

№4 2023

научно-технический и производственный

# ГОРНЫЙ

## ЖУРНАЛ КАЗАХСТАНА

Қазақстанның кен журналы



 **MKS**

\* – статья по правам рекламы  
 @ – информационное сообщение  
 / – статья публикуется в авторской редакции

- 3 Колонка главного редактора
- 4 *Мирас Жакупов, Бақытбек*  
 Еще раз о созидательной роли печатного слова раньше и сейчас
- Новости ESAB в Центральной Азии
- 6 Не сбавляй обороты! ESAB в Центральной Азии
- Геоэкология
- 12 *Ю.Н. Шенников, А.Н. Козлов, С.Н. Шенников, \*Э.А. Кручин*  
 Закладочные работы на водосмыльных рудниках Крайнего Севера
- Геоэкология
- 20 *Ж.Т. Жалбыров, \*Н.М. Заманов, Н.Т. Валиев, А.Т. Жансейитов*  
 Подбор технического оборудования для работы в сложных условиях карьерных разработок руды
- Гидроэкологические работы
- 28 *Н.В. Мельников, \*В.А. Кутуров, С.Н. Жарина*  
 Сравнительный анализ формул по расчету скорости движения взвешенных веществ
- Нефтегазовое дело
- 37 *Н.Б. Грозинский, А.В. Арыстанбек, А.Т. Талов, \*А.К. Абдылов*  
 Кумкол кен орнындағы технологиялар жер сілкіну максимумдыстары
- Переработка полезных ископаемых. Производственный опыт
- 42 *\*А. Деберев, А. Карюков, А. Рейн*  
 Ступенное взрывное пыления на южном горно-обогатительном комбинате
- Металлургия
- 49 *\*Э.А. Серафимович, D. Muretafu, K.K. Mung'anya, M. Rajendran*  
 The studying of pyrite and arsenopyrite specific surface and porosity at roasting condition
- Геоэкология
- 57 *Е.Т. Кадеев, \*М.В. Науретов, А.А. Бай, А.А. Ешимов*  
 Prospects for technogenic waste processing for production of construction materials
- 65 Требования к оформлению и условия предоставления статей

Код МРНТИ 53.81.29

\*T.A. Chepushtanova<sup>1</sup>, D. Maratuly<sup>1</sup>, K.K. Mamyrbayeva,<sup>1</sup> M. Brajendra<sup>2</sup><sup>1</sup>Satbayev University (Almaty, Kazakhstan),<sup>2</sup>Worcester Polytechnic Institute (Worcester, AKSH)

## THE STUDYING OF PYRITE AND ARSENOPYRITE SPECIFIC SURFACE AND POROSITY AT ROASTING CONDITION

**Abstract.** The paper presents the results of studying the modification of the specific surface area and porosity of pyrite and arsenopyrite during their thermal decomposition. It has been established that the decomposition of pyrite and arsenopyrite is accompanied by an increase in the pore volume from  $0.303 \cdot 10^{-3}$  to  $1.23 \cdot 10^{-3}$  with an increase in the degree of pyrite decomposition by about 41%, and then a decrease by about  $0.131 \cdot 10^{-3} \text{ m}^3/\text{g}$ , at a degree of decomposition of about 100%. The surface area of the pores increases from 0.31 to  $1.085 \text{ m}^2/\text{g}$  with a subsequent decrease due to the coarsening and merging of small pores. An increase in porosity is accompanied by an increase in the aerodynamic resistance of particles resulting from increased dust formation of the furnace.

**Keywords:** pyrite, arsenopyrite, sulfur, surface area, porosity, thermal decomposition, degree of decomposition, furnace reaction zone.

### Пирит пен арсенопириттің меншікті беті мен кеуектілігін зерттеу

**Аңдатпа.** Мақалада пирит пен арсенопириттің термиялық ыдырауындағы меншікті бетінің өзгеруі мен кеуектілігін зерттеу нәтижелері келтірілген. Пирит пен арсенопириттің ыдырауы кеуек көлемінің  $0,303 \cdot 10^{-3}$ -тен  $1,23 \cdot 10^{-3}$ -ке дейін ұлғайымен, пириттің ыдырау дәрежесінің шамамен 41% жоғарылауымен, содан кейін ыдырау дәрежесі шамамен  $0,131 \cdot 10^{-3} \text{ м}^3/\text{г}$  төмендеуімен бірге жүретіні анықталды. Шамамен 100% Кеуектердің беткі қабаты  $0,31$ -ден  $1,085 \text{ м}^2/\text{г}$ -ға дейін артады, содан кейін ұсақ кеуектердің кеңеюі мен бірігуіне байланысты төмендейді. Кеуектіліктің жоғарылауы пештің шағының жоғарылауы нәтижесінде пайда болатын бөлшектердің жел жылдамдығының жоғарылауымен, пирит пен арсенопириттің бөлшектерін пештің реакциялық аймағынан ауа ағылымен ішінара ыдыратуымен бірге жүреді.

