TASHKENT STATE UNIVERSITY OF ECONOMICS

International journal of topics

INNOVATION SCIENCE AND TECHNOLOGY

Scopus || Electronic journal specializing in Scopus

ISSUE 9

Acceptance of papers **September, 2025**

Acceptance of papers

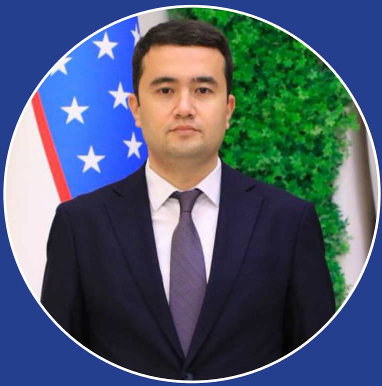
Published monthly

Topics

economics, technology, social sciences

ISSN 3060-5229

Electronic publication, Issue 9. 52 pages.
Approved for publication on September 1, 2025.



THE SCIENTIFIC-POPULAR ELECTRONIC JOURNAL **"INNOVATION SCIENCE AND TECHNOLOGY"** HAS BEEN REGISTERED UNDER THE NUMBER **C-5669633** BY THE AGENCY FOR INFORMATION AND MASS COMMUNICATIONS (AOKA) OF THE REPUBLIC OF UZBEKISTAN, EFFECTIVE FROM OCTOBER 9, 2024.

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ANALYSIS OF TECHNOGENIC WASTE FROM IRON-CONTAINING METALLURGICAL PRODUCTION PROCESSES

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Abstract: This article examines iron-containing metallurgical wastes, including electric arc furnace (EAF) dust, steelmaking slags, copper smelting slags, and tailings from copper concentrators. The chemical and phase composition of these wastes was analyzed, highlighting both environmental and economic benefits of recycling. The study revealed significant contents of iron, zinc, copper, and other valuable components, supporting their potential as secondary raw materials.

Key words: metallurgical wastes, EAF dust, slag, tailings, iron oxides, recycling.

INTRODUCTION

Today, various types of technogenic waste are generated as a result of production processes in different industrial sectors. Technogenic waste produced in the modern metallurgical industry is not only an environmental problem but also an important source of secondary raw materials that can be transformed into economic resources through recycling. Among these, iron-containing technogenic wastes hold particular significance, and their effective recycling is important from the perspectives of environmental purification and resource conservation.

Iron-containing technogenic wastes mainly include dust from electric arc steelmaking furnaces, steel production slags, as well as slags from copper production and waste from copper beneficiation plants. These wastes are generated at various stages of the metallurgical industry, each having distinct composition and properties. For example, steel production slags can be widely used in construction materials and other industrial fields. Steelmaking dust, in turn, has important environmental significance, as its recycling enables resource savings. Slags from copper production and wastes from copper beneficiation plants, due to their composition and properties, are considered promising technogenic wastes for recycling and utilization in the metallurgical industry.

At the same time, the issue of recycling these wastes is not only about solving environmental problems but also about increasing economic efficiency, producing import-substituting products, and creating innovative materials. In the context of Uzbekistan, this issue is even more pressing because the country has limited iron ore reserves, while the volume of waste generated at various stages of metallurgical production is increasing year by year. This calls for a comprehensive approach to expanding the local raw material base and obtaining high value-added products through recycling industrial wastes.

LITERATURE REVIEW ON THE TOPIC

I.Yildirim and M.Prezzi[1] systematically analyze the chemical-mineral composition and morphology of BOF, EAF and LF slags from steelmaking. The authors show that the ratio of free CaO/MgO, RO-phase and Fe-oxides determines the volumetric stability (swelling), pH and leaching behavior. The applications in construction, road base and cement additive are explained by the dependence of pre-process stabilization (environmentalization, carbonation, grain size control). The work provides a scientific basis for the conversion of technogenic steel waste into safe and valuable streams.

X.Lin et al.[2] comprehensively review the properties of EAF dust (franklinite, Zn-, Pb-, Fe-rich phases) and pyrometallurgical processing routes. Waelz, RHF, PRIMUS, OXYCUP and plasma methods are compared in terms of thermodynamic basis, sensitivity to chlorine and alkali contaminants and secondary waste streams. The analysis highlights the need for iron recovery, process integration and LCA criteria to be combined in the design of cement production based on blast furnace slag using LCA (ISO 14040/44). Although partial replacement of clinker reduces the energy and emissions burden, the results are shown to be sensitive to allocation rules, grinding/transport parameters and energy mix. The work establishes a methodology for evaluating BF slag as a "by-product" and justifies the need to consider thresholds, sensitivity and data quality to reliably calculate environmental benefits at the plant level.

