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CAPABILITIES OF DRY MAGNETIC SEPARATION IN PROCESSING OF OLD MANGANESE ORE TAILINGS AT THE ZHEZDY CONCENTRATION PLANT

The authors investigate processibility of old manganese ore tailings of the Zhezdy Concentration Plant (Mn 10.6%, Fe 2.7%, SiO_2 60%) by dry and high-intensity magnetic separation. The chemical and material analyses of the representative sample show that manganese occurs mainly in weakly magnetic minerals (braunite, psilomelane), which predetermines the expediency of application of high magnetic fields. Laboratory tests on roller separator 138T were carried out at the inductions of 0.33–0.90 T. In the optimum mode of 0.48 T, the resultant magnetic concentrate features the Mn content of 29.7% at the recovery of 69.4% and yield of 24.7%, which is 2.6–2.8 times higher than the manganese content of the initial material. An increase of the induction up to 0.68–0.90 T provides the maximum yield and recovery, but is accompanied by a decrease in the quality of the concentrate due to an increase in the content of SiO_2, so such modes are only recommended for the rough processing stage with the subsequent after-treatment. The tendency of Mn concentration is confirmed by the data of the chemical analysis and energy dispersive X-ray spectroscopy (SEM ZEM-20 + EDS Oxford). The results clearly show the promising nature of dry magnetic separation of manganese ore tailings.

Keywords: *manganese, manmade mineral raw materials, tailings, X-ray phase analysis, energy dispersive X-ray analysis, magnetic separation, manganese minerals*
DOI: *10.17580/em.2026.01.08*

Introduction

To date, manmade minerals are commonly the promising, competitive and sustainable resource [1–7]. Manmade minerals incite interest because the actual ore reserves and quality in operating mines worsen. In the meantime, mine waste accumulate large volumes of raw materials comparable with natural deposits. An additional advantage is that this material is already extracted, lies on ground surface and is preliminary milled, and useful minerals are partly separated from barren rocks.

The above arguments are equally applicable to tailings of manganese ore processing [8–11]. It is more often than not that manganese is only partially recovered during processing and goes in a great measure to tailings [12–16].

In Kazakhstan a large manmade source of manganese is the tailings dams of the Zhezdy Concentration Plant. The old tailings reserves here are estimated as follows: Category C_1 is 1 804.7 thousand tons, category C_2 is 512.2 thousand tons, with the average Mn content of 9.08% [17]

According to the State Cadastre, the chemical composition of the tailings being discussed is, %: Mn 10.5; Fe 1.98; SiO_2 32.0; Al_2O_3 7.2; CaO 3.1; MgO 1.2; Sr 0.04; Zn 0.02; Rb 0.018; Ag 1.6 g/t; Au 0.1 g/t [18].

Subject and methods

For the laboratory-scale dressability tests, the subsoil user provided some representative samples of the Zhezdy tailings with the following Mn content: No. 1—9.82%; No. 2—10.23% and No. 3—11.60%.

The bulk sample composed of the three samples above features the following contents, %: Mn—10.59; Fe—2.74; SiO_2—59.82. The moisture content is 5.0%. The bulk density is 1.52 g/cm^3.

The grain-size composition is, %: size –5.0+2.0 mm—1.36; –2.0+1.0 mm—8.20; –1.0+0.5 mm—28.06; –0.5+0.315 mm—19.29; –0.315+0.16 mm—22.00; –0.16+0.0 mm—21.09.

Microscopically, the material represents a typical manganiferous ore material related to silica–calcareous rocks by their structural, textural and lithological characteristics.

The base ore minerals are braunite and psilomelane; the secondary ore minerals are pyrolusite, rhodochrosite, grey manganese, hematite and rhodonite. The nonmetallic minerals are dominated by quartz and silicon–carbonate clayey sandstone. The iron minerals represent magnetite, limonite and hematite; the latter is pseudomorph after magnetite (martite).

The X-ray phase analysis of the test sample proves manganesian minerals, mostly, braunite ($3Mn_2O_3 \cdot MnSiO_3$) and psilomelane ($MnO \cdot MnO_2 \cdot nH_2O$); there are smaller amounts of hematite, magnetite, limonite, etc. The nonmetals are potassic feldspar, quartz, microcline, sericite, kaolinite, calcite, chlorite and gypsum.