**Түйінді сөздер:** пирит, арсенопирит, күкірт, меншікті бет, кеуектілік, термиялық ыдырау, ыдырау дәрежесі, пештің реакциялық аймағы.

### Исследование удельной поверхности и пористости пирита и арсенопирита

**Аннотация.** В статье приведены результаты изучения модификации удельной поверхности и пористости пирита и арсенопирита при их термическом разложении. Установлено, что разложение пирита и арсенопирита сопровождается увеличением объема пор с  $0,303 \cdot 10^{-3}$  до  $1,23 \cdot 10^{-3}$  при увеличении степени разложения пирита примерно на 41%, а затем уменьшением примерно на  $0,131 \cdot 10^{-3} \text{ м}^3/\text{г}$  при степени разложения около 100%. Площадь поверхности пор увеличивается с 0,31 до  $1,085 \text{ м}^2/\text{г}$  с последующим снижением за счет укрупнения и слипания мелких пор. Повышение пористости сопровождается увеличением аэродинамического сопротивления частиц, возникающим в результате повышенного пылеобразования печи.

**Ключевые слова:** пирит, арсенопирит, сера, удельная поверхность, пористость, термическое разложение, степень разложения, реакционная зона печи.

### Introduction

The mining industry is experiencing difficulties associated with an increase in demand for metals. Discovery rates are slowing, grades are declining, and undeveloped deposits tend to be complex, presenting us with unique environmental and technological challenges. Careful study of deposits and the use of acquired knowledge in the field of metal recovery is a key aspect of the successful implementation of new mining projects and extending the life of old ones. The prospect of processing arsenopyrite ores is to extract gold, but the problem lies in the refractory of such ores, and often even in double refractory, the study of the structure of arsenopyrite, specific surface, porosity will make it possible to more accurately determine the conditions for the technological opening of gold [1].

Gold that is adsorbed onto the surface of other minerals during primary ore formation, oxidation, and/or processing is generally referred to as surface-bound gold. It is this kind of gold that is often found in pyrite-arsenopyrite ores. [2] In refractory ores, the gold is strongly isolated from the cyanide solution, and some oxidative pre-treatment is necessary to open it, this may be roasting, oxidation (biological or auto-clave) or ultrafine grinding followed by oxidative leaching to make the ores suitable for cyanidation.

Thus, it is relevant to study the structure of arsenopyrite, specific surface area and porosity for the subsequent technological opening of gold.

As a result of ore base exhaustion of ferrous and nonferrous metallurgy at metallurgical treatment are involving more complicated and less qualitative ores. Magnetizing ores content considerable quantity of pyrite complicate the technology

of iron extraction. At the same time the pyrite concentrates processing at dressing content different nonferrous metals in industrial quantities [3-4].

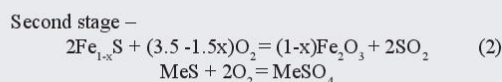
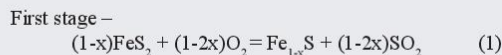
Extracting ores of nonferrous metals are containing considerable quantity of arsenic at the present time. Extraction of base metals from complicated raw materials demands new technologies. Arsenic contenting in ores is necessary to utilize (waste burial) in more ecological compatible form. Arsenic on acting metallurgical and chemical enterprises from technological cycle is withdrawing in the form of arsenate – arsenite cakes, burial of their may lead to seriously ecological problems as times goes by.

It was carried out the cycle of researching by pyrite, arsenopyrite and arsenate – arsenite cakes treatment with the object of arsenic withdrawal in sulfide form – in more ecological and safe form and with the object of preparation of initial ore raw materials to following pyro- and hydrometallurgical treatment [5]. As a result of sulfidizing of arsenate – arsenite cakes by pyrite are forming the volatile arsenic forms and pyrrhotite of variable structure.

The experience of one-stage sulfatizing roast carrying out of pyrite concentrates in fluidized bed furnaces is show that more higher results by sulfurizing (the degree of cobalt sulfatizing – till 75%) achieve at carrying out of process in furnaces with return cyclone.

The positive influence on return cyclone degree of sulfatizing may be explain by that underdecomposed substances of higher sulfides return on roast from cyclone the time of sulfatizing at that is increase. This circumstance is increase the duration of process and decrease the productivity of roast.

We propose to conduct roasting in two stages: pyrrhotizing roasting in the atmosphere with limited oxygen quantity at the first stage and oxidizing-sulfatizing roasting of pyrrhotizing cinder at the second stage according to the next equations:



Using two-stage process of roasting of pyrite concentrates instead of one-stage roasting allows to decrease by 40 % the necessity heat of the furnaces, to increase the efficiency of use of blast oxygen, to decrease more than twice the quantity of the flush acid, to improve labor conditions and to stabilize the technological parameters of the process.

The pilot scale testing of the technology of oxidizing-sulphatizing roasting of pyrite-cobalt concentrates from Sokolovsk-Sarybai Integrated Industrial Plant gave extraction into solution of 90.0% (2).

