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APPLICATION OF ELECTROSTATIC AND ELECTROMAGNETIC SEPARATION FOR BENEFICIATION OF ILMENITE ORES FROM VIETNAM

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ABSTRACT

The possibility of ilmenite ores beneficiation from the Ha Tinh deposit (Vietnam) by electrostatic and electromagnetic separation methods was carried out. The ilmenite concentrates obtained as a result of beneficiation can be used for further processing to obtain pigment titanium dioxide or titanium metal in a compact or in powder form. The beneficiation processes of ilmenite ores from Vietnam deposits have not been studied enough, therefore, for their beneficiation, the most widely used in industrial practice methods of electrostatic and electromagnetic separation were used, which provide the required results in the ores beneficiation of complex composition, in which the main components is contained both in ilmenite and rutile. It is shown that in order to obtain ilmenite concentrates with a high concentration and beneficiation degree of titanium, electrostatic separation must be carried out at a voltage of 25-30 kV between the separator electrodes. In this case, the main components that make up the original ilmenite ore (titanium and iron) are distributed in the first cells of the separator, and the main impurities of the ilmenite concentrate – silicon, zirconium and aluminum – will be in the last cells. Under these conditions, impurities are separated from ilmenite and rutile. The separation of the beneficiated titanium-containing fraction into individual minerals must be carried out by electromagnetic separation methods. At a current strength of 11 A between the electrodes, ~67 % goes into a magnetic fraction and ~33 % of titanium will be in a non-magnetic product. In the magnetic fraction, the maximum value of $\eta_{ilmenite}$ reaches ~85 %; therefore, magnetic separation is an effective method for beneficiating ilmenite. As a result, an ilmenite concentrate is obtained with a titanium dioxide concentration of at least 50 % and a beneficiation degree of 49 %. Such a concentrate can later be used in the process of chemical processing to obtain titanium and its various compounds.

KEYWORDS: *Beneficiation Degree, Electrostatic and Electromagnetic Separation, Ilmenite Ores, Magnetic Properties, Magnetic and Non-Magnetic Fractions*

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INTRODUCTION

Titanium and its compounds have a number of special properties, such as high strength-to-weight ratio, corrosion resistance, high mechanical stability temperature, biocompatibility and ability to work at low temperatures, so they are widely used in the aerospace, navigation, medical industries, and are also used as catalysts in chemistry. Titanium sponge consumption in the world is currently estimated at 150 thousand tons/year and, according to forecasts, will increase annually by 6 % up to ∼200 thousand tons/year.

Vietnam is one of the countries with the largest titanium reserves in the world ~1.6 million tons. The deposits include primary and alluvial ores (with an admixture of aluminum – deluvi titanium ores), as well as titanium-zirconium sand ores. Stocks deluvi (deluvi) titanium ores are more than 4 million tons of ilmenite. The reserves of primary titanium ores are ∼4.8 million tons in the form of ilmenite, however, they are distinguished by the complexity of mining and difficult operating conditions and subsequent processing. The TiO_2 content in ilmenite is ∼22 %. One of the key titanium ore processing processes is the beneficiation process. The choice of processing method, its efficiency and competitiveness in the world market depend on the beneficiation quality of ilmenite ores.

When enriching ilmenite ores, combined methods are used, including gravity, flotation, magnetic and electrostatic separation, and chemical or hydrometallurgical processes [1-4]. The main difficulty in beneficiation of Vietnamese ilmenite ores, for example, the Ha Tinh deposit located in the north of Vietnam, is the presence of ilmenite and rutile in ores [5-8].

These minerals must first be separated from the waste rock to the maximum degree, and then ilmenite and rutile concentrates should be obtained separately [9-11]. Thus, the study of the conditions and the choice of a technological scheme for the beneficiation of ilmenite ores from Vietnam determines the choice of methods and technology for their subsequent processing.

MATERIALS AND METHODS

For beneficiation studies, ilmenite ore from the Ha Tinh deposit, located in the northern part of Vietnam, was used, the chemical and granulometric compositions of which are presented in Table 1 and 2.