Judging by the material constitution and magnetic properties, the test sample are suitable for dry and strong-field magnetic separation as manganese occurs mainly in weak-magnetic minerals [19–21]. High-intensity separators create a high-gradient magnetic field capable of pulling even fine grains of braunite, psilomelane and other manganese oxides [22], while nonmagnetic components (quartz, feldspar, clayey minerals) go to tailings. The dry method eliminates water supply and dewatering of a product, which reduces operating costs and simplifies processing.

The test dry magnetic separation was carried out on separator 138T at the magnetic field intensity of 0.48 T. The results are compiled in **Table 1**.

It follows from Table 1 that the content and recovery of Mn in the magnetic product is, respectively, 29.73% and 69.40%, at the concentrate yield of 24.71%. The magnetic product acquires only 39.00% of iron because of the dominance of the nonmagnetic iron forms (hematite, limonite); Fe remains to a greater extent in tailings. At the same time, 68.58% SiO_2 goes to the nonmagnetic product, which proves efficiency of dry magnetic separation in the magnetic field of the selected intensity.

Figure 1 shows the distribution map of Mn in the initial material and in the separation products, and **Fig. 2** offers the resultant spectra of maps of the test materials obtained on scanning electron microscope

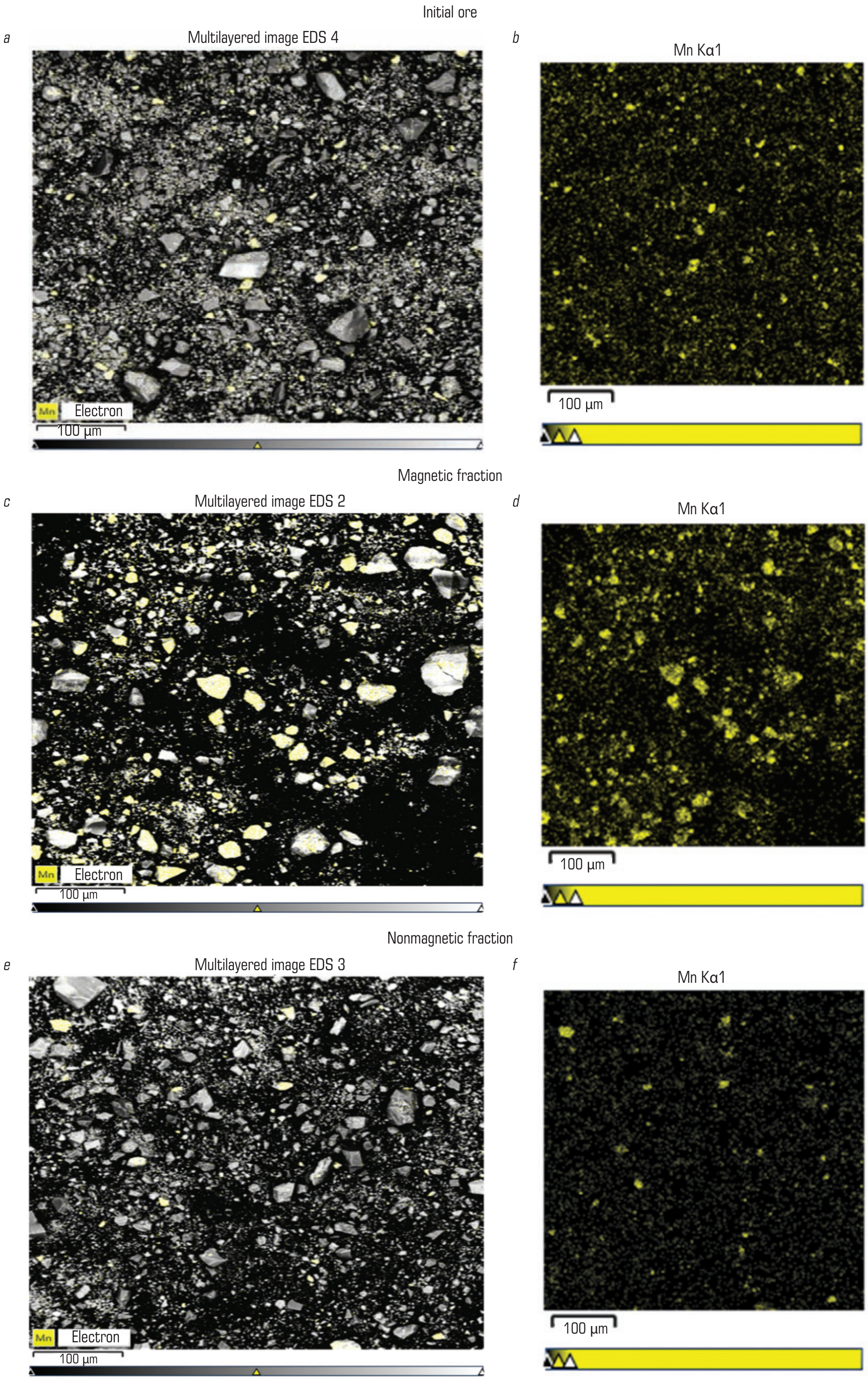

Fig. 1. Multilayered image maps: initial material (*a*); magnetic fraction (*c*); nonmagnetic fraction (*e*) and Mn distribution in: initial material (*b*); magnetic fraction (*d*); nonmagnetic fraction (*f*)

Table 1. Dry magnetic separation on separator 138T

Product	Yield, %	Content, %			Recovery, %		
		Mn	Fe	SiO_2	Mn	Fe	SiO_2
Initial sample	100.00	10.59	2.74	59.82	100.00	100.00	100.00
Magnetic product	24.71	29.73	4.32	33.12	69.40	39.00	13.68
Nonmagnetic product	75.29	4.31	2.22	68.58	30.60	61.00	86.32
Total	100.00	10.59	2.74	59.82	100.00	100.00	100.00

Table 2. Contents of basic elements

Elements	Type of line	Initial material, wt%	Magnetic fraction, wt%	Nonmagnetic fraction, wt%
O	K-series	50.60	49.94	54.19
Si	K-series	24.02	16.69	24.16
Mn	K-series	6.67	17.72	3.84
Fe	K-series	2.08	2.23	1.90

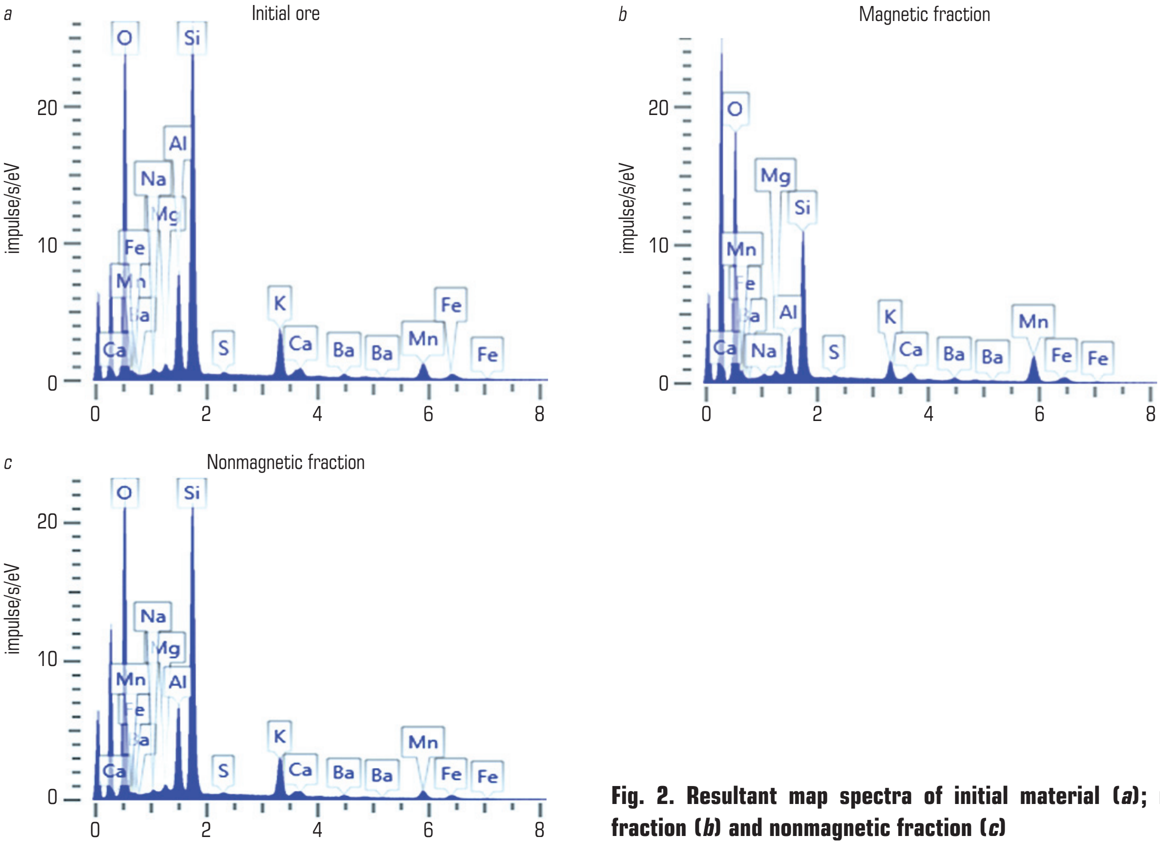

Fig. 2. Resultant map spectra of initial material (*a*); magnetic fraction (*b*) and nonmagnetic fraction (*c*)