On the basis of the results of laboratory and pilot scale tests of the two-stage roasting technology (pyrrhotizing-sulphatizing) and their comparison with the results of the one stage sulphatizing we give recommendations on improving the two stages process of sulphatizing roasting of pyrite concentrates with the aim of increasing cobalt and nickel sulphatization degree with simultaneous decrease of iron sulphatization, increase of roasting efficiency, increase of the oxygen blast utilization coefficient, increase of sulfur dioxide and decrease of sulfur trioxide in the escaping gases, etc [6-7].

Raw materials with strictly limited arsenic content are used in smelting processes. Direct hydrometallurgical processing of raw materials with high arsenic content is used in a limited number of cases. Forecasting of the roasting process parameters is possible from the study of behavior of arsenic-bearing materials under high temperatures. The behavior of arsenopyrite under roasting is of theoretical and practical interest. The mechanism of pyrite and arsenopyrite decomposition at their thermal treatment has an influence on properties and behavior.

The research has shown that during the pyrite roasting in the autogenous mode with limited oxygen content in the gaseous phase the quantity of the sulfide anhydride and elemental sulfur formed in course of the reaction depends on the blast oxygen content (1). Presence in the roasting gaseous phase of high concentrations of sulfur dioxide and elemental sulfur will influence the mechanism of arsenopyrite roasting and the composition of the products formed under roasting.

Behavior of roasted arsenopyrite was studied by many authors. In [8] it was determined that arsenopyrite begins to dissociate at 550°C and at 700-900°C the process goes on with high velocity. Two stages of the process are observed: first arsenic vapor and high sulfur pyrrhotite are formed, and then the high pyrrhotite changes into low sulfur pyrrhotite and troilite. Thermodynamic analyses has shown that under thermal processing of arsenopyrite in the presence of pyrite and limited quantities of oxygen in the gaseous phase forma-

tion of arsenic sulfides is possible according to the following reactions:



The process of arsenopyrite thermal treatment in faintly oxidizing atmosphere also accomplish by arsenic isolation to gas phase with pyrrhotites of variable structure forming, containing some quantity of arsenic [9-11].

The arsenopyrite dissociation velocity depends on the grain size of the initial material. It is established that the velocity of arsenopyrite dissociation process limited by diffusion factor. In the presence of pyrite the arsenopyrite dissociates at lower temperatures and with higher velocities.

In this work introduce the results of studying of pyrite and arsenopyrite specific surface modification and porosity at their thermal decomposition at depends of decomposition degree [12].

#### Initial materials

The structure of arsenopyrite %: iron – 34.8, arsenic – 44.3, sulfur 20.5 and monomineral pyrite (99.05% pyrite), taking from industrial iron-magnetite ore, containing 53.9% of iron and 45.25% sulfur.

#### Methods and equipment

The decomposition of initial materials was realized in fixed layer in alumina tube. We studied the initial materials influence of decomposition degree on specific surface and porosity of cinders. The different decomposition degree was provided by variation of temperature from 650 until 850° C, and duration from 15 until 60 minutes.

Initial materials and decomposition products analyzed by chemical and X-ray methods, carried out electron – microscopic researching and defined their specific surface and porosity.

The electron – microscopic researching were carried out on electron scanning microscope JEOL M – 25 S3.

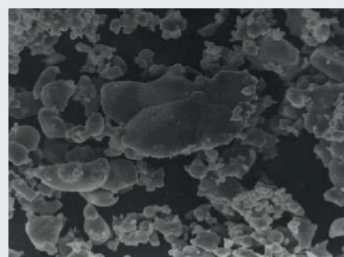
Electron – microscopic researching show that surface of initial pyrite is too much developing. Were defined the pores, splits in pyrite grains (figures a, b).

At the beginning of pyrite decomposition is observing the increasing of particles porosity, their some loosening making increasing their specific surface. At the end of decomposition the quantity of pores are decrease, the separate pores interflow, the size of pores increase and surface of materials smoothing (c, d). Reaction descends from surface to depth of particle. The form of initial particles are not change, the considerable particle destruction is absent.

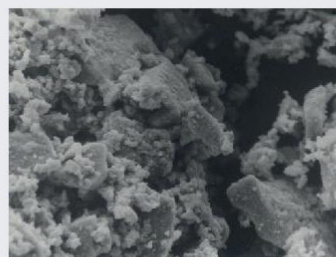
Photomicrographs of forming pyrrhotites at pyrite decomposition show the forming of layer-like structure (fig. 1c), this mechanism of appearance such structure demand additional studying. The results of pyrrhotites samples show that solution is occur anisotropically by layer in acids.

Electron-microscopic studying of arsenopyrite and products of arsenopyrite decomposition show that at arsenopyrite decomposition is forming the friable, porous structure with very developing surface. The decipitation of arsenopyrite grains is absent, geometrical sizes and particles form is differ slightly.

