TECHNOLOGICAL POSSIBILITIES FOR THE UTILIZATION OF IRON-CONTAINING WASTE FROM METALLURGICAL INDUSTRIES

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ABSTRACT

The study presents the possibilities for processing iron-containing waste from metallurgical production. The raw material for the experiments was obtained from the tailing's storage of a metallurgical plant in Bulgaria with the aim of obtaining a product that can be used as a raw material in blast furnace production. The test is performed in a rotary kiln at 1150°C, 1100°C, 1050°C in the presence of a reducer. Three different iron ore pellets and additionally coal grits were the raw materials for the direct reduction process. During the provided experiments, the main technological parameters of the reduction process were established, such as temperature, process time, pressure in the furnace and the composition of the exit gases from the process. Marketable iron - containing pellets were obtained and tested.

Keywords: tailings reprocessing, rotary kiln, reduction, pellets, coal, sponge iron, palletization.

INTRODUCTION

In the context of the circular economy and the development of new technologies, the recovery of valuable elements from materials that are considered waste is becoming increasingly important. Reprocessing tailings to transform them into valuable materials offers mining companies a lucrative opportunity for technological innovation while providing an effective solution to environmental challenges.

Here we present a technological way for the selective utilization of tailings waste with the possibility of minimizing carbon emissions. The tailings storage facility was used for disposal of waste material originating from various manufacturing processes, such as, steelmaking and enrichment plant production.

Various methods have been developed for recovering iron from tailings, typically combining magnetic separation with selective flocculation [1 - 4]. Another approach to beneficiate iron ore tailings is magnetizing roasting, an energy-intensive process that is therefore rarely employed. Despite its high energy demands, this method has the advantage of converting paramagnetic hematite into ferromagnetic magnetite, which can then be efficiently recovered through wet low-intensity magnetic separation [5]. As demonstrated below, magnetizing roasting could prove highly beneficial when the recovered iron concentrate is intended for pelletizing.

Another emerging technology for iron recovery from tailings is the production of electrolytic iron, which offers a promising method for producing iron with reduced associated CO_2 emissions [6]. This approach provides the benefit of producing a product of exceptional purity and can utilize ores that are unsuitable for traditional smelting. However, the high production costs present a significant disadvantage. Despite the advancements in 'green' technologies discussed in the literature, none have yet matched the benefits of the widely used blast furnace technology for recovering iron from mine tailings [7, 8].

In this paper we present the possibilities for processing iron-containing waste from metallurgical production into marketable iron - containing pellets. Three different process scenarios have been investigated to identify the most appropriate route.

Three different iron ore pellets and additionally coal grits were the raw materials for the direct reduction process. Selected properties of the pellet's batches used can be found in (Table 1).

Iron ore was used as the base material to produce pellets on a laboratory-scale pelletizer disc, operating under the following conditions: 12.5 wt. % moisture content in the iron concentrate, 2.5 wt. % bentonite concentration, pellet sizes between 9 and 16 mm, a rotation speed of 15 r min^{-1}, and a disc inclination of 60°.

For the reducer agent is used coal with the next chemical composition (Table 2).

The particle size of the coal grits was 0 - 6 mm.

EXPERIMENTAL

Equipment

The used kiln has the following technical parameters (Table 3):

Scheme of the experimental equipment

The aim is the reduction of iron ore pellets with coal in a rotary kiln at 1150°C to obtain sponge iron as a product. Also process data including exhaust gas composition to be taken (Fig. 1 -3).

The product was collected in metallic buckets. The bucket could be purged with nitrogen if necessary. Nitrogen could also be introduced into the kiln outlet head (Fig. 4, Table 4) to obtain a lean air atmosphere.

Fig. 1. Iron ore pellets for direct reduction.

Table 1. Chemical composition of the head sample, wt. %.