For the synthesis of high-quality concentrates from poor and complex ores, enrichment is usually carried out in two or three stages [12-14]:

- Primary beneficiation of ores and obtaining rough concentrates with the maximum beneficiation degree of titanium;
- Fine-tuning of rough concentrates to obtain high-grade titanium concentrates. Together with the rich, poor substandard titanium concentrates (industrial products) are sometimes obtained, for the processing of which chemical and metallurgical processes are used, which ensures a high total titanium degree extraction into concentrates.

In the primary beneficiation and refinement of rough concentrates, combined methods are often used, most often including electrostatic and electromagnetic separation. The choice of titanium ores beneficiation method is determined by their composition, dissemination size, density of titanium and associated minerals, and their technological properties [15-18].

It must be taken into account that there are so many types of titanium ores, and their composition is so diverse that almost every deposit has its own specific features. Therefore, beneficiation schemes based on some general principles for ores close in composition for each specific deposit will have their own distinctive features.

Table 1: The Concentration of the Main Components in the Ilmenite Ore of the Ha Tinh Deposit (Vietnam)

No	Element	Content, %
1	Silicon(Si)	4.52
2	Titanium(Ti)	27.82
3	Vanadium (V)	0.044
4	Iron(Fe)	14.16
5	Zirconium(Zr)	9.23
6	Niobium(Nb)	0.11
7	Cerium (Ce)	0.18
8	Hafnium(Hf)	0.17

Table 2: Granulometric Composition of Ilmenite Ore Particles

No	Size	Mass of ore,g	Content, %	Concentration, %		Size Distribution, %	
				TiO_2	ZrO_2	TiO_2	ZrO_2
1	+0.5–1	91	4.54	0.046	0.010	0.44	0.62
2	+0.25–0.5	318	19.37	0.049	0.009	2.13	2.38
3	+0.125–0.25	1311	65.54	0.114	0.022	16.79	19.69
4	+0.074–0.125	61	3.06	6.34	0.865	43.47	36.15
5	+0.045–0.074	22	1.12	11.36	2.573	28.60	39.36
6	+0.02–0.045	11	0.54	1.444	0.133	1.74	0.97
7	+0.01–0.02	14	0.69	0.622	0.027	0.96	0.25
8	–0.01	103	5.16	0.507	0.008	5.87	0.56
	Initial ore	2000	100	0.445	0.073	100	100

EXPERIMENTAL EQUIPMENT

The possibility of using the electrostatic separation method was studied using an ELCOR-1 electrostatic separator with a changing polarity of high-voltage electrodes. The diameter and length of the collecting electrode (drum) are 240 and 250 mm, respectively, its rotation speed is 55-370 rpm.

When conducting research using methods based on the difference in the magnetic properties of materials, an electromagnetic roller separator EVS-10/5 was used. This separator is designed for dry separation of weakly magnetic ores and materials into magnetic and non-magnetic fractions.

To determine the components concentration in the original ore and in the resulting fractions, an ELAN 9000 mass spectrometer [19] with an ion source in the form of an inductively coupled argon plasma (ICP-MS) was used. ELAN 9000 is equipped with an RF generator with plasma stability (less than 0.1 % power variation) in the power range of 600-1600W. This mass spectrometer features a robust plasma interface with large diameter (1.1 mm and 0.9 mm) inlets.

To confirm the results obtained on an ELAN 9000 mass spectrometer, a Thermo Scientific™ ARL™ QUANT'X energy dispersive spectrometer was used [20]. It is designed to measure the concentration of substances by X-ray diffraction (EDXRF). For EDXRF analysis, Cu-Kα radiation (1.54 Å) is used, which excites the Fe-Kαline (1.94 Å) and induces X-ray fluorescence, leading to XRD noise patterns. To eliminate noise, Co-Kα radiation (1.79 Å) is used or a PVC filter is installed in front of the detector to absorb low-energy patterns. This spectrometer uses a highly sensitive Silicon Drift Detector (SDD) to determine the energy of the incoming radiation, so it can measure all elements from Na (Z = 11) to U (Z = 92). It is equipped with a 50W Rh or Ag lamp that can operate up to 50kV. The spectra were converted to elemental concentrations using the UniQuant universal software package using fundamental parameters (FP).