Specific surface and porosity were defined by BET methods by quantity of adsorbing nitrogen at his boiling-point.



a) x300



b) x1000



c) x1500

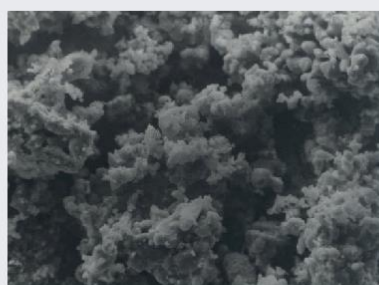


d) x1500

Figure 1. Electron photomicrography of initial pyrite and products of pyrite decomposition: a – initial pyrite concentrate; b – products of pyrite decomposition on 50%; c, d – products of pyrite decomposition on 95%.

Сурет 1. Бастапқы пирит пен оның ыдырау өнімдерінің электронды фотомикрографиясы: а – пириттің бастапқы концентраты; б – пириттің 50-ге ыдырау өнімдері %; c, d – пириттің 95-ке ыдырау өнімдері %.

Рис. 1. Электронная фотомикрография исходного пирита и продуктов его разложения: а – исходный концентрат пирита; б – продукты разложения пирита на 50%; c, d – продукты разложения пирита на 95%.



a) x200



b) x4500

Figure 2. Electron photomicrography of initial arsenopyrite and products of arsenopyrite decomposition: a – initial arsenopyrite; b – products of arsenopyrite decomposition on 97%.

Сурет 2. Бастапқы арсенопирит пен арсенопириттің ыдырау өнімдерінің электронды фотомикрографиясы: а – бастапқы арсенопирит; б – арсенопириттің 97-ге ыдырау өнімдері %.

Рис. 2. Электронная фотомикрография исходного арсенопирита и продуктов разложения арсенопирита: а – исходный арсенопирит; б – продукты разложения арсенопирита на 97%.

BET (Brunauer – Emmett – Taylor) analysis – analysis of measurement of the specific surface of dispersed materials by the method of low-temperature gas adsorption.

Specific surface was defined by following equations (5, 6):

$$S = \frac{X}{M} \cdot N \cdot A_N \cdot 10^{-20} \quad (5)$$

where:  $S$  – specific surface of sample,  $\text{m}^2/\text{g}$ ;

$X$  – mass of nitrogen monomolecular layer, adsorbing 1 g of sample;

$M$  – nitrogen molecular weight,  $M = 28 \text{ g}$ ;

$N$  – number of molecules in gram-mole,  $N = 6,023 \cdot 10^{23}$  molecules/mole;

$A_N$  – area, engaging by one adsorbing nitrogen molecule  $10^{-23} \text{ m}^2/\text{molecule}$ .

$$A_N = 1,091 \left( \frac{M}{\rho N} \right)^{\frac{2}{3}} \cdot 10^{16} \text{ m}^2/\text{molecule}, \quad (6)$$

$\rho$  – nitrogen density;  $\rho = 0,80925 \text{ g}/\text{cm}^3$ ;

$A_N = 16,2 \cdot 10^{-20} \text{ m}^2/\text{molecule}$ .

If we should substitute the getting expressions in initial equation we get the equation for calculation of specific surface:

$$S = \frac{X}{M} \cdot 6,023 \cdot 10^{23} \cdot 16,2 \cdot 10^{-20} = \frac{1}{(m+1) \cdot M} \cdot 9,75726 \cdot 10^4 \quad (7)$$

### Results and discussion

The studying of modification of pyrite and arsenopyrite specific surface and porosity at their thermal decomposition.

We're studied the pyrite decomposed in nitrogen atmosphere at 823, 873, 923 and 973 K, decomposition degree was equal 20,1, 41,0, 85,8 and 100% accordingly, and arsenopyrite was decomposed at 823, 873, 923 and 973 K, decomposition degree was equal – 19,1, 35,0, 84,8 and 97,0%. The calculation of adsorbing nitrogen weight was made according with B.E.T. (Brunauer – Emmett – Taylor) method.

Table 1

Specific surface (S<sub>ss</sub>) and porosity products of pyrite decomposition in nitrogen atmosphere

Кесте 1

Азот атмосферасындағы пириттің ыдырау өнімдерінің меншікті беті (S<sub>ss</sub>) және кеуектілігі

Таблица 1

Удельная поверхность (S<sub>ss</sub>) и пористость продуктов разложения пирита в атмосфере азота