ZEM 20, Zeptools, China in the mode of detection of back-scattering electrons using energy dispersive spectrometer Oxford, Oxford, UK.

Table 2 describes the content of the basic elements in the test materials by the resultant map spectra.

The data in Tables 1 and 2 are reflective of an approximately similar multiple increase in the Mn content of the magnetic fraction as compared with the initial material. In Table 2 the content of Mn grows from 6.67% to 17.72% (2.6 times growth), and in Table 1 the total mass fraction of Mn increases from 10.59% to 29.73% (2.8 times growth). So, the trend—concentration of manganese in the magnetic product—is proved by both analytical techniques, though the absolute values differ because of the difference between the methods and the ways of presentation of the results.

The tests of the effect of magnetic induction on the qualitative and quantitative indicators of products of manganese-bearing tailings processing were carried out at the magnetic field intensity of 0.33, 0.48, 0.68 and 0.90 T. The results are presented in a graphical form in **Figs. 3**

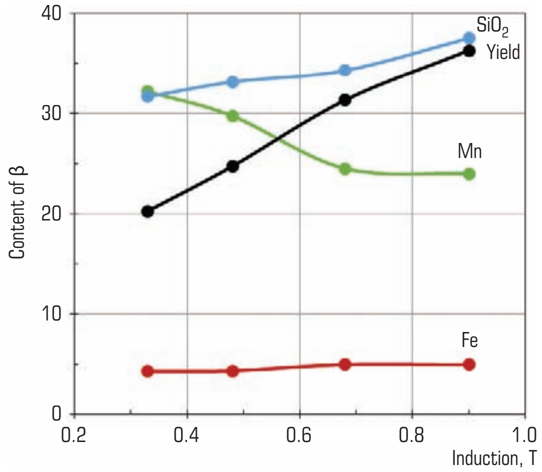

Fig. 3. Mn, Fe and SiO_2 contents of magnetic concentrate and bulk product yield versus magnetic field intensity

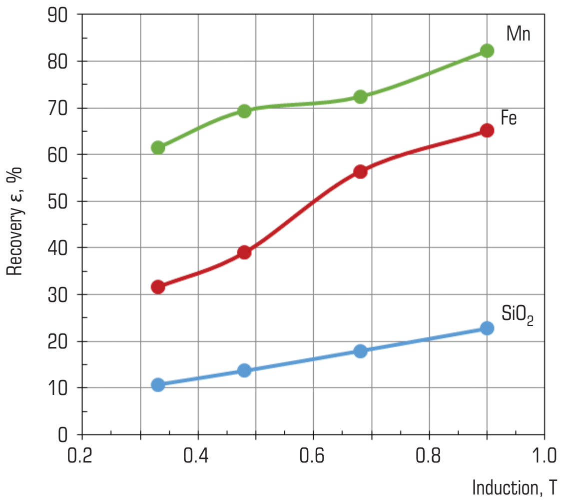

Fig. 4. Recovery of Mn, Fe and SiO_2 in magnetic concentrate versus magnetic field intensity

and **4** as the curves of the magnetic concentrate yield (γ), target material recovery (ε), target material content (β) and the initial conditions of magnetic separation. These relationships make it possible to assess processing efficiency at different intensity of the magnetic field, and to optimize the process parameters.

It is seen in Fig. 3 that with the increasing magnetic induction from 0.33 to 0.90 T, the composition of the magnetic concentrate and the product yield change. At 0.33 T the concentrate features the maximum content of manganese (32.1%), a small amount of iron (4.28%) and the least content of silica (31.6%), but the yield of the magnetic product is only 20.3% of the mass of the initial material. The increase in the magnetic field induction to 0.48 T leads to a moderate decrease in the content of Mn to 29.7% and to a slight increase in the content of SiO_2 to 33.1%, but also increases the yield of the concentrate to 24.7%. At 0.68 T the Mn content decreases more (24.5%) at an increase in the content of SiO_2 to 34.3% and a substantial increase in the product yield to 31.3%. When the induction is 0.90 T, the content of manganese drops to 24.0%, the content of silica grows to 37.5%, and the yield reaches 36.3%. This is reflective of a noticeable dilution of the concentrate with barren rock at the maximum recovery.