P.Grudinsky et al.[4] characterized the slag from the Waelz process by ICP-AES, XRD and Mössbauer and performed low-intensity wet magnetic separation tests. The complex phase composition of the samples (Fe^0, wüstite, goethite/lepidocrocite, Zn oxide/silicates) hindered selective separation, and the formation of secondary hydroxide phases during storage reduced efficiency. The results suggest that Waelz slag should not be considered a "waste" but rather a product whose composition can be optimized.

A.Andersson et al.[5] tested the feasibility of converting the high-zinc fraction of tornado-enriched BF sludge into self-reducing, cold-bonded briquettes/pellets in a plant-scale. The problems of dissolution/dissolution in the desulfurization section and re-injection into the BOF, the control of Zn loading and the criticality of recipe parameters (cement content, carbon, granulometry) are shown. The approach prevents Zn accumulation in the BF, while opening the way to a more complete reuse of dust/sludge.

RESEARCH METHODOLOGY

Black metallurgy dust is generated as a result of intensive physico-chemical processes occurring in metallurgical furnaces and raw material transfer systems. Under high-temperature conditions (1000–1600°C), oxidation of iron and other elements takes place, along with the thermal decomposition and mechanical fragmentation of raw material particles, resulting in the formation of dust particles sized at the micron level (1–100 μm). These particles are carried by gas flows to dust collection devices (cyclones, electrostatic precipitators, fabric filters), where they accumulate.

ANALYSIS AND RESULTS

The dust generated in the ferrous metallurgy industry belongs to the group of iron-containing technogenic wastes. Based on the iron content by weight, these dusts are classified as follows: rich dust (Fe ≥ 55%), mainly composed of Fe3O4 and Fe2O3; relatively rich dust (Fe 40–55%), primarily containing iron oxides along with silicon dioxide and aluminum oxide; poor dust (Fe < 40%), mainly composed of SiO2, CaO, and MgO. This classification is crucial for selecting appropriate recycling technologies.

Therefore, the chemical composition of dust emitted from electric arc steelmaking furnaces at metallurgical enterprises was specifically studied. The following tables (Tables 1, 2, 3, and 4) present the main components and quantitative composition of dust generated at various enterprises. This data serves as an important source for evaluating the potential for dust recycling.

Table 1 shows the chemical composition of dust produced from the electric arc steelmaking furnace in the steelmaking shop of "Uzmetkombinat" JSC (Table 1) [6].

Table 1.

Name and Chemical Formula	Fe (Iron)	Fe_2O_3 (Hematite)	MgO (Magnesium Oxide)	S (Sulfur)	SiO_2 (Silicon Dioxide)	Zn (Zinc)
Amount, %	38,60	55,62	0,01	2,0	10,98	14,43
Name and Chemical Formula	Pb (Lead)	Cu (Copper)	CaO (Calcium Oxide)	Cr (Chromium)	MnO (Manganese Oxide)	Al_2O_3 Aluminum (Oxide
Amount, %	0,69	0,12	3,67	0,13	1,30	5,41

Table 2 presents the chemical composition of the dust generated from the electric arc steelmaking furnace in the Casting Shop of the Central Repair Mechanical Plant of "OKMK" JSC (Table 2).

Table 2.

Name and Chemical Formula	Fe (Iron)	Fe_2O_3 (Hematite)	MgO (Magnesium Oxide)	S (Sulfur)	SiO_2 (Silicon Dioxide)	Zn (Zinc)
Amount, %	34,63	52,08	0,01	3,75	10,98	13,96
Name and Chemical Formula	Pb (Lead)	Cu (Copper)	CaO (Calcium Oxide)	Cr (Chromium)	MnO (Manganese Oxide)	Al_2O_3 (Aluminum Oxide)
Amount, %	1,23	0,24	0,80	0,71	9,60	4,26

Table 3 shows the chemical composition of the dust generated from the electric arc steelmaking furnace at "LI DA METAL TECHNOLOGY" LLC (Table 3).

Table 3.

Name and Chemical Formula	Fe (Iron)	Fe_2O_3 (Hematite)	MgO (Magnesium Oxide)	S (Sulfur)	SiO_2 (Silicon Dioxide)	Zn (Zinc)
Amount, %	29,57	41,40	0,02	2,02	17,05	13,50
Name and Chemical Formula	Pb (Lead)	Cu (Copper)	CaO (Calcium Oxide)	Cr (Chromium)	MnO (Manganese Oxide)	Al_2O_3 (Aluminum Oxide)
Amount, %	1,42	0,20	5,74	0,18	1,86	13,50

Table 4 presents the chemical composition of the dust generated from the electric arc steelmaking furnace at the Tashkent Pipe Plant (Table 4).

Table 4.