| T, K | Decomposition degree, % | S <sub>ss</sub> , m <sup>2</sup> /g | Pore radius, 10 <sup>-10</sup> m | Void space, cm <sup>3</sup> /g | Pores surface area, m <sup>2</sup> /g | Pore distribution, % | Total Pores surface, m <sup>2</sup> /g |
|------|-------------------------|-------------------------------------|----------------------------------|--------------------------------|---------------------------------------|----------------------|----------------------------------------|
| 823  | 20.1                    | 0.79                                | More 84.067                      | 0.0503                         | 0.0162                                | 5.60                 | 0.0162                                 |
|      |                         |                                     | 57.911-84.067                    | 0.0768                         | 0.0578                                | 19.90                | 0.074                                  |
|      |                         |                                     | 38.239-57.911                    | 0.0649                         | 0.076                                 | 34.60                | 0.11405                                |
|      |                         |                                     | 19.229-38.239                    | 0.065                          | 0.0806                                | 48.0                 | 0.21935                                |
| 873  | 41.0                    | 1.7                                 | More 84.067                      | 0.0372                         | 0.12                                  | 5.1                  | 0.012                                  |
|      |                         |                                     | 57.911-84.067                    | 0.2345                         | 0.0317                                | 13.6                 | 0.0437                                 |
|      |                         |                                     | 38.239-57.911                    | 0.158                          | 0.401                                 | 36.9                 | 0.829                                  |
|      |                         |                                     | 19.229-38.239                    | 0.2392                         | 0.256                                 | 23.7                 | 1.085                                  |
| 923  | 85.8                    | 1.57                                | More 84.067                      | 0.4725                         | 0.152                                 | 14.0                 | 0.152                                  |
|      |                         |                                     | 57.911-84.067                    | 0.3660                         | 0.276                                 | 25.4                 | 0.428                                  |
|      |                         |                                     | 38.239-57.911                    | 0.104                          | 0.1218                                | 24.6                 | 0.2602                                 |
|      |                         |                                     | 19.229-38.239                    | 0.145                          | 0.2549                                | 47.4                 | 0.4951                                 |
| 973  | 100                     | 1.20                                | More 84.067                      | 0.1010                         | 0.0325                                | 6.6                  | 0.0325                                 |
|      |                         |                                     | 57.911-84.067                    | 0.1404                         | 0.1059                                | 21.4                 | 0.1384                                 |
|      |                         |                                     | 38.239-57.911                    | 0.0776                         | 0.0908                                | 24.1                 | 0.1515                                 |
|      |                         |                                     | 19.229-38.239                    | 0.1313                         | 0.2253                                | 58.8                 | 0.3768                                 |

The results of studying specific surface and porosity show (table 1), that the initial pyrite concentrate has very developing surface this confirmed by the results of electron-microscopic researching.

With the increasing of decomposition degree the void space is increasing from  $0.303 \cdot 10^{-3}$  to  $1.23 \cdot 10^{-3}$  at increasing of pyrite degree decomposition about 41% and then decrease about  $0.131 \cdot 10^{-3} \text{ m}^3/\text{g}$  at degree of decomposition near 100%. The sur-

face area of pores increase from 0.31 to 1.085  $\text{m}^2/\text{g}$  with following lowering due to 0.18-0.138  $\text{m}^2/\text{g}$ , specific surface increased at the beginning from 1.088 to 1.7  $\text{m}^2/\text{g}$ , and decrease to 0.488.

As development of dissociation process is occur the desulphurization that lead to confluence of separate micropores, forming of large pores, decreasing of specific surface. Electron-microscopic researching are confirming such modification of pyrite particles in decomposition process. Thus,

modification of pyrite porosity and specific surface at decomposition will be influence on velocity of gaseous sulfur removal forming as a result of process.

Further are introduced the results of researching specific surface and porosity products of arsenopyrite decomposition in nitrogen atmosphere (table 2).

*Specific surface (Sss) and porosity products of arsenopyrite decomposition in nitrogen atmosphere*

Table 2

*Азот атмосферасындағы арсенипириттің ыдырау өнімдерінің меншікті беті (Sss) және кеуектілігі*

Кесте 2

*Удельная поверхность (Sss) и пористость продуктов разложения арсенипирита в атмосфере азота*

Таблица 2

| T, K | Decomposition degree, % | S <sub>ss</sub> , m <sup>2</sup> /g | Pore radius, 10 <sup>-10</sup> m | Void space, cm <sup>3</sup> /g | Pores surface area, m <sup>2</sup> /g | Pore distribution, % | Total Pores surface, m <sup>2</sup> /g |
|------|-------------------------|-------------------------------------|----------------------------------|--------------------------------|---------------------------------------|----------------------|----------------------------------------|
| 823  | 19.1                    | 0.85                                | More 84.07                       | 0.0061                         | 0.00201                               | 0.5                  | 0.00201                                |
|      |                         |                                     | 57.91-84.07                      | 0.0786                         | 0.06912                               | 13.3                 | 0.7113                                 |
|      |                         |                                     | 38.24-57.91                      | 0.1181                         | 0.1317                                | 29.7                 | 0.60283                                |
|      |                         |                                     | 19.23-8.24                       | 0.140                          | 0.2509                                | 56.5                 | 0.45373                                |
| 873  | 35.0                    | 1.89                                | More 84.07                       | 0.2463                         | 0.0776                                | 7.3                  | 0.0776                                 |
|      |                         |                                     | 57.91-84.07                      | 0.1428                         | 0.1068                                | 10.0                 | 0.1844                                 |
|      |                         |                                     | 38.24-57.91                      | 0.2897                         | 0.373                                 | 35.0                 | 0.5574                                 |
|      |                         |                                     | 19.23-8.24                       | 0.231                          | 0.5079                                | 47.7                 | 1.0653                                 |
| 923  | 84.8                    | 1.23                                | More 84.07                       | 0.2372                         | 0.0758                                | 12.6                 | 0.0758                                 |
|      |                         |                                     | 57.91-84.07                      | 0.1406                         | 0.1062                                | 16.6                 | 0.1820                                 |
|      |                         |                                     | 38.24-57.91                      | 0.1276                         | 0.1430                                | 23.7                 | 0.3250                                 |
|      |                         |                                     | 19.23-8.24                       | 0.163                          | 0.2783                                | 46.1                 | 0.6033                                 |
| 973  | 97.0                    | 1.13                                | More 84.07                       | 0.2483                         | 0.0787                                | 15.5                 | 0.0787                                 |
|      |                         |                                     | 57.91-84.07                      | 0.1534                         | 0.1166                                | 12.9                 | 0.1947                                 |
|      |                         |                                     | 38.24-57.91                      | 0.1483                         | 1.0854 0.1346                         | 34.9                 | 0.371                                  |
|      |                         |                                     | 19.23-8.24                       | 0.0831                         |                                       | 26.7                 | 0.5056                                 |