Composition		Pallets batch 1	Pallets batch 2	Pallets batch 3
Fe (total)	%	49.2	46.5	43.2
$BaSO_4$	%	2.20 - 3.00	2.20 - 3.00	2.20 - 3.00
Mn	%	7.0 - 9.0	7.0 - 9.0	7.0 - 9.0
SiO_2	%	6.7 - 8.00	6.7 - 8.00	6.7 - 8.00
CaO	%	1.4 - 2.0	1.4 - 2.0	1.4 - 2.0
MgO	%	0.7 - 1.1	0.7 - 1.1	0.7 - 1.1
Pb	%	0.40 - 0.45	0.40 - 0.45	0.40 - 0.45
Al_2O_3	%	1.2 - 1.5	1.2 - 1.5	1.2 - 1.5
Cu	%	0.12 - 0.14	0.12 - 0.14	0.12 - 0.14
Zn	%	0.78 - 0.8	0.78 - 0.8	0.78 - 0.8
Particle size	mm	9 - 12	9 - 12	9 - 12
Bulk density	kg dm^{-3}	1.2	1.2	1.2

Table 2. Chemical composition of the coal. wt. %.

C	H	N	O_2	S	A	W	%
45.60	3.29	1.41	8.42	1.28	15.00	25.00	100

**A-ash, W-moisture*

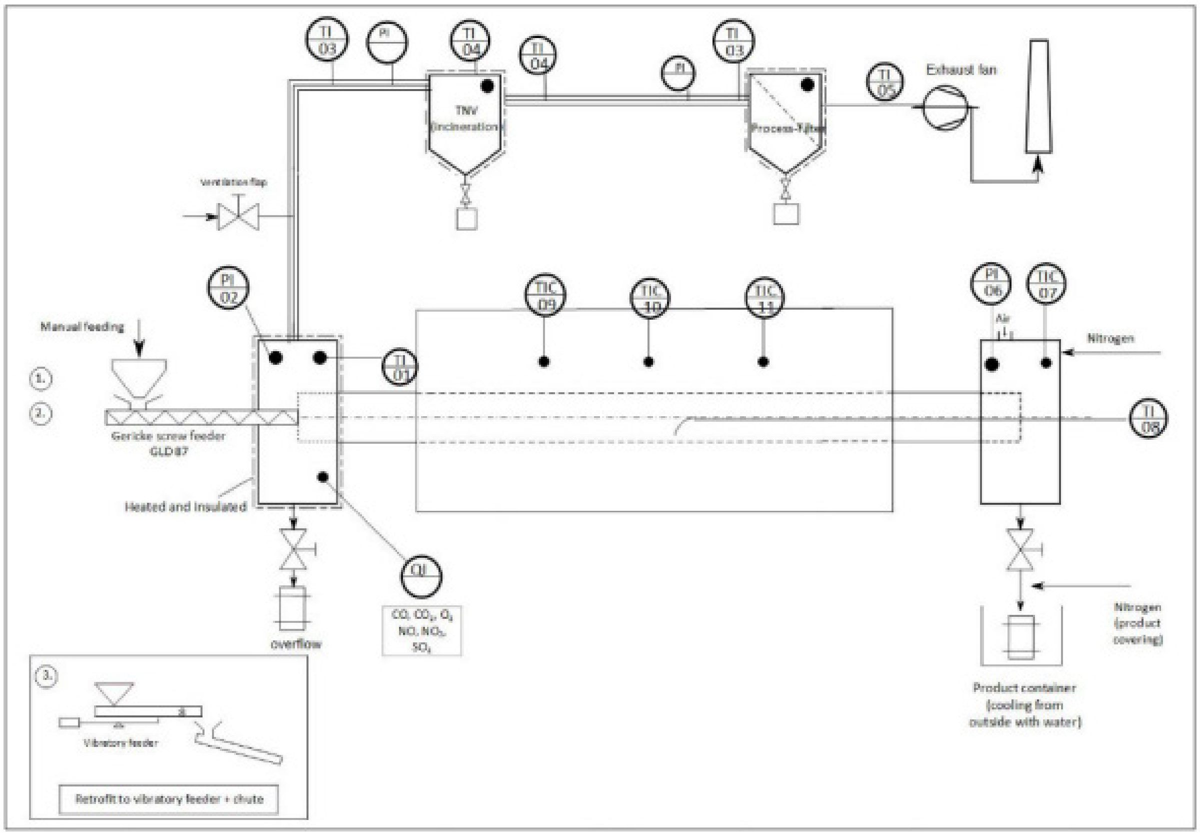

Fig. 2. Scheme of the using equipment for the tests.

