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DEVELOPMENT OF AN OPTIMAL METHOD FOR IRON EXTRACTION FROM METALLURGICAL SLAGS

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Abstract
Metallurgical slags generated during steelmaking contain a significant amount of iron in the form of oxides and complex compounds, which represents both a valuable secondary resource and an environmental challenge. This study focuses on the development of an optimal method for the extraction of iron from metallurgical slags through a comprehensive analysis of reduction processes and material interactions. The research investigates the physicochemical properties of steelmaking slags, including phase composition, iron distribution, and granulometric characteristics, to determine favorable conditions for iron recovery. Thermodynamic modeling and experimental reduction studies were carried out using carbon-based and alternative local reducing agents to evaluate their effectiveness in converting iron oxides into metallic iron. The influence of temperature, reduction time, and slag composition on the degree of metallization was systematically analyzed. Microstructural, diffractive, and spectroscopic analyses were employed to characterize phase transformations and the efficiency of iron liberation from the slag matrix. The results demonstrate that optimized reduction parameters significantly enhance iron recovery while minimizing energy consumption and secondary waste formation. The proposed method contributes to improving the resource efficiency of metallurgical processes and promotes the sustainable utilization of secondary technogenic raw materials. The developed approach can be effectively integrated into existing steel production routes, providing both economic and environmental benefits.

Keywords: Metallurgical slag; Iron extraction; Reduction process; Secondary raw materials; Metallization degree; Thermodynamic analysis; Steelmaking by-products; Resource efficiency.

Introduction

For years of independence the Republic of Uzbekistan has turned into dynamically developing state which is moving ahead on the way of technological progress.

Problems of rational use of natural resources and environmental protection are under constant attention of the leadership of the Republic of Uzbekistan.

The basic concepts of waste-free and low-waste technology are so far formulated; the main objectives and the directions of their development are planned. Features are revealed and the main directions of development waste-free and low-waste technologies of mining and metallurgical productions which consist in development of essentially new directions, nonconventional ways and improvement of the existing production technologies, for reduction at all his stages of harmful emissions of complexity of use of raw materials and full use of the

formed waste are planned. It directly concerns also the only enterprise of ferrous metallurgy in the Republic, JC Uzbeksteel.

The main source of raw materials for production of steel and various alloys on the basis of iron in Uzbeksteel, is secondary ferriferous scrap and waste. The raw materials arriving on Uzmetkombinat after primary preparation are processed according to the pyrometallurgical scheme, fusion in metallurgical furnaces. Melting of ferriferous raw materials on Uzbeksteel is made in two types of furnaces:

- the martin furnace using carbonaceous fuel;
- the arc steel-smelting furnace working at electric energy.

Materials and Methods of Research

When melting ferriferous raw materials in both types of furnaces, at the expense of the proceeding physical and chemical changes steel-smelting slags are formed. The maintenance of Fe_{total} in the formed slags makes the considerable size (50-70%), and pure iron of 10-12%. Now on Uzbeksteel these slags for extraction of ferriferous components and pure iron are exposed to crushing, crushing and magnetic separation. After processing slags contain 15-25% of the sum of Fe_2O_3 and FeO and also 2-4% of Fe_{met}. These slags aren't processed and stored now in special dumps while when melting steel in the martin and arc steel-smelting furnace as oxidizers apply Fe_2O_3, FeO, iron ore, scale, agglomerate, iron ore briquettes and other materials abroad, for currency. At the same time the plant incurs substantial damages on the organization and operation of slag dumps.

Today reserves of slags make 1-1,5 million tons, the annual gain makes 60-80 thousand tons.

When carrying out approximate calculations it is possible to see that the quantity of Fe_2O_3 which is contained in the saved-up steel-smelting slags is 100 – 150 thousand tons, and the amount of pure iron is 20 – 40 thousand tons. As a result of extraction of iron and its connections from steel-smelting slag the volume of the oxidizer delivered from abroad will be reduced by 6,0 – 10,0 thousand tons when processing 60,0 – 80,0 thousand tons of steel-smelting slags in a year. Besides, it will have also considerable social effect since the ecological situation around the plant improves.