The results show that (table 2) as a developing of arsenopyrite thermal dissociation process specific surface and porosity of products of arsenopyrite decomposition is increasing at first (also windage) and at the end of decomposition are decreasing. At the degree of decomposition near 100% pores surface area increasing from 0.1166 until 1.0854 m<sup>2</sup>/g with following decreasing due to enlargement and confluence of minor pores.

From the beginning of process are forming many minor pores which for the end of decomposition enlarge. The increasing of windage partially decomposed pyrite and arsenopyrite particles could lead to their higher emission with dust obviously.

At sulfatizing roast of sulfide concentrates observe dust emission of underdecomposed pyrite particles possessing heightened windage which could be located by dust extractors. At the return of locating dust on roast from return cyclone pyrite decomposition degree increase and their windage diminish. Dust particles returning from return cyclone partially not rush out and follow to sulfatizing roast in full capacity.

### Conclusion

Thus, was established that pyrite and arsenopyrite decomposition accomplish by increasing of porosity and specific surface at increasing of pyrite decomposition degree until 40-45% at following decomposition the specific surface and porosity are decreasing – occur enlargement and confluence of minor pores this also confirm by results of microscopic analysis. The increasing of porosity accomplishes by increasing of particle windage and this is lead to heightened dust emission partially decomposed pyrite and arsenopyrite particles by air stream from furnaces reaction zone. This is explaining heightened content of sulfide sulfur in roast dusts of sulfide concentrates.

Simultaneous modification of pyrite and arsenopyrite specific surface and porosity show that for more full arsenic sulfidizing of arsenopyrite the process more effectively realize in continuous conditions at constant receipt of elemental sulfur to reaction zone.

### Acknowledgements

This research was funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan №AP15473200.