Figure 4 illustrates dynamics of recovery of different components in the magnetic concentrate. The manganese recovery grows linearly from 61.5% at 0.33 T to 82.2% at 0.90 T, which demonstrates a heightened completeness of recovery of the target element in a strong field. The iron recovery grows even faster, from 31.6% to 65.1%, pointing at an increased capture of iron-bearing minerals and at an additional dilution of the concentrates. The silica recovery remains relatively low, but it doubles with an increase in the magnetic field intensity (10.7 → 22.7%), which proves the tendency toward an increased impurity of the concentrate with nonmagnetic rocks at high induction.

Thus, the increase in the magnetic field intensity in a range of 0.33–0.90 T leads to a consistent redistribution of minerals between the magnetic concentrate and tailings, which shows up as mutually antithetic dynamics of the qualitative and quantitative indicators of the process. At the induction of 0.33 T, the concentrate features high quality but low quantity, at 0.48 T the content of Mn is reasonable (30%) at the recovery of 70% and moderate impurity with SiO_2, which is an optimal quality–quantity ratio. At the induction increased to 0.68 T, the yield and recovery grow with the noticeable decrease in the content of Mn and increase in the content of SiO_2. At the maximum induction of 0.90 T, the recovery and yield of manganese is the highest, but the concentrate quality is the worst because of its impurity. Consequently, the optimized working range of induction is 0.48–0.55 T. The range of 0.60–0.68 T is admissible at the slackened quality requirements, and the induction of 0.90 T is advisable for the rough processing stage to be followed with obligatory recleaning.

Conclusions

1. The chemical composition and material constitution of a representative sample of old manganese ore tailings from the Zhezdy Concentration Plant are studied.

2. The analysis of the material constitution and magnetic properties of the old tailing sample from the Zhezdy CP shows that the material is a promising subject for dry magnetic separation in a high-intensive magnetic field as manganese is mostly concentrated in weakly magnetic minerals such as braunite, psilomelane and other.

3. The dry magnetic separation efficiency of the Zhezdy tailings is proved on separator 138T at the induction of 0.48 T: the produced magnetic concentrate contains Mn 29.73%, which is 2.6–2.8 times higher than the manganese content of the initial material. The tendency of manganese concentration in the magnetic product is proved by the chemical and energy-dispersive X-ray analysis.

4. The influence of the magnetic field induction (0.33–0.90 T) on the qualitative and quantitative indicators of dry magnetic separation of old tailings is investigated: the increase in the field intensity within this range leads to the consistent redistribution of minerals between the concentrate and tailings. The optimized working mode of separation is admitted as the induction of 0.48 T: the produced concentrate features the Mn content of 29.7% at the recovery of 69.4% and yield of 24.7%. The range of 0.60–0.68 T is admissible at lower quality standards and the induction of 0.90 T is only advisable for the rough processing stage with the obligatory recleaning afterwards.

Acknowledgements

This research is funded by the Committee of Industry of the Ministry of Industry and Construction of the Republic of Kazakhstan under program-targeted funding for scientific research for 2024-2026, BR23991563: «Creation of Innovative Resourch-Saving Technologies for Mining and Integrated Processing of Mineral and Technogenic Raw Materials».

References

1. Bykhovsky L. Z., Sporykhina L. V. Industrial waste as a reserve to replenish mineral resources: Status and development problems. *Mineral recourses of Russia. Economics and management*. 2011. No. 4. pp. 15–20.
2. Technical Assessment of Mineral Raw Material. Development of Ore Concentration Technology. Reference book. Moscow : Nedra, 1992. 414 p.
3. Chanturiya V. A., Kozlov V. A. Current problems in processing of refractory ore and manmade resources. *International Conference Proceedings : Current Problems of Integrated Processing of*

Refractory Ore and Manmade Mineral Resources—Plaksin's Lectures–2017. 2017. pp. 3–6.

4. Shapovalov V. V., Kozyr D. A. Resource-saving technology for utilization of waste dumps of mining industries. *Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering*. 2023. Vol. 334, No. 4. pp. 175–184.
5. Studentsov V. V., Klets A. N. Mining and Metallurgy Sector of Kazakhstan : Review, Resources, Technologies. Almaty : Informatsionno-analiticheskiy centr geologii, ecologii I prirodnykh resursov RK, 1997. P. 2. 234 p.
6. Singh V., Chakraborty T., Tripathy S. K. A review of low grade manganese ore upgradation processes. *Mineral Processing and Extractive Metallurgy Rev*iew. 2020. Vol. 41, Iss. 6. pp. 417–438.
7. Lugovskaya I. G., Yakushina O. I., Pechenkin I. G. Managerial decisions in the mineral raw processing according to an integrated principle as a basis for waste-free production. *MIAB*. 2025. No. 1. pp. 154–167.
8. Nefedova I. N., Lotov V. A., Krasheninnikova N. S. Manmade waste as an additional resource. *Uspehi sovremennogo estestvoznaniya*. 2004. No. 4. pp. 148–149.
9. Information Analysis of Performance of the State Waste Cadastre in 2021. Available at: https://ecogosfond.kz/wp-content/uploads/2022/12/Informacionnyj-obzor_2021.pdf (accessed: 26.01.2026).
10. Chanturia V. A., Shadrunova I. V., Gorlova O. E., Orehova N. N. Formation of resource-saving technologies of processing of secondary raw metal-based adaptation principles. *MIAB*. 2017. No. 1. pp. 347–360.
11. Jamieson H. E., Walker S. R., Parsons M. B. Mineralogical characterization of mine waste. *Applied Geochemistry*. 2015. Vol. 57. pp. 85–105.
12. Dyusenbekov K. B., Shekhirev D. V. Manganese ores: Processing volumes and enrichment methods. *News of the Ural State Mining University*. 2024. No. 3(75). pp. 124–132.
13. Uzhkenov B. S., Mazurov A. K., Seliphonov E. M., Freyman G. G., Morozov A. V. Tantalum and niobium resources in the Republic of Kazakhstan : Current situation and recovery prospects. *International Conference Proceedings. Ulba Metallurgical Plant, Ust-Kamenogorsk. 2003*. pp. 5–6.
14. Yuan Sh., Zhou W., Han Yu., Li Ya. An innovative technology for full component recovery of iron and manganese from low-grade iron-bearing manganese ore. *Powder Technology*. 2020. Vol. 373. pp. 73–81.
15. Mehdilo A., Irannajad M., Hojjati-Rad M. R. Characterization and beneficiation of Iranian low-grade manganese ore. *Physicochemical Problems of Mineral Processing*. 2013. Vol. 49(2). pp. 725–741.
16. Wu H. L., Zhang Y., Liu J. A novel strategy for efficient utilization of manganese tailings: High SO_2 resistance SCR catalyst preparation and faujasite zeolite synthesis. *Waste Management*. 2023. Vol. 164. pp. 66–73.
17. Mustakhimov A. T., Zeynullin A. A., Musin M. T. Study of material composition and enrichability of Zhezdy processing plant manganiferous tailings. *International Journal of Applied and Fundamental Research*. 2020. No. 3. pp. 75–82.
18. Ministry of Ecology, Geology and Natural Resources of the Republic of Kazakhstan. State Waste Cadastre. 2018. Available at: https://ecogosfond.kz/kz-ndiris-zh-ne-t-tynu-aldy-taryny-memlekettik-kadastry-ru-gosudarstvennyj-kadastr-othodov-proizvodstva-i-potreblenija. (accessed: 20.11.2025).
19. Yang C., Li S., Zhang C., Bai J., Guo Z. Application of superconducting high gradient magnetic separation technology on silica extraction from iron ore beneficiation tailings. *Mineral Processing and Extractive Metallurgy Review*. 2018. Vol. 39, No. 1. pp. 44–49.
20. Pelevin A. E. Weakly magnetic minerals processing in roller separators with a system of permanent magnets. *MIAB*. 2022. No. 11-1. pp. 155–168.
21. Huang Q., Yao J., Jiang J. et al. Preparation of $Mn_2O_3/Fe_3O_4/Al_2O_3$ composites with superior zinc storage performance by utilizing the leaching solution of manganese ore tailing. *Journal of Power Sources*. 2025. Vol. 652. ID 237584.
22. Eghbali R., Khanmohammadi Hazaveh P., Rashchi F., Ataie A. Recovery of manganese from a low-grade waste and valorization via the synthesis of a nanostructured magnetic manganese ferrite. *Materials Science and Engineering B*. 2021. Vol. 269. ID 115177.