Name and Chemical Formula	Fe (Iron)	Fe_2O_3 (Hematite)	MgO (Magnesium Oxide)	S (Sulfur)	SiO_2 (Silicon Dioxide)	Zn (Zinc)
Amount, %	31,90	38,32	17,97	2,15	17,05	11,53
Name and Chemical Formula	Pb (Lead)	Cu (Copper)	CaO (Calcium Oxide)	Cr (Chromium)	MnO (Manganese Oxide)	Al_2O_3 (Aluminum Oxide)
Amount, %	0,69	0,15	3,41	0,17	1,9	6,34

The results of research on the chemical composition of dust show that the main components of the dust are iron and its oxides (Fe, Fe_2O_3), with their quantities recorded up to 29–39% for iron and 38–55% in the form of hematite. Additionally, the presence of economically important components such as silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), manganese oxide (MnO), calcium oxide (CaO), as well as zinc (Zn) and lead (Pb) was identified. These results indicate that metallurgical dust is not simply waste but an important secondary raw material source for recycling.

Another major technogenic waste generated in metallurgical processes is slags. Slags are primarily formed during the melting of metal-containing raw materials at high temperatures (1400–1600 °C). Chemically, slags are complex oxide systems usually composed of main components such as SiO_2, Al_2O_3, CaO, and MgO. At the same time, slags also retain certain amounts of iron, manganese, and other metal oxides.

It is important to emphasize that large volumes of various slags are produced annually in metallurgical enterprises of Uzbekistan. Their chemical composition and mineralogical properties vary significantly from one another. The following tables (Tables 5, 6, 7, 8, and 9) present the main compositions of slags generated at different metallurgical enterprises.

Table 5 presents the chemical composition of the slag generated from the electric arc steelmaking furnace in the steelmaking shop of "Uzmetkombinat" JSC (Table 5).

Table 5.

Name and Chemical Formula	CaO	SiO_2	MnO	Al_2O_3	S	Fe_{um}	MgO	Asos
Sample 1	52,8	24,3	2,4	4,7	0,34	5,2	6,9	2,2
Sample 2	56,2	25,1	0,3	5,0	0,88	0,8	8,2	2,2
Sample 3	40,8	19,2	3,0	5,4	0,14	19,4	3,7	2,1

Table 6 presents the chemical composition of the slag generated from the electric arc steelmaking furnace in the Casting Shop of the Central Repair Mechanical Plant of "OKMK" JSC (Table 6) [7].

Table 6.

Name and Chemical Formula	CaO	SiO_2	MnO	Al_2O_3	SO_3	Fe_2O_3	MgO	P_2O_5
Sample 1	5,493	30,26	20,64	4,847	1,288	13,70	26,07	0,15
Sample 2	5,352	29,92	20,51	4,56	1,12	14,30	25,4	0,09
Sample 3	5,121	30,52	19,52	3,93	1,322	14,02	24,9	1,02

Table 7 presents the chemical composition of the slag generated from the electric arc steelmaking furnace at "LI DA METAL TECHNOLOGY" LLC (Table 7).

Table 7.

Name and Chemical Formula	CaO	SiO_2	MnO	Al_2O_3	S	Fe_{um}	MgO	Asos
Sample 1	29,5	13,1	5,3	5,5	0,12	21,4	8,5	2,3
Sample 2	30,5	15,1	5,5	6,1	0,10	17,2	10,5	2,0
Sample 3	29,1	13,4	5,8	7,2	0,08	17,7	7,9	2,2

Table 8 presents the analysis results of the slags from the smelting reverberatory furnace at the Copper Smelting Plant of "OKMK" JSC (Table 8).

Table 8.

Name and Chemical Formula	CaO	SiO_2	Cu	Al_2O_3	S	Fe_{um}	MgO	Ni
Sample 1	3,6	30,6	0,29	2,4	0,6	41,7	1,6	0,12
Sample 2	4,9	34,7	0,43	6,5	1,3	44,8	0,9	0,01
Sample 3	1,8	35,6	0,46	3,2	0,4	49,1	3,6	0,2

Table 9 presents the analysis results of the converter furnace slags at the Copper Smelting Plant of "OKMK" JSC (Table 9).

Table 9.

Name and Chemical Formula	CaO	SiO_2	Cu	Al_2O_3	S	Fe_{um}	MgO	Fe_3O_4
Sample 1	1,6	26,0	1,60	1,7	-	44,2	-	16,5
Sample 2	2,2	23,2	1,95	2,1	-	46,8	-	23,2
Sample 3	0,75	19,8	2,3	3,16	-	48,5	0,46	16,3

The results of studying the chemical composition of slags show that the main mass of slags consists of CaO and SiO_2 oxides, with significant amounts of FeO/Fe_2O_3, MgO, Al_2O_3, and MnO also present. Additionally, slags produced at some enterprises contain SO_3 and P_2O_5 components, the quantities of which vary depending on the type of raw materials used and technological conditions. The analysis results revealed significant differences between enterprises. For example, slags from "Uzmetkombinat" JSC are characterized by high CaO and SiO_2 content, while slags from "OKMK" JSC have relatively higher levels of MgO and MnO. Slags from "LI DA METAL TECHNOLOGY" LLC, on the other hand, are distinguished by a high content of iron oxides. These differences determine the mineralogical composition, physico-chemical properties, and technological approaches to processing the slags.