## REFERENCES

1. Langmuir I. The adsorption of gases on plane surfaces of glass, mica and platinum // *Journal of the American Chemical Society*. 1918. V. 40, N 9. P. 1361-1403 (in English)
  2. Karnaukhov A.P. Adsorbtsiya. Tekstura dispersnyx i poristyx materialov. Novosibirsk: Nauka. Sib. predpriyatie RAN, 1999. 470 s. (in Russian)
  3. Vyacheslavov A.S., Yefremova M.E. Opredelenie ploshchadi poverxnosti i poristosti materialov metodom sorbtsii gazov: metodicheskaya razrabotka. M.: MGU, 2011. 65 s. (in Russian)
  4. Li, M., Chen, J., Lin, X., Li, X., Yan, J. The effect of extracellular polymeric substances (EPS) of iron-oxidizing bacteria (*Ochrobactrum EEEELCW01*) on mineral transformation and arsenic (As) fate. *Journal of Environmental Sciences (China)*, 130, PP. 187-196. 2023 (in English)
  5. Zhao C., Yao, J. Knudsen, T.S. Cao, Y., Liu, B. Performance and mechanisms for Cd(II) and As(III) simultaneous adsorption by goethite-loaded montmorillonite in aqueous solution and soil. *Journal of Environmental Management*, 330, 117163. 2023 (in English)
  6. Song, H., Liang, W., Luo, K., Zhang, W., Peng, C. Simultaneous stabilization of Pb, Cd and As in soil by rhamnolipid coated sulfidated nano zero-valent iron: Effects and mechanisms. *Journal of Hazardous Materials*, 443, 130259. 2023 (in English)
  7. Gomes, T., Da Rosa, R., Cargnin, M., Da Rosa Rabelo, N., Angioletto, E. Pyrite roasting in modified fluidized bed: Experimental and modeling analysis. *Chemical Engineering Science*, 261, 117977. 2022 (in English)
  8. Su, M., Liu, H., Zhang, C., Liu, C., Pei, Y. H<sub>2</sub>O<sub>2</sub> mediated oxidation mechanism of pyrite (0 0 1) surface in the presence of oxygen and water. *Applied Surface Science*, 617, 156568. 2023 (in English)
  9. Feng, F., Qu, C., Tang, J., Xiao, R., Tang, C.-J. Quantification of enhanced nitrogen removal pathways of pyrite interaction with Anammox sludge system. *Chemical Engineering Journal*, 459, 141519. 2023 (in English)
  10. Sasmaz, A., Didem Kilic, A., Akgul, B., Sasmaz, B. A spectral approach on mineralogy and geochemistry of garnet skarns in Arc-Type granitoids. *Spectrochimica Acta – Part A: Molecular and Biomolecular Spectroscopy*, 286, 122037. 2023 (in English)
  11. Chu, Y., Liu, W., Tan, Q., Wu, Z., He, F. Vertical-flow constructed wetland based on pyrite intensification: Mixotrophic denitrification performance and mechanism. *Bioresource Technology*, 347, 126710. 2022 (in English)
  12. Yao, Y., Hu, H., Yin, H., Qiu, Y., Wang, S. Pyrite-embedded porous carbon nanocatalysts assembled in polyvinylidene difluoride membrane for organic pollutant oxidation. *Journal of Colloid and Interface Science*, 608, PP. 2942-2954. 2022 (in English)
- ПАЙДАЛАНЫЛҒАН ӘДБИЕТТЕР ТІЗІМІ
1. Лангмюр І. Әйнектің, слюданың және платинаның жазық беттеріндегі газдардың адсорбциясы // *Американдық химия қоғамының журналы*. 1918. – Б. 40, Н 9. – Б. 1361-1403 (ағылшын тілінде)
  2. Карнаухов А.П. Адсорбция. Дисперсті және кеуекті материалдардың құрылымы. Новосибирск: Ғылым. Сиб. кәсіпорын РАН, 1999. – Б. 470 (орыс тілінде)
  3. Вячеславов А.С., Ефремова М.Е. Газ сорбциясы арқылы материалдардың бетінің ауданы мен кеуектілігін анықтау: әдістемелік өңдеу. М.: МГУ, 2011. – Б. 65 (орыс тілінде)
  4. Ли, М., Чен, Дж., Лин, Х., Ли, Х., Ян, Дж. Темір тотықтырғыш бактериялардың (*Ochrobactrum EEEELCW01*) жасушадан тыс полимерлі заттардың (EPS) минералды трансформацияға және мышьякқа (As) әсері тағдыр. *Journal of Environmental Sciences (Қытай)*, 130, – Б. 187-196. 2023 (ағылшын тілінде)
  5. Чжао, Ц., Яо, Дж., Кнудсен, Т.Ш., Цао, Ю., Лю, Б. Судағы гетитпен жүктелген монтмориллонит арқылы Cd(II) және As(III) бір мезгілде адсорбциялаудың өнімділігі мен механизмдері. ерітінді және топырақ. *Қоршаған ортаны басқару журналы*, 330, 117163. 2023 (ағылшын тілінде)
  6. Сонг, Н., Линг, В., Луо, К., Джанг, В., Пенг, С. Pb, Cd және As топырақтағы рамнолипидпен қапталған сульфидтелген нано валентті темір арқылы бір мезгілде тұрақтандыру: әсерлері мен механизмдері. *Қауіпті материалдар журналы*, 443, 130259. 2023 (ағылшын тілінде)
  7. Гомес, Т., Да Роза, Р., Каргнин, М., Да Роза Рабело, Н., Ангиолетто, Э. Пиритті түрлендірілген қабатта қуыру: Эксперименттік және модельдеу талдауы. *Химиялық инженерия ғылымы*, 261, 117977. 2022 (ағылшын тілінде)
  8. Су, М., Лю, Х., Чжан, С., Лю, С., Пэй, Ю. Оттегі мен судың қатысуымен пирит (0 0 1) бетінің H<sub>2</sub>O<sub>2</sub> тотығу механизмі. *Қолданбалы беттік ғылым*, 617, 156568. 2023 (ағылшын тілінде)

9. Фэн, Ф., Цю, С., Тан, Дж., Сяо, Р., Тан, С.-Дж. Анаммокс илам жүйесімен тириктің өзара әрекеттесуінің жақсартылған азотты кетіру жолдарының сандық көрсеткіштері. «Химиялық инженерия» журналы, 459, 141519. 2023 ж. (ағылшын тілінде)
10. Сасмаз, А., Дидем Килич, А., Акгуль, Б., Сасмаз, Б. Доғалы гранитоидтардағы гранат скарндарының минералогиясы мен геохимиясына спектрлік көзқарас. *Spectrochimica Acta – A бөлігі: молекулалық және биомолекулалық спектроскопия*, 286, 122037. 2023 (ағылшын тілінде)
11. Чу, Ю., Лю, В., Тан, К., Ву З., Хэ, Ф. Колчеданды интенсификациялау негізінде тік ағынды салынған сулы-батпақты алқаптар: Миксотрофты денитрификация өнімділігі мен механизмі. *Биоресурс технологиясы*, 347, 126710. 2022 (ағылшын тілінде)
12. Яо, Ю., Ху, Х., Инь, Х., Цю, Ю., Ван, С. Органикалық ластаушы заттардың тотығуы үшін поливинилиден дифторидті мембранада жиналған тиритке енгізілген кеуекті көміртекті нанокатализаторлар. *Калойдты және интерфейс журналы Science*, 608, – Б. 2942-2954. 2022 (ағылшын тілінде)

## СПИСОК ИСПОЛЬЗОВАННЫХ ИСТОЧНИКОВ

1. Ленгмюр И. Адсорбция газов на плоских поверхностях стекла, слюды и платины // Журнал Американского химического общества. 1918. Т. 40, №9. – С. 1361-1403 (на английском языке)
2. Карнаухов А.П. Адсорбция. Текстура дисперсных и пористых материалов. Новосибирск: Наука. Сиб. предприятие РАН, 1999. – С. 470 (на русском языке)
3. Вячеславов А.С., Ефремова М.Е. Определение площади поверхности и пористости материалов методом сорбции газов: методическая разработка. М.: МГУ, 2011. – С. 65 (на русском языке)
4. Ли, М., Чен, Дж., Лин, Х., Ли, Х., Ян, Дж. Влияние внеклеточных полимерных веществ (EPS) железобактерий (*Ochrobactrum tritici*) на минеральную трансформацию и мышьякового (As) участка. Журнал наук об окружающей среде (Китай), 130, –С. 187-196. 2023 (на английском языке)
5. Чжао С., Яо Дж., Кнудсен Т.Ш., Цао Ю., Лю Б. Эффективность и механизмы одновременной адсорбции Cd(II) и As(III) монтмориллонитом, содержащим гетит, в водной среде расторг и грунт. Журнал экологического менеджмента, 330, 117163. 2023 (на английском языке)
6. Сонг Х., Лян В., Луо К., Чжан В., Пэн С. Одновременная стабилизация Pb, Cd и As в почве сульфидированным нанонанульвалентным железом, покрытым рамнолитидом: эффекты и механизмы. Журнал опасных материалов, 443, 130259. 2023 (на английском языке)
7. Гомес Т., Да Роса Р., Каргнин М., Да Роса Рабело Н., Анжиолетто Э. Обжиг тирита в модифицированном псевдооживленном слое: экспериментальный и модельный анализ. Химическая инженерия, 261, 117977.2022 (на английском языке)
8. Su, M., Liu, H., Zhang, C., Liu, C., Pei, Y. Опосредованный H<sub>2</sub>O<sub>2</sub> механизм окисления поверхности тирита (0 0 1) в присутствии кислорода и воды. Прикладная наука о поверхности, 617, 156568. 2023 (на английском языке)
9. Фэн Ф., Цю С., Тан Дж., Сяо Р., Тан С.-Дж. Количественная оценка путей усиленного удаления азота при взаимодействии тирита с системой ила Анаммокс. Журнал химической инженерии, 459, 141519. 2023 (на английском языке)
10. Сасмаз А., Дидем Килич А., Акгуль Б., Сасмаз Б. Спектральный подход к минералогии и геохимии гранатовых скарнов в гранитоидах дугового типа. *Spectrochimica Acta – Часть А: Молекулярная и биомолекулярная спектроскопия*, 286, 122037. 2023 (на английском языке)
11. Чу, Ю., Лю, В., Тан, К., Ву З., Хе, Ф. Водно-болотные угодья, построенные с вертикальным потоком на основе интенсификации тирита: эффективность и механизм миксотрофной денитрификации. Биоресурсные технологии, 347, 126710. 2022 (на английском языке)
12. Яо, Ю., Ху, Х., Инь, Х., Цю, Ю., Ван, С. Пористые углеродные нанокатализаторы с включением тирита, собранные в поливинилидендифторидной мембране, для окисления органических загрязнителей. Журнал науки о коллоидах и интерфейсах, 608. – С. 2942-2954. 2022 (на английском языке)

## Information about the authors:

**Chepushtanova T.A.**, Head of Department, candidate of technical sciences, PhD, Associate Professor, Department of «Metallurgical Processes, Heatengineering and Technology of Special Materials», Mining and Metallurgical Institute, Satbayev University (Almaty, Kazakhstan), [t.chepushtanova@satbayev.university](mailto:t.chepushtanova@satbayev.university); <https://orcid.org/0000-0002-6526-0044>

**Maratuly D.**, Master's degree, PhD student of the Department «Metallurgical processes, heat engineering and technology of special materials», Mining and Metallurgical Institute, Satbayev University, (Almaty, Kazakhstan), [d.maratuly@satbayev.university](mailto:d.maratuly@satbayev.university); <https://orcid.org/0000-0001-5101-7484>

**Manyrbayeva K.K.**, Ph.D., Associate Professor, «Metallurgical processes, heatengineering and technