showed a recovery of 48,214 tonnes of residues per year**, on the basis of the quantities of BOF residues equivalent to an annual steel production of the plant of Euro 8 million.
- **The volume of the 2b mixture was 54,003 tonnes**.
- **The recovery of iron equivalent was estimated at 15,391** tonnes per year.



Conclusions

Conclusions

- **The obtained results showed how each mixture was able to make briquettes of good consistency and integrity; the 2b mixture was found to be optimal in terms of crush resistance (CS = 75.33 daN/ briquette) and iron content (29%).** The 2b mixture consisted of a molasses and hydrated lime content of 8% and 2.7%, respectively;
- **The large-scale mass balance of the entire steelworks has made it possible to estimate the potential annual recovery of about 48.200 tons of residues and the potential annual production volume of briquettes at about 54.000 tons**, considering steel production of 8 million tons/year. **The recovery of iron could be about 15.400 tons/year.**
- **The chemical characterization of the briquettes confirmed the absence of significant concentrations of metals, strengthening the possibility of re-use in the production cycle.**

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Thank you for your attention

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