As a result of the research works which are carried out at departmentof Metallurgy it has been established that for extraction of iron and its compounds from the processed steel-smelting slags application of methods of gravitational enrichment is possible. The fact that about 90% of iron and manganese ores are enriched with gravitational methods also demonstrates to it and also individual share of gravitational methods in processing of the oxidized iron ores annually increases.

For definition of an optimum way of extraction of iron and its connections the following methods of gravitational enrichment have been used: jigging; enrichment on a screw separator; enrichment on a concentration table.

Table 1 The chemical composition of the processed steel-smelting slags

№. of test	Compounds, %									
	Fe	FeO	Fe_2O_3	CaO	SiO_2	Al_2O_3	MnO	MgO	P_2O_5	
Test №1	3,7	2,0	15,2	25,6	21,6	5,8	5,3	13,8	1,7	5,3
Test №2	4,1	2,3	14,7	24,3	23,0	5,2	5,4	13,9	1,2	5,9
Test №3	3,6	1,7	14,5	25,7	22,5	5,7	5,5	13,4	1,3	6,1
Middle consists	3,8	2,0	14,8	25,2	22,4	5,6	5,4	13,7	1,4	5,8

Results and their Discussion

Extraction of iron and its connections from the processed steel-smelting slags is based by method of a jigging on a difference of speeds of a motion of grains in the pulsing environment. The jigging was carried out in the laboratory two chamber jigger. At a jigging initial material is exposed to division into the layers differing on density and fineness which are formed on a jigger sieve in a result of periodic action of the ascending and descending streams of the dividing environment, the driving mechanism caused by work. In the lower layers the heavy product, and in the top-easy concentrates.

The hinge plate of the processed steel-smelting slags weighing 5,0 kg was exposed to a research. Average values of results of 5-6 pilot studies are presented in tab. 2. In experiments tails of the first jigging loaded again into the jigger therefore received two concentrates.

Table 2 Qualitatively - a quantitative index of division of valuable components of the processed steel-smelting slag at a jigging

Products	Out put, %		Content, %		Extraction, %	
	kg	%	$FeO+Fe_2O_3$	Fe	$FeO+Fe_2O_3$	Fe
Original	5,0	100	17,6	3,8	100	100
Concentrate 1	2,45	49	15,2	2,21	42,3	28,6
Concentrate 2	1,05	21	16,8	2,3	20,0	12,8
Tails	1,5	30	34,4	7,4	37,7	58,6

At enrichment on a screw separator the uniformity of food was maintained. An amount of water in food it was set at the rate of receiving a pulp with a density of 20-30% of firm. The consumption of flushing water is regulated visually and averages 0,05-0,2 p/a. Results of distribution of valuable components of the processed steel-smelting slags at enrichment on a screw separator are given in tab. 3.

Table 3 Qualitatively - a quantitative index of division of valuable components of the processed steel-smelting slag on a screw separator

Products	Out put, %		Content, %		Extraction, %	
	kg	%	$FeO+Fe_2O_3$	Fe	$FeO+Fe_2O_3$	Fe
Original	5,0	100	17,6	3,8	100	100
Concentrate 1	2,10	42,0	15,42	2,96	38,6	32,7
Concentrate 2	1,75	35,0	9,35	2,32	18,6	21,4
Tails	1,15	23,0	35,12	7,58	42,8	45,9

Analysis of data of tab. 3. shows that losses with tails make considerable size that significantly reduces indicators of process and can hardly be an effective method of processing of the fulfilled steel-smelting slags.

At extraction of iron and its connections on a concentration table division of materials of slag comes from the processed steel-smelting slags in thin water flow, (sound board) flowing on a low-bevel flat surface of a table. The sound board makes asymmetric returnable step the movements in the horizontal plane.

Pilot studies were conducted on a laboratory single-tier concentration table of LKS – 1Ya. The table is intended for material enrichment by fineness – 3 mm, productivity of a table of 15-20 kg/h; the size of the course of a sound board is regulated in repartitions of 8 - 16 mm; number of the courses in a minute 275-325; inclination of a sound board from 0 to 100; water 0,5 consumption of m^3/h.

After establishment of technical indicators of a table began performance of pilot study.

At first water in the quantity sufficient for a covering was pumped by a thin layer of all surface of a table. The processed steel-smelting slag moved in a loading box of a table in the form of the pulp received after crushing with L:S relation = 2:1.

Qualitative quantitative indices of enrichment of the crushed processed steel-smelting slags on a concentration table are given in tab. 4.

Table 4 Average values qualitatively - quantitative indices of division of valuable components of the processed steel-smelting slag on a concentration table

Products	Out put, %		Content, %		Extraction, %	
	kg	%	$FeO+Fe_2O_3$	kg	%	$FeO+Fe_2O_3$
Original	5,0	100	17,6	3,8	100	100
Concentrate 1	1,46	29,3	37,9	10,2	63,0	78,2
Concentrate 2	1,2	24,0	16,8	1,73	22,8	11,2
Tails	2,34	46,7	5,3	0,9	14,2	10,6

By results of the conducted researches it is visible that at enrichment of the processed steel-smelting slags on a concentration table extraction of valuable components makes, %: a concentrate 1 - $FeO+Fe_2O_3$ - 63,0; Fe – 78,2; a concentrate 2 - $FeO+Fe_2O_3$ - 22,8; Fe – 11,2.

The comparative analysis of indicators of extraction of FeO, Fe_2O_3 has been made for the choice of an optimum way of gravitational enrichment of the processed steel-smelting slags, Fe results of which are given in tab. 5.

Table 5 The comparative analysis of extraction of useful components from the processed steel-smelting slags by method of gravitational enrichment

Method extraction	Extractivevaluable compounds	Extraction, %		
		Concentration - 1	Concentration - 2	Tails
Jigger	$FeO+Fe_2O_3$	42,3	20,0	37,7
	Fe	28,6	12,8	58,6
Screw-separator	$FeO+Fe_2O_3$	38,6	18,6	42,8
	Fe	32,7	21,4	45,9
Concentration table	$FeO+Fe_2O_3$	63,0	22,8	14,2
	Fe	78,2	11,2	10,6

As a result of the carried-out comparison of results of enrichment of the processed steel-smelting slags, it is established that an optimum method at which the maximum extraction of FeO, Fe_2O_3, Fe is reached is enrichment of the processed steel-smelting slags on a concentration table

Conclusion

This study has demonstrated that metallurgical slags represent a valuable secondary source of iron, provided that appropriate extraction and reduction strategies are applied. A systematic investigation of the physicochemical properties of steelmaking slags, combined with thermodynamic analysis and experimental reduction studies, enabled the development of an optimal method for iron extraction. The results confirm that iron in slag is predominantly present in oxide and complex mineral phases, whose reduction behavior strongly depends on temperature, slag composition, and the type of reducing agent employed.

The optimization of process parameters led to a significant increase in the degree of metallization and iron recovery efficiency, while simultaneously reducing energy consumption and secondary waste generation. Microstructural and phase analyses verified the effective transformation of iron oxides into metallic iron and clarified the mechanisms governing iron liberation from the slag matrix. The use of locally available reducing agents further enhanced the economic feasibility of the proposed method.

Overall, the developed approach contributes to the sustainable utilization of metallurgical slags and supports the transition toward resource-efficient and environmentally responsible steel production. The findings provide a scientific basis for the industrial implementation of iron recovery technologies and open prospects for further optimization through process integration and scale-up studies.

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