RESULTS AND DISCUSSION

When beneficiating ilmenite ores by electrostatic separation, it was found that with an increase in the voltage between the separator electrodes from 25 to 35 kV, the distribution of the main components that make up the original ilmenite ore (titanium and iron) in 10 cells of the separator changes (Figure 1). It is shown that Ti and Fe are distributed in cells 1 to 5 depending on the applied voltage. The distribution of these components does not change at 30 kV or more. Therefore, to ensure separation efficiency, the voltage applied to the electrostatic separator must be at least 30 kV.

The behavior of the main impurities of ilmenite concentrate – silicon, zirconium and aluminum in the beneficiation process by electrostatic separation is shown in Figure 2. With an increase in the voltage between the separator electrodes from 25 to 35 kV, the region of precipitation of silicon and zirconium oxides (Figure 2 a, b) shifts from 4-6 cells to 8-10 cells. This makes it possible to separate these oxides from ilmenite and rutile [21, 22].

Separating aluminum oxide from target titanium minerals is much more difficult. With an increase in the voltage between the separator electrodes from 25 to 30 kV, Al_2O_3, as before, is released together with the main minerals in 4-6 cells of the separator. Only when the voltage is increased to 35 kV, the Al_2O_3 release peak shifts to 8-10 cells (Figure 2c, 2d).

Thus, taking into account the behavior of the main components of titanium mineral impurities, for their separation from ilmenite and rutile, it is necessary to maintain a voltage between the separator electrodes of at least 35 kV.

A further increase in the concentration of titanium in the main fraction must be carried out by the method of electromagnetic separation. The separation of ilmenite and rutile in the beneficiated product must be carried out by the electromagnetic separation method, which makes it possible to separate the magnetic ilmenite from non-magnetic rutile.

When carrying out electromagnetic separation, the effect of current strength (I) on the beneficiation degree of titanium (η_{Ti}) and their concentration (c_{Ti}) in the magnetic fraction is given. Figure 3 and 4 shows that c_{Ti} gradually decreases with increasing I. At I = 11 A, η_{Ti} reaches ~67 %. Thus, ~33 % of titanium will be in the non-magnetic fraction. In the magnetic fraction, $\eta_{ilmenite}$ reaches ~85 %; therefore, magnetic separation is an effective method for beneficiating ilmenite. However, $c_{ilmenite}$ and c_{Ti} reach ~67 and ~43 %, respectively; therefore, the product is contaminated with impurities, to separate which it is necessary to determine the conditions under which the amount of impurities in the magnetic fraction will be minimal.

Figure 4 shows that in order to obtain ilmenite with a low content of impurities, the magnetic separation process must be carried out at a low current strength (less than 11 A).

To evaluate the efficiency of the magnetic separation process at different current strengths, a comparison was made of the change in titanium and iron benefication degree in the magnetic fraction (Figure 5).

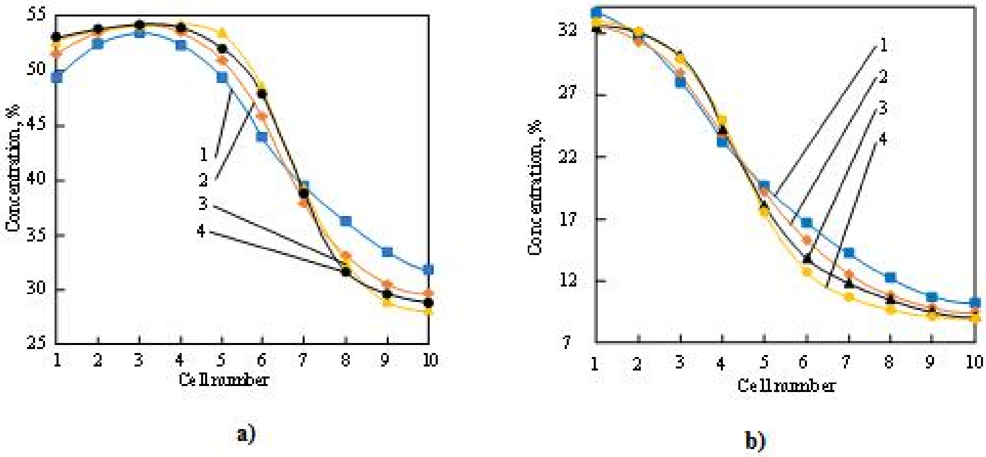


Figure 1: Dependence of Changes in the Titanium (a) and Iron (b) Concentrations of the Product in the Separator Cells on the Voltage at the Electrodes. Voltage Between Separator Electrodes: 1 – 25 Kv; 2 – 27,5 Kv; 3 – 30 Kv; 4 – 35 Kv.

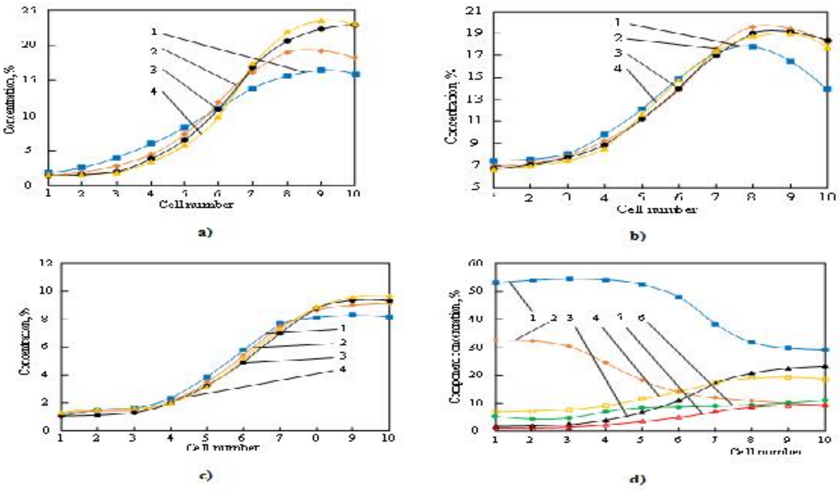
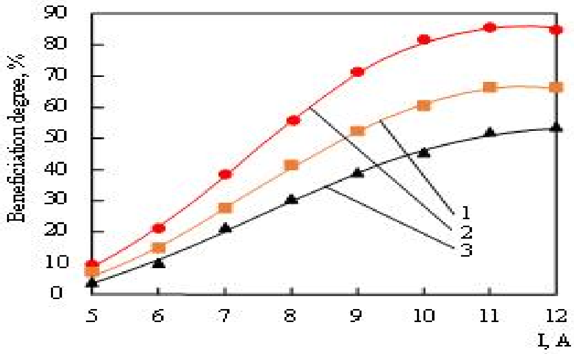


Figure 2: Dependence of Changes in the Concentration of Silicon (a), Zirconium (b), Aluminum (c) and All Components At Voltage 30 Kv (d) in the Product in the Separator Cells on the Voltage at the Electrodes. Voltage between Separator Electrodes: 1 – 25 Kv; 2 – 27,5 Kv; 3 – 30 Kv; 4 – 35 Kv.



1 – totaltitanium minerals; 2 – ilmenite; 3 – rutile (free titanium)

Figure 3: Change of the Total Beneficiation Degree (H_{ti}) of Titanium Minerals, Ilmenite ($H_{ilmenite}$) and Rutile(H_{rutile}) (Free Titanium) at the First Beneficiation Stage at Different Current Strengths.

