International Journal of Academic and Applied Research (IJAAR)
ISSN: 2643-9603
Vol. 7 Issue 9, September - 2023, Pages: 1-5

An Alternative Method of Cleaning the Air Mixed With Acid Gases around Copper Smelters

Khojiev Sh.T.[1], Sultonov H.Sh.[2], Rakhmataliev Sh.A.[3], Rajabov Q.K.[4], Uralova N.A.[4], Shukurova M.T.[4]

[1]Associate professor of the Department of Metallurgy, Ph.D., Tashkent State Technical University,
[2]Assistant of the Department of Metallurgy, Tashkent State Technical University,
[3]PhD student of Faculty of Materials Science and Engineering, University of Miskolc in Hungary;
[4]Students of the Department of Metallurgy, Tashkent State Technical University;
E-mail: hojiyevshohruh@yandex.ru

Abstract: *The article considers the study of the absorption of sulfur dioxide with an aqueous solution of sodium and calcium hydroxides. To absorb sulfur dioxide, the strongest auditory medium of the solution was chosen, during which a decrease in the moisture content of the solution was detected during sulfur dioxide. It has been found that the degree of absorption of sulfur dioxide depends on the size of the gas bubbles passing through the mucous solution. Based on the information presented in the research work, it was proposed to process the technological gases with an acidic environment, which are collected in the territory of non-ferrous metallurgical plants, using the absorption method. According to this, technological gases spreading throughout the territory of the metallurgical plant do not require excessive cooling. Process gases are sent directly to the gas purification department.*

Keywords— acid process gases, environmental problem, sulfur dioxide, absorption, alkaline solution, bubble diameter, absorption rate of gases in liquid.

1. INTRODUCTION

Nowadays, cleaning and processing of technological waste gases and creation of environmentally friendly technology is the demand of the time all over the world [1-3]. Metallurgical plants, in addition to the production of metals or products based on them, which are necessary for technology with a high production capacity, cause a large amount of damage to the environment and ecology due to the release of a large amount of technological toxic gases into the atmosphere [4-9]. In particular, releasing process gases from metallurgical furnaces directly into the air without processing has bad consequences. For example, the smoke from the furnace in the copper smelter is partially cleaned of dust [10-13]. Unfortunately, the technological gases of the furnace are released directly into the atmosphere. However, in the composition of these waste gases, about 4% by volume is SO_2 gas, and the rest is nitrogen, water vapor and carbon dioxide gases. Due to the fact that the sulfur dioxide coming out of the furnace is not captured, its amount in the atmosphere of the area near the factory exceeds the maximum allowed amount [14-20]. From an environmental point of view, the maximum amount of sulfur dioxide (SO_2) allowed in atmospheric air is determined by air quality standards and regulations set by national or international bodies. These standards are aimed at protecting human health and the environment from the harmful effects of air pollution. Specific allowable levels may vary between countries and regions, but they are generally based on scientific studies and assessments of the effects of SO_2 on human health, ecosystems and air quality [21-25].

In the process of production of zinc and copper metals at "Almalik Mining and Metallurgical Combine" JSC ("AMMC" JSC), a large amount of technological gases containing sulfur dioxide are released [26-27]. Nowadays, production of sulfuric acid from these gases has been started. In the metallurgical shop of "AMMC" JSC copper smelting plant, due to the non-hermetic nature of the gas moving systems and the fact that the process gases from the metallurgical aggregates do not reach the full degassing department, environmental norms of the metallurgical shop area are being violated [28-30]. Today, the composition of the process gases coming to the gas treatment department consists of approximately 6-7% SO_2, 0.2-0.3% SO_3 and other gases. Before receiving sulfuric acid from these gases, they are treated with 8% sulfuric acid according to the opposite scheme. is given [31-33]. The purpose of this is, firstly, to reduce the temperature of outgoing gases, and secondly, to be free of volatile components such as As, F, Se [34-35]. As a result of the research, it was found that the amount of SO_2 in the process gases released in the area of the workshop was ineffective for the production of sulfuric acid [36]. A number of scientific studies have been carried out on the production of other types of products in cases where the outgoing technological gases are low in sulfur dioxide and thereby prevent the release of harmful gases into the environment [37-42].

In many industrialized countries, including the USA, Germany, and various enterprises of Japan, the purification of technological gases with low sulfur dioxide content and the production of other types of products have been launched [43-47].

SO_2 gas is found in the production of sulfuric acid, ammonium sulfate, solid fuel processing, metallurgy, thermal power plant, kapron, linoleum, ruberoid, penoplast, textile, paper, and food industries. SO_2 gas is included in the group of poisonous gases, under its influence it suffocates the respiratory tract, inflames the eyes, causes coughing, tears, headaches, shortness of breath, dries up the bronchi, and so on as well as corrodes metal equipment, corrodes building materials, falls on agricultural land in the form of "Acid rain", makes it unusable and causes serious damage to the national economy [48]. The permissible limit concentration of SO_2 gas is PLC - 0.5 mg/m^3 [49].

Internationally, the World Health Organization (WHO) provides air quality guidelines for various pollutants, including sulfur dioxide. The WHO guideline for SO_2 is an annual average of 20 µg/m³ (micrograms per cubic metre) and a 10-minute average of 500 µg/m³ [50].

It should be noted that the permissible limit concentration of SO_2 is set in order to minimize the negative impact of SO_2 on human health, ecosystems and the environment. These levels are periodically reviewed and updated based on new scientific knowledge and advances in understanding the effects of air pollution.

Based on the above-mentioned ecological situation, it can be noted that the development of an effective method of purifying industrial waste gases from sulfur dioxide is an urgent issue. The use of absorption methods for cleaning the atmosphere near the factory from sulfur dioxide is considered a promising method for cleaning the air from sulfur gases. However, the low efficiency and complexity of disposal of the resulting product requires further improvement of these methods on an industrial scale.

The purpose of this study is to study some technological parameters of absorption of sulfur dioxide into a solution consisting of a mixture of calcium and sodium hydroxides.

2. MATERIALS AND METHODS

A mixture of SO_2 and air obtained by oxidation of technical sulfur was chosen as the research object. In order to absorb SO_2 gas in this mixture, a solution consisting of a mixture of calcium and sodium alkali was used as an absorber. The study of the process of absorption of sulfur dioxide using a solution consisting of a mixture of calcium and sodium hydroxides was carried out under the following conditions:

Table 1. Required parameters for the study of absorption of sulfur dioxide

№	The main parameters of the research work	Quantitative indicators
1	Sulfur dioxide concentration in air	1,0 – 5,0 g/m^3
2	The temperature of the gas-air mixture	30 °C
3	Initial alkalinity of the environment	pH = 14
4	The concentration of NaOH in the solution	0,4 mol/l
5	Concentration of $Ca(OH)_2$ in solution	0,3 mol/l

In the study, a strong alkaline solution was prepared as an absorber. The amounts of sodium and calcium hydroxides were taken in such a molar ratio that the hydrogen index of the resulting solution was strongly alkaline (pH=14). The absorption of sulfur dioxide into the alkaline solution was carried out in an aspirator at a gas flow rate of 1 l/min. The concentration of sulfur dioxide in the gas was determined by the photocolorometric method. The change of the solution medium was controlled by a pH-meter.

Tools and equipment necessary for the implementation of the research work were collected. The scheme of the hardware chain proposed in the research work is depicted in Figure 1.

According to the scheme shown in Fig. 1, after preparing an alkaline solution with a specified pH value, the solution is fed to the absorber. Air containing a mixture of sulfur dioxide is sprayed into the solution from the lower side of the absorber. For better mixing of solution components, air is supplied from the other side of the absorber under pressure. In this case, the solution is mixed with air. Mixing with air increases the reaction yield.

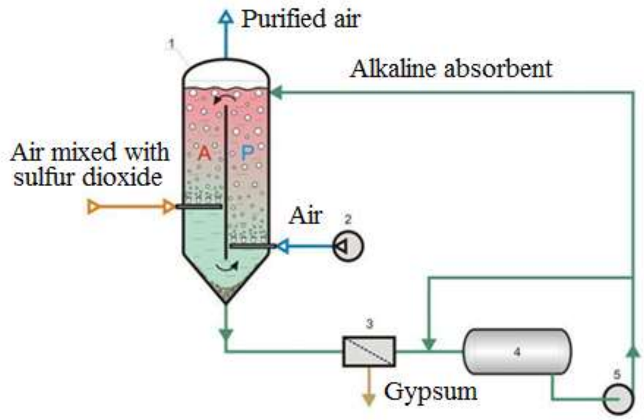

Fig.1. Apparatus chain diagram of sulfur dioxide absorption process in alkaline solution: 1-absorber, 2-compressor, 3-filter, 4-capacity, 5-pump, A-absorption zone, P-mixing zone

After the reaction, solid residues are removed from the bottom of the absorber and filtered. The composition of the solid residue (gypsum) is analyzed, and if it is suitable, it is sent to the preparation of building material, and the purified solution is sent to a special machine to create a re-alkaline solution. In the experiment, 1 m^3 of air mixed with sulfur dioxide and an absorbent solution with a volume of one liter were used.