The obtained data confirm that electric arc steelmaking furnace slags are not simple waste but can be considered as promising raw materials for the production of construction materials, pigments, secondary sources of metals, and other value-added products.

In the metallurgical industry, the significant content of valuable elements in technogenic wastes generated during ore and raw material processing forms the basis for considering them as important secondary raw materials. Such wastes include those from beneficiation plants as well as slags from non-ferrous metallurgy plants. These wastes contain key elements such as iron, silicon, aluminum, calcium, manganese, as well as copper, nickel, zinc, and other non-ferrous metals. This further increases their value and scientifically and practically justifies the need for recycling.

Within the scope of this study, technogenic wastes generated in large enterprises in Uzbekistan were chemically analyzed, including wastes from the Chodak gold extraction plant and wastes from the 1st and 2nd copper beneficiation plants. The obtained results are presented in Tables 10 and 11, allowing for the identification of the unique characteristics of each waste.

Table 10 presents the chemical composition of the wastes from the Chodak gold extraction plant (Table 10) [3].

Table 10.

Name and Chemical Formula	(Iron (Fe	Hematite ((Fe_2O_3	Manganese Oxide (MnO)	Sulfur (S)	Silicon Dioxide (SiO_2)	(Potassium (K
Amount, %	2,054	2,937	0,030	0,28	83,42	2,85
Name and Chemical Formula	Silicon (Si)	Copper (Cu)	Calcium Oxide (CaO)	Potassium Oxide (K_2O)	(Aluminum (Al	**Aluminum Oxide (Al_2O_3)**
Amount, %	38,99	0,001	0,84	3,4	6,38	12,06

Table 11 presents the analysis results of the waste from the 1st Copper Beneficiation Plant of "OKMK" JSC (Table 11).

Table 11.

Name and Chemical Formula	Iron (Fe)	Hematite (Fe_2O_3)	Iron oxide (FeO)	Sulfur (S)	Silicon dioxide (SiO_2)	Zinc (Zn)
Amount, %	8,69	8,83	3,23	2,77	67,3	0,026
Name and Chemical Formula	Magnesium oxide (MgO)	Manganese oxide (MnO)	Calcium oxide (CaO)	Potassium oxide (K_2O)	Titanium oxide (TiO_2)	Aluminum (III) oxide (Al_2O_3)
Amount, %	1,97	0,08	1,30	4,27	0,36	11,57

Table 12 presents the analysis results of the waste from the 2nd Copper Beneficiation Plant of "OKMK" JSC (Table 12).

Table 12.

Name and Chemical Formula	Iron (Fe)	Hematite (Fe_2O_3)	Copper oxide (CuO)	Sulfur (S)	Silicon dioxide (SiO_2)	Zinc oxide (ZnO)
Amount, %	52,8	48,3	0,617	0,80	32,3	1,56
Name and Chemical Formula	Magnesium oxide (MgO)	Manganese oxide (MnO)	Calcium oxide (CaO)	Potassium oxide (K_2O)	Titanium oxide (TiO_2)	Aluminum (III) oxide (Al_2O_3)
Amount, %	1,15	0,25	2,31	2,11	0,29	6,73

According to the studied results, the wastes from the Chodak gold extraction plant are mainly rich in SiO_2 and Al_2O_3 and are characterized as a source of siliceous materials. The slags from the copper smelting plant of "OKMK" JSC contain a high amount of FeO (41.7–49.1%), making them a secondary source of iron and non-ferrous metals. The wastes from the 1st Copper Beneficiation Plant, due to their silicate composition, are a promising source for the production of construction materials, while the wastes from the 2nd Copper Beneficiation Plant, because of their high iron oxide content, are of significant importance for recycling as a source of iron.

CONCLUSION AND RECOMMENDATIONS

The conducted analyses show that metallurgical production wastes contain not only iron oxides but also zinc, copper, manganese, and other elements. Recycling these wastes not only addresses environmental issues but also enhances economic efficiency. It is possible to separate zinc and iron from steelmaking dust, use slags in construction materials, and extract iron oxide pigments from the wastes of copper beneficiation plants. Thus, the effective utilization of these wastes serves the purpose of producing import-substituting products and conserving resources in the context of Uzbekistan.

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Proofreader: Zokir ALIBEKOV

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