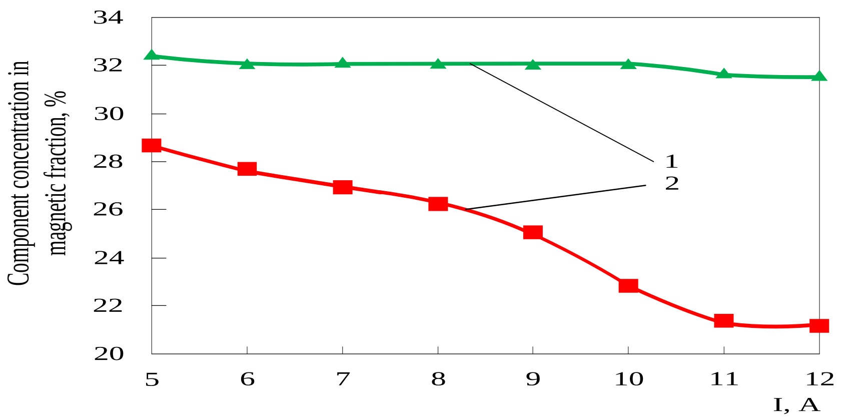
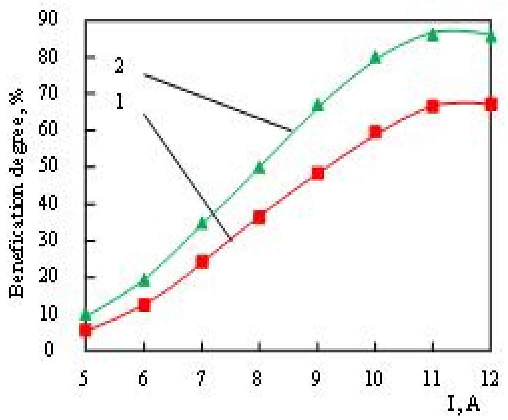


Figure 4: Dependence of Changing Concentrations Titanium (C_{ti}) and Iron (C_{fe}) on the Different Current Strengths at the 1-St Separation Stage.



1 – titanium beneficiation degree, %; 2 – iron benefication degree, %

Figure 5: Dependence of Changing Benefication Degree of Titanium (η_{Ti}) and Iron (η_{Fe}) on the Current Strength.

In the Magnetic Fraction

- TiO_2 concentration increases from 46 to 53 %;
- The beneficiation degree of titanium reaches 67 %, ilmenite – 85 % and rutile – 33 %.
- For the non-magnetic fraction:
- The TiO_2 concentration in the product is reduced from 34 to 25 %. In this case, the concentration of ilmenite decreases from 42 to 14 %, and the concentration of rutile increases from 12 to 18 %.

As a beneficiation result, an ilmenite concentrate is obtained, the composition of which is given in Table. 3.

Table 3: The Content of the Main Components in the Vietnamese Ilmenite Concentrate

Sample Name	Chemical Components, %										
	TiO_2	FeO	Fe_2O_3	MnO	SiO_2	CaO	MgO	Al_2O_3	V_2O_5	P_2O_5	Cr_2O_3
Ilmenite concentrate	51,74	23,31	16,73	3,35	2,48	0,06	0,23	1,02	0,14	0,12	0,05

CONCLUSIONS

Thus, when beneficiating Vietnamese ilmenite ores at the Ha Tinh deposit by electrostatic separation methods, it was shown that heavy minerals (ilmenite and rutile) are concentrated in the initial cells (from 1 to 5) of the electrostatic separator, depending on the applied voltage. At a voltage of 30 kV or more, the maximum degree of separation of titanium and iron-bearing minerals from waste rock (impurity minerals) is achieved, which does not change with a further increase in the voltage between the separator electrodes. Therefore, to ensure separation efficiency, the voltage applied to the electrostatic separator must be at least 30 kV.