3. RESULTS AND DISCUSSION

In the experimental work, the degree of absorption of sulfur dioxide into the solution was determined depending on the change in the alkalinity of the solution over time. The results obtained in the experiment are presented in Table 2.

Table 2. Changes in solution alkalinity with increasing duration of sulfur dioxide absorption

№	Time, min	The medium of the solution, pH

1	5	13,937
2	10	13,864
3	15	13,776
4	20	13,666
5	25	13,518
6	30	13,293
7	35	12,795
8	40	12,299
9	45	11,801
10	50	11,304
11	55	10,807
12	60	10,309

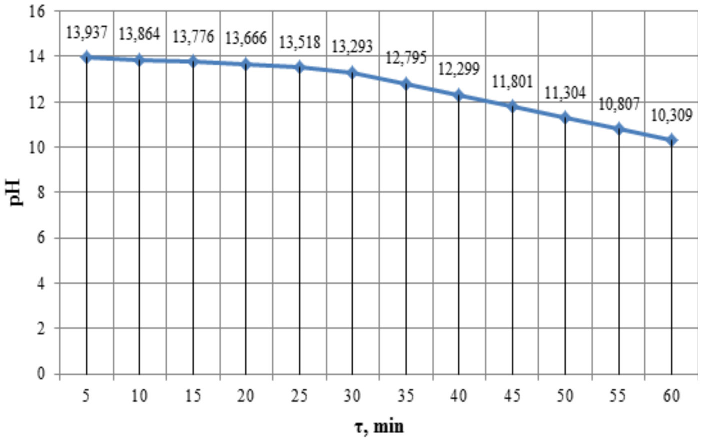

Fig.2. Changes in the solution medium per unit of time during the absorption of sulfur dioxide in an alkaline solution

The results in Figure 2 and Table 2 show that the alkalinity of the absorbent solution decreased with increasing duration of sulfur dioxide supply from the solution. This situation indicates that sulfur dioxide has gone into solution. Calculations showed that 30% of the total SO_2 gas passed through the absorbent solution was absorbed into the solution. In order to completely absorb sulfur dioxide in the air and obtain clean air, it was required to pass the mixture of air and SO_2 through the solution four times at the given speed. An hour was spent passing the mixture of air and SO_2 through the absorbent solution four times. When the experiment was continued again, it was observed that the hydrogen index of the solution did not change. This indicates that SO_2 gas is not left in the mixture of gases passing through the absorbent solution after one hour. By controlling the composition and alkalinity of the absorbent solution obtained for complete purification of the air mixed with sulfur dioxide of the given concentration from SO_2 gas, when it was used for the second time, results similar to the previous results were obtained.

The study of the kinetics of the process showed that the absorption of SO_2 gas into the solution is intrinsically dependent on the size of the gas bubbles passing through the solution, and the smaller the size of the SO_2 gas bubbles, the smaller the size of the SO_2 gas bubbles with the absorbent solution. The larger the glazing surface and the better absorption into the solution.

The law related to the size of gas bubbles during the absorption of SO_2 gas in water is called Hige-Romijn equation. This equation describes the relationship between the size of a gas bubble and the rate of mass transfer or absorption.

The mathematical formula of the Hige-Romijn equation is as follows:

$$d = 1{,}4 \cdot \sqrt[3]{\sigma \cdot g \cdot \frac{\rho L}{\rho G}} \qquad (1)$$

Where:

d - average diameter of gas bubbles;

σ - interfacial tension between gas and liquid phases;

g - acceleration due to gravity;

ρL - density of the liquid phase (water in this case);

ρG - density of the gas phase (in this case SO_2 gas).

It should be noted that the Hige-Romijn equation provides an approximation for the bubble size and assumes certain conditions. Other factors such as gas flow rate, fluid properties, and equipment design can also affect bubble size in gas absorption processes.