Fig. 3. Pictures of the using equipment for the tests.

Trial program

Trial point 1 started with a feed rate of 2.5 kg h^{-1} iron ore pellets and 0.25 kg h^{-1} coal grits under a nitrogen atmosphere (2 x 15 L min^{-1} N_2). The initial rotation speed was 2.0 rpm but it was later increased to 2.2 and 2.5 rpm. In the meantime, was agreed to open a small vent for the air intake at the outlet side because the CO- concentration went up to > 10 vol. % which means above the lower explosion limit. The pellet reduction process then proceeded according to the plan mentioned above. A regular supply of pellets and coal was started to achieve stable process parameters. It gradually reached 2.5 kg h^{-1} of pellets and 0.250 kg h^{-1} of coal. The main goal of the process was achieved to run the reduction of the pellets at constant process parameters for the specified time of 60 min. At these parameters, all three experiments were carried out, the difference being the temperature of the medium for the reduction of iron oxides.

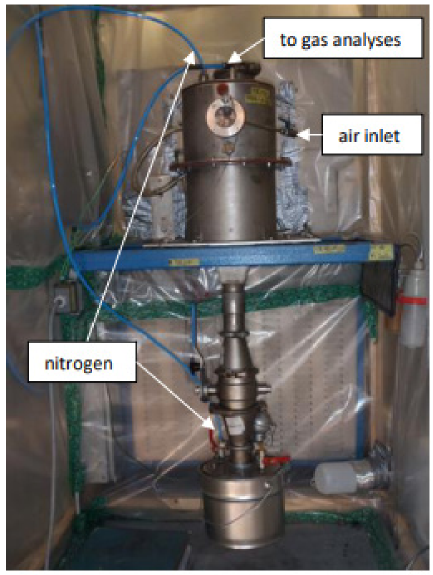

Fig. 4. Kiln outlet side with product collection and nitrogen supply.

Table 3. Technical parameters.

Kiln/Plant	IDC
Material of rotary kiln tube	2.4851(Inconel alloy 601)
Heating	Indirect, electric, 3 heating zones
Dimensions (diameter x length; heated tube)	0.1 m x 1.0 m
Throughput (raw material), depending on material properties	0.1 - 2 kg h^{-1}
used	1 - 2 kg h^{-1}
Temperature range	100 - 1400°C
Exhaust cleaning	Post combustion

RESULTS AND DISCUSSION

Exhaust gas analysis during the direct reduction

The research was done on direct reduction in a tubular rotary kiln. The process parameters for the iron oxide reduction process to occur are determined. From the obtained results the value of iron in the pellets has increased after the reduction process (Fig. 5, 6). The amounts of harmful impurities Pb and Zn within the necessary limits for the reduced pellets have decreased. Material with that chemical composition can be used as raw material for blast furnace production.

The appropriate coals for the process are identified and shown in Table 5.

Studies were also made on the strength of the pellets after the direct reduction process in a tube rotary kiln. The mechanical strength of the pellets was tested, and the results are shown in Table 6.

Table 4. Trial points overview.

Batch	Raw material	Raw material feed, kg h^{-1}	Temp. HZ 1-3, °C	Inclination, degree	Rotation, rpm	Dwell time (calc.), min
1	Iron ore pellets (49.2 % Fe) / coal grits	2.5/0.25	1150	1.5	2.5	60
2	Iron ore pellets (46.5 % Fe) / coal grits	2.5/0.25	1100	1.5	2.5	60
3	Iron ore pellets (43.2 % Fe) / coal grits	2.5/ 0.25	1050	1.5	2.5	60

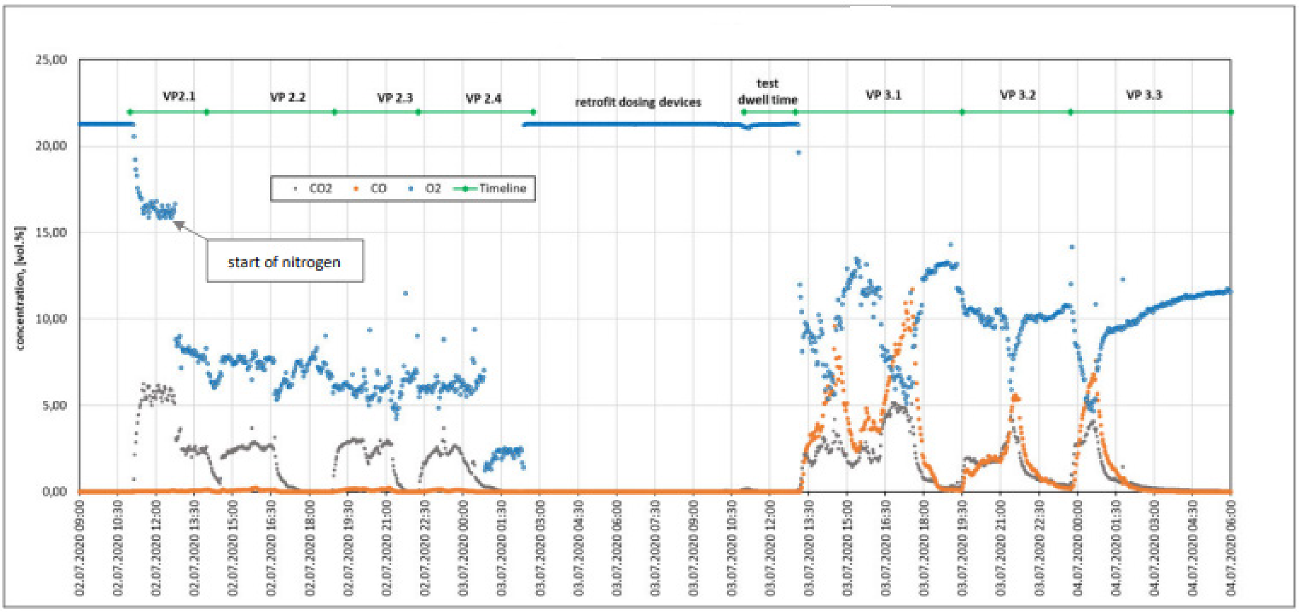

Fig. 5. Exhaust gas analysis during the direct reduction process.

Fig. 6. Pellets after reduction in rotary kiln.

Table 5. Chemical composition of the pellets produced from iron concentrate obtained by direct reduction in rotary kiln pallets batch 1, wt. %.

Fe	MgO	CaO	SiO_2	Mn	Pb	C	Zn	Cu
68.0	1.53	7.92	8.10	2.02	0.007	0.19	0.09	0.04

Table 6. The mechanical strength of the pellets.

Batch	Raw material	Raw material feed, kg h^{-1}	Temp. HZ 1 - 3,°C	Inclination, degree	Rotation, rpm	Dwell time (calc.), min	Strength kg/pellet
1	Iron ore pellets (49.2 % Fe)/ coal grits	2.5/0.25	1150	1.5	2.5	60	240
2	Iron ore pellets (46.5 % Fe)/ coal grits	2.5/0.15	1100	1.5	2.5	60	220
3	Iron ore pellets (43.2 % Fe)/ coal grits	2.5/ 0.15	1050	1.5	2.5	60	200

CONCLUSIONS

After the metallization process, pellets with better strength characteristics are obtained and a high degree of metallization is achieved. All pellets have satisfactory strength characteristics. The process parameters for the iron oxide reduction process to occur are determined. The best results were achieved with sample number 1 with the following process parameters: residence time of the pellets 60 min at a temperature of 1150°C. Under these conditions, the degree of metallization is the highest compared to the other two samples and hence the strength of pellets is satisfactory for further blast furnace production. From the obtained results the value of iron in the pellets has increased after the reduction process. The amounts of harmful impurities Pb and Zn within the necessary limits for the reduced pellets have decreased Table 5. Material with that chemical composition can be used as raw material for blast furnace production. The appropriate coals for the process have been identified.

Authors' contribution: *For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, V.K., I.M., methodology, V.K, I.M.; formal analysis, I.N., B.Y.; investigation, I.M., B.Y.; resources, R.G.; data curation, I.M, R.G.; writing-original draft preparation, I.M, B.Y.; writing-review and editing, I.M., B.Y.; visualization, R.G., I.M; supervision, I.M.; project administration, B.Y.; funding acquisition, I.M. All authors have read and agreed to the published version of the manuscript."*

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