As a result of the beneficiation of the above ilmenite ores by electrostatic methods, two fractions are formed: ilmenite-rutile, containing main components, and waste rock, containing elements of impurities. For the subsequent separation of ilmenite and rutile, it is necessary to use the difference in their magnetic properties using electromagnetic separation methods.

It has been established that when using the process of separating titanium minerals based on their difference in magnetic susceptibility, ilmenite will be found mainly in the magnetic, and rutile, in the non-magnetic fractions. The separation of these minerals proceeds with high efficiency at a current strength of 11 A. To increase the concentration of ilmenite in the product, it is necessary to carry out a process of multiple electromagnetic separation, as a result of which both ilmenite and rutile of a higher degree of purity can be obtained.

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REFERENCES

1. *Zhao, X., Meng, Q., Yuan, Z., Zhang, Y., Li, L. Effect of sodium silicate on the magnetic separation of ilmenite from titanaugite by magnetite selective coating //Powder Technology. – 2019. –V. 344. – P. 233-241. https://doi.org/10.1016/j.powtec.2018.12.026*
2. *Cai, J., Deng, J., Wena, S., Zhang, Y., Wu, D., Luo, H., Cheng, G. Surface modification and flotation improvement of ilmenite by using sodium hypochlorite as oxidant and activator //Journal of Materials Research and Technology. – 2020. – V. 9. – № 3. – P. 3368-3377. https://doi.org/10.1016/j.jmrt.2020.01.031*
3. *Du, Y., Meng, Q., Yuan, Z., Zhao, X., XuY. Impact of acid surface pretreatment on the flotation of ilmenite and titanaugite and its functional mechanism //Powder Technology. – 2020. – V.376. – P. 622-630. https://doi.org/10.1016/j.powtec.2020.08.057*
4. *Chen, G., Chen, J., Li, J., Guo, S., Srinivasa-kannan, C., Peng, J. Optimization of combined microwave pretreatment–magnetic separation parameters of ilmenite using response surface methodology //Powder technology. – 2012. – V. 232. – P. 58-63. https://doi.org/10.1016/j.powtec.2012.08.009*
5. *Galvin, K.P., Zhou J., Price A.J., Agrwal P., IvesonS.M. Single-stage recovery and concentration of mineral sands using a reflux™ classifier //Minerals Engineering. – 2016. – V. 93. – P. 32-40. https://doi.org/10.1016/j.mineng.2016.04.010*

6. *Rejith, R.G., Sundararajan M. Combined magnetic, electrostatic, and gravity separation techniques for recovering strategic heavy minerals from beach sands //Marine Georesources & Geotechnology. – 2018. – V. 36. – №. 8. – P. 959-965. https://doi.org/10.1080/1064119X.2017.1403523*

7. *Nanthakumar, B., Pickles, C. A., Kelebek, S. Microwave pretreatment of a double refractory gold ore //Minerals Engineering. – 2007. V. 20. Issue 11. P. 1109-1119. – https://doi.org/10.1016/j.mineng.2007.04.003*

8. *Guo X., Dai S., Wang Q. Influence of different comminution flowsheets on the separation of vanadium titano-magnetite //Minerals Engineering. – 2020. – V. 149. – Article number 106268. https://doi.org/10.1016/j.mineng.2020.106268*

9. *Dobbins, M., Dunn, P., Sherrell, I. Recent advances in magnetic separator designs and applications //The 7th International Heavy Minerals Conference "What next", The Southern African Institute of Mining and Metallurgy. – 2009. – P. 63-70.*

10. *Nelson, T., Van der Watt, J.G., Laudal, D., Feilen, H., Mann M., Srinivasachar S. Reactive jet and cyclonic attrition analysis of ilmenite in chemical looping combustion systems //International Journal of Greenhouse Gas Control. – 2019. – V. 91. – Article number 102837. https://doi.org/10.1016/j.ijggc.2019.102837*

11. *Moreno, T., Amato, F., Querol, X., Alastuey, A., Gibbons, W. Trace element fractionation processes in resuspended mineral aerosols extracted from Australian continental surface materials //Soil Research. – 2008. – V. 46. – №. 2. – P. 128-140.https://doi.org/10.1071/SR07121*

12. *Pownceby, M.I., Sparrow, G.J., Aral, H., Smith L.K., Bruckard W.J. Recovery and processing of zircon from Murray Basin mineral sand deposits //Mineral Processing and Extractive Metallurgy. – 2015. – V. 124. – №. 4. – P. 240-253. https://doi.org/10.1179/1743285515Y.0000000016*

13. *Yuan, Z., Zhao, X., Meng, Q., Xua, Y., Li L. Effect of selective coating of magnetite on improving magnetic separation of ilmenite from titanaugite //Minerals Engineering. – 2020. – V. 149. – Article number 106267. https://doi.org/10.1016/j.mineng.2020.106267*

14. *Gyllén, A. Knutsson, P., Lind, F., Thunmana, H. Magnetic separation of ilmenite used as oxygen carrier during combustion of biomass and the effect of ash layer buildup on its activity and mechanical strength //Fuel. – 2020. – V. 269. – Article number 117470. https://doi.org/10.1016/j.fuel.2020.117470*

15. *Zeng, J.,Chen, L., Yang, R., Tong, X., Ren, P., Zheng, Y. Centrifugal high gradient magnetic separation of fine ilmenite //International Journal of Mineral Processing. – 2017. – V. 168. – P. 48-54.https://doi.org/10.1016/j.minpro.2017.09.005*

16. *Kieu T.B., Le Sh. H., Karelin V.A. Application of magnetic separation process for beneficiation of Vietnamese ilmenite ores // Chemistry and chemical technology in research XXI: materials of the XXII international scientific-practical conference of students and young scientists named after outstanding chemists L. P. Kulev and N. M. Kizhner, Tomsk, May 17-20, 2021: in 2 vols. – Tomsk: TPU Publishing House, 2021. – V. 2. –P. 117-118.http://earchive.tpu.ru/bitstream/11683/67706/1/conference_tpu-2021-C27_V2_p117-118.pdf*

17. *Zeng, J., Tong, X., Yi, F., Chen L. Selective capture of magnetic wires to particles in high gradient magnetic separation //Minerals. – 2019. – V. 9. – №. 9. – P. 509.*

18. *Xiong, D. SLon magnetic separator applied in the ilmenite processing industry. //Phys. Sep. Sci. Eng.– 2004. – V. 13. – P.119-126.*

19. *Mass spectrometer ELAN 9000. Optimizing routine UltratraCe analysis by ICP-MS. Perkln ElmerSCIEX. https://resources.perkinelmer.com/lab-solutions/resources/docs/BRO_ELAN9000ICPMS.pdf*

20. *Energy dispersive spectrometer Thermo Scientific™ ARL™ QUANT'X. https://www.thermofisher.com/order/catalog/product/IQLAAHGABMFAAWMACL*

21. *Kieu T.B., Le Sh.H., Karelina N.V., Karelin V.A. Electrostatic separation in the enrichment of ilmenite ores from Vietnam //Isotopes: technologies, materials and applications collection of abstracts of the VII International scientific conference of young scientists, graduate students and students, Tomsk, October 25-28, 2021 / National Research Tomsk Polytechnic University (TPU). – Tomsk, 2021. – P. 123-124. http://earchive.tpu.ru/bitstream/11683/69080/1/conference_tpu-2021-C84_p123-124.pdf*

22. *Le Sh.H., Karelina N.V. Features of enrichment of ilmenite concentrates from Vietnam // Chemistry and chemical technology in the XXI century materials of the XXI International scientific-practical conference of students and young scientists named after outstanding chemists L.P. Kulyova and N.M. Kizhner, September 21-24, 2020, Tomsk / National Research Tomsk Polytechnic University. – Tomsk: TPU Publishing House, 2020. – P. 457-458.http://earchive.tpu.ru/bitstream/11683/63467/1/conference_tpu-2020-C27_p457-458.pdf*