When SO_2 gas is absorbed in water, the interphase tension between gas and liquid phases is 0.02 N/m. If the acceleration under the influence of gravity (g) is 9.8 m/s^2, the density of water (ρL) is 1000 kg/m^3, and the density of the gas phase (ρG) is 2 kg/m^3, then in the process of absorption of SO_2 gas, the average diameter (d) of the total gas bubbles can be calculated as follows:

$$d = 1{,}4 \cdot \sqrt[3]{0{,}02 \cdot 9{,}8 \cdot \frac{1000}{2}} = 6{,}45 \text{ m} \qquad (2)$$

The average diameter of the gas bubbles formed in the process of absorption of SO_2 gas transferred through the solution is approximately 6.45 meters (or the average radius r =3.227 m). Since the surface of the gas bubbles passing through the solution with a total diameter of 6.45 m, that is, the gas-liquid contact boundary is affected by the components of the solution, it is important to determine the total surface of these bubbles. Considering that the gas bubbles are spherical, the surface of these bubbles is found as follows:

$$S = 4\pi r^2 \qquad (3)$$

In this case, the total surface of the gases obtained in the experiment is $S=4*3.14*(3.227)^2 =130.82\ m^2$.

The absorption of SO_2 gas into a solution really depends on various factors, including the size of the gas bubbles passing through the solution. When the gas bubbles come into contact with the solution, they provide an interface for transferring the gaseous component (SO_2) to the liquid phase. The speed and efficiency of this assimilation process depends on several factors, and the size of the bubble is one of them.

Smaller gas bubbles have a greater total surface area for a given volume of gas than larger bubbles. As a result, more surface area is available for the gas-liquid interface, allowing for higher absorption rates. This increased surface area allows for more interactions between the gas molecules and the liquid and facilitates the transition of SO_2 from the gas phase to the solution.

In addition, smaller bubbles have a tendency to disperse and disperse throughout the solution. This dispersion ensures that the gas has an equal effect on the liquid and enhances the absorption process. Larger bubbles quickly rise to the surface, limiting contact time with the liquid and reducing overall absorption efficiency.

It should be noted that the size of gas bubbles passing through the solution can be affected by various factors, for example, the method of gas introduction (e.g., diffuser, sparger) and the properties of the solution (e.g., viscosity, surface tension). Bubble size control can be critical in optimizing the absorption process, as it directly affects the rate and efficiency of SO_2 absorption.

In the absorption of SO_2 gas in water, the gas dissolves and forms gas bubbles when it comes into contact with water. According to Henry's law, the size of gas bubbles depends on the partial pressure of SO_2 gas over water.

If the partial pressure of SO_2 gas is high, more gas molecules will dissolve in the water, resulting in smaller bubbles. Conversely, if the partial pressure of SO_2 gas is low, fewer gas molecules will dissolve, resulting in larger bubbles.

4. CONCLUSION

The amount of absorbed sulfur dioxide and the speed of its processing with an aqueous solution of sodium and calcium alkalis was 1 l/min, and when the temperature of the solution was 30^{o}C, the degree of absorption of SO_2 gas into the alkaline solution was 30% compared to the initial volume of the gas. In this case, a conclusion was drawn about the results depending on the change in the pH indicator of the solution. The obtained results show that for complete absorption of sulfur dioxide in 1m^3 gas mixture when the concentration of sulfur dioxide in the air is 1.0-5.0 g/m^3, a mixture of air and sulfur dioxide must be taken for one hour from one liter of the absorbent solution obtained for the experiment was requested to transfer. It was found that the absorbent solution can be used twice in the process. Saturated absorbent solution is fed to the crystallization process. In this case, the sodium sulfate salts in the solution are crystallized and the remaining aqueous part is returned to the process to form a re-absorbent solution.

5. REFERENCES

[1] Smotraev R.V., Manidina E.A. Investigation of the thermodynamic equilibrium of the process of absorption of sulfur dioxide by an electrochemically treated absorption solution // Vopr. chemistry and chem. technologies. - 2013. - No. 2. - p. 17 - 20.

[2] Hojiyev Sh.T. Mahalliy ikkilamchi hosil bo‘lgan texnogen chiqindilardan foydalanish asosida mis ishlab chiqarish shlaklarini qayta ishlash texnologiyasini takomillashtirish: t.f.f.d. (PhD) dissertatsiyasi avtoreferati. – Toshkent: 2022. 46 b.

[3] Yusupkhodzhaev A.A., Khozhiev Sh.T., Akramov U.A. Use of non-traditional reducing agents to expand the resource base of OJSC Uzmetkombinat // Chernye Metally, Volume 2021, Issue 4. P. 4 – 8.

[4] Yusupkhodjayev A.A., Khojiyev Sh.T. Methods of decreasing of Copper loss with Slag in Smelting Processes // International Academy Journal Web of Scholar. Kiev, March 2017, № 2(11), Vol. 1, P. 5 – 8.

[5] Yakubov M.M., Yusupxodjayev A.A., Hojiyev Sh.T. Eritish jarayonida misning shlak bilan isrofini kamaytirish yo’llari // Kompozitsion materiallar. 2017, №1. 18 – 19 b.

[6] Yusupkhodjaev A.A., Khojiev Sh.T., Valiev X.R., Saidova M.S., Omonkhonov O.X. Application of Physical and Chemical Methods for Processing Slags of Copper Production // International Journal of Advanced Research in Science, Engineering and Technology. Vol. 6, Issue 1, January 2019. pp. 7957 – 7963.

[7] Khojiev Sh.T. Pyrometallurgical Processing of Copper Slags into the Metallurgical Ladle // International Journal of Advanced Research in Science, Engineering and Technology. Vol. 6, Issue 2, February 2019. pp. 8094 – 8099.

[8] Сафаров А.Х., Хожиев Ш.Т. Разработка безотходной технологии производства золота // Международный научный журнал “Молодой Учёный”, № 17 (255), часть I., 2019. P. 47 – 49.

[9] Yusupkhodjaev A.A., Khojiev Sh.T., Berdiyarov B.T., Yavkochiva D.O., Ismailov J.B. Technology of Processing Slags of Copper Production using Local Secondary Technogenic Formations// International Journal of Innovative Technology and Exploring Engineering, Volume-9, Issue-1, November 2019. P. 5461 – 5472.

[10] Khojiev Sh.T., Yusupkhodjaev A.A., Aribjonova D.Y., Beknazarova G.B., Abdullaev D.N. Depletion of Slag from Almalyk Copper Plant with Aluminum Containing Waste // International Journal of Innovative Technology and Exploring Engineering, Volume-9, Issue-2, December 2019. P. 2831 – 2837. DOI: 10.35940/ijitee.B7200.129219

[11] Hojiyev Sh.T., Norqobilov Y.F., Raxmataliyev Sh.A., Suyunova M.N. Yosh metallurg [Matn]: savol-javoblar, qiziqarli ma’lumotlar va metallar ishlab chiqarish texnologik jarayonlari. – Toshkent: “Tafakkur” nashriyoti, 2019 . - 140 b. ISBN 978-9943-24-273-9

[12] Yusupxodjayev A.A., Mirzajonova S.B., Hojiyev Sh.T. Pirometallurgiya jarayonlari nazariyasi [Matn]: darslik. – Toshkent: “Tafakkur” nashriyoti, 2020. – 300 b. ISBN 978-9943-24-295-1

[13] Abjalova Kh.T., Khojiev Sh.T. Intensification of the process of depletion the converter slag // Texnika yulduzlari, № 4, Toshkent: “ToshDTU”, Dekabr, 2019. 59 – 63 b.

[14] Matkarimov S.T., Yusupkhodjaev A.A., Khojiev Sh.T., Berdiyarov B.T., Matkarimov Z.T. Technology for the Complex Recycling Slags of Copper Production // Journal of Critical Reviews, Volume 7, Issue 5, April 2020. P. 214 – 220.

[15] Khojiev Sh. Modern Scientific Researches in Metallurgy: from Theory to Practice: monograph // Shokhrukh Khojiev (Ed.). - Beau Bassin (Mauritius): LAP LAMBERT Academic Publishing, 2020. P. 154. ISBN 978-613-9-47121-8

[16] Хожиев Ш.Т. Разработка эффективной технологии извлечения меди из конверторных шлаков // Journal of Advances in Engineering Technology, Vol.1(1), Sept, 2020. P. 50 – 56.

[17] Khojiev Sh.T., Yusupkhodjaev A.A., Rakhmonaliev M., Imomnazarov O.O’. Research for Reduction of Magnetite after Converting // Kompozitsion materiallar, 2019, №4. P. 54 – 55.

[18] Khojiev Sh.T., Matkarimov S.T., Narkulova E.T., Matkarimov Z.T., Yuldasheva N.S. The Technology for the Reduction of Metal Oxides Using Waste Polyethylene Materials // Conference proceedings of “Metal 2020 29th International Conference on Metallurgy and Materials”, May 20 – 22, 2020, Brno, Czech Republic, EU. P. 971-978.

[19] Khojiev Shokhrukh, Berdiyarov Bakhriddin, Mirsaotov Suxrob. Reduction of Copper and Iron Oxide Mixture with Local Reducing Gases // Acta of Turin Polytechnic University in Tashkent, 2020, Vol.10, Iss.4. P. 7-17.

[20] Alamova G.Kh., Khojiev Sh.T., Okhunova R.Kh. Current State Of Copper Smelting Slags And Their Processing: A Review // Central Asian Journal of Literature, Philosophy and Culture, 2021, 02(02). P. 49-55.

[21] Alamova G.Kh., Khojiev Sh.T., Okhunova R.Kh. Comparative Estimation of the Efficiency of Various Materials in the Reduction of Magnetite in Slag Melt // International Journal for Innovative Engineering and Management Research, 2021, 10(3). P. 191-196.

[22] Hojiyev Sh.T., Mirsaotov S.U., Ergasheva M.S. Metall oksidlarini amminotermik tiklashning ba’zi termodinamik jihatlari //

UzACADEMIA: scientific-methodical journal, Vol. 2, Issue 1(12), 2021. P. 6-16.

[23] Khojiev S.T., Nuraliev O.U., Berdiyarov B.T., Matkarimov S.T., Akramov O‘.A. Some thermodynamic aspects of the reduction of magnetite in the presence of carbon // Universum: технические науки: электрон. научн. журн., Часть 3, 3(84), 2021. P. 60-64.

[24] Khojiev Sh.T., Berdiyarov B.T., Alamova G.X., Abjalova H.T. Application of Energy-Saving Technology in The Smelting of Copper Sulfide Concentrates in Autogenous Processes // International Journal of Academic and Applied Research, 5(3), 2021. P. 30-33.

[25] Khojiev Sh., Berdiyarov B., Yavkochiva D., Abduraimov J. Study of the Factors Influencing the Decoppering Process of Non-Ferrous Metallurgy Slags: A Review // International Journal of Academic and Applied Research, 5(3), 2021. P. 84-93.

[26] Ergasheva M.S., Mirsaotov S.U., Khojiev Sh.T. Use of Zinc Plant Clinker as a Reducing Agent in The Processing of Copper Slags // European Scholar Journal, Vol. 2, Issue 3, 2021. P. 218-222.

[27] Khojiev Sh., Nurmatov M. Methods of Using Secondary Energy Resources in Industry // International Journal of Academic and Applied Research, 5(4), 2021. P. 87-96.

[28] Khojiev Sh., Berdiyarov B., Samadov A., Narkulova E. New Technology for Decreasing Copper Content in Dump Slags: A Review // International Journal of Academic and Applied Research, 5(4), 2021. P. 212-220.

[29] Khasanov A.S., Berdiyarov B.T., Khojiev Sh.T., Abdullaev D.N., Ergashev J.K. New Technological Solutions to Reduce the Copper Content in the Slags of the Oxygen-Flare Smelting of Sulfide Copper Concentrates // International Journal of Academic and Applied Research, 5(4), 2021. P. 206-211.

[30] Khojiev Sh., Fayzieva D., Mirsaotov S., Narkulova E. New The Main Trends in the Integrated Processing of Waste from Mining and Metallurgical Industries // International Journal of Engineering and Information Systems, 5(4), 2021. P. 182-188.

[31] Khojiev Sh., Berdiyarov B., Gulomov I., Mamatov M. The Current State and Development of the Integrated Use of Technogenic Waste // International Journal of Engineering and Information Systems, 5(4), 2021. P. 189-194.

[32] Khojiev Sh., Mirsaotov S., Khamroev J., Khamroqulov Sh. Development of Promising Technologies in the Production of Non-Ferrous Metals and Improvement of Existing Technologies // International Journal of Academic Multidisciplinary Research, 5(4), 2021. P. 356-361.

[33] Khojiev Sh.T., Ergasheva M.S., Khamroqulov Sh.F., Khamroev J.O’. The Current State of Copper Metallurgy and Its Raw Material Base // IJEAIS, 5(5), 2021. P. 7-14.

[34] Karimova T.P., Khojiev Sh.T., Saidova M.S., Bakhodirova N.Q. To Prevent the Loss of Copper with Slag during the Casting of the Converter Slag // IJEAIS, 5(5), 2021. P. 15-22.

[35] Berdiyarov B., Khojiev Sh., Rakhmataliev Sh., Suyunova M., Rasulova N. Modern Technologies of Aluminum Production // IJEAIS, 5(5), 2021. P. 100-105.

[36] Mukhametdjanova Sh., Khojiev Sh., Rakhmataliev Sh., Avibakirov I., Mamatov M. Modern Technologies of Copper Production // IJEAIS, 5(5), 2021. P. 106-120.

[37] Rakhmataliev Sh., Sultonov Kh., Khojiev Sh., Abdukholiqov A. Modern Technologies of Gold Production // IJEAIS, 5(5), 2021. P. 121-131.

[38] Khojiev Sh.T., Berdiyarov B.T., Kadirov N.A., Obidov B.M. and Turan M.D. (2021) Utilization of household waste-based solid fuel // Technical science and innovation: Vol. 2021: Iss.1. P. 168-176.

[39] Toshpulatov D.D., Khojiev Sh.T., Berdiyarov B.T. Analysis of Non-Ferrous Metallurgy Waste Processing Capacity // IJEAIS, 5(11), 2021. P. 41-50.

[40] Berdiyarov B.T., Khojiev Sh.T. Thermodynamic analysis of reduction of oxidized copper compounds in a slag phase // Kompozitsion materiallar, 2021, №4. P. 39 – 43.

[41] Хожиев Ш.Т., Бердияров Б.Т., Мухаметджанова Ш.А., Нематиллаев А.И. Некоторые термодинамические аспекты карботермических реакций в системе Fe-Cu-O-C // O‘zbekiston kimyo jurnali. – Toshkent, 2021, – №6. – С. 3 – 13.

[42] Berdiyarov B.T., Khojiev Sh.T., Matkarimov S.T., Munosibov Sh. Study of the thermodynamic properties absorption sulfur storage gas of zinc and copper industry // Technical science and innovation, Vol. 2021, Iss.4. P. 293-301.

[43] Khojiev Sh.T., Suyunova M.N., Saidova M.S., Yarashev U.Q. Thermodynamical Properties of the Process of Sintering of Iron Storage Copper Concentration Factories with Lime // International Journal of Engineering and Information Systems, 6(5), 2022. P. 11-16.

[44] Khojiev Sh.T., Berdiyarov B.T., Nuraliyev O.U., Mirsaotov B.U., Mirsaotov S.U., Osmanov Z.B. Quality Steel Production Research Based on the Introduction of Deoxidation Technology // International Journal of Engineering and Information Systems, 5(12), 2021. P. 91-101.

[45] Berdiyarov B., Khojiev Sh., Nuraliyev O., Mirsaotov B., Mirsaotov S., Osmanov Z. Monitoring the oxygen removal process at the final stage of melting steel // Journal of Physics: Conference Series, 2131(2), 2021. P. 022071.

[46] Khojiev Sh.T., Saidova M.S., Kholboev N.M. Research On The Extraction Of Iron Oxide From Iron-Bearing Tailings Of Concentrating Plants // International Journal of Academic and Applied Research, 6(6), 2022. P. 83-87.

[47] Khojiev Sh.T., Saidova M.S., Mirzajonova S.B., Ibrokhimov H.X., Ismatov Sh.O’. Development of Technology for Processing Zinc Cakes Based on the Use of Petroleum Coke // International Journal of Academic Engineering Research, 6(6), 2022. P. 23-28.

[48] Khojiev Sh.T., Saidova M.S., O’rinboyev M.J. Modern Methods of Coating Zinc and Chromate Shells on the Surface of Structural Materials // International Journal of Engineering and Information System, 6(6), 2022. P. 1-6.

[49] Berdiyarov B.T., Hojiyev Sh.T., Matkarimov S.T., Nosirxo‘jayev S.Q. Metallurgiyada biotexnologik jarayonlar: darslik. –Toshkent: “Lesson press”, 2023. – 178 b. ISBN 978-9943-0000-0-1

[50] Бердияров Б.Т., Маткаримов С.Т., Носирхужаев С.К., Хожиев Ш.Т. Металлургия благородных металлов: учебник. –Ташкент: “Ziyo nashr-matbaa”, 2023. – 205 с. ISBN 978-9943-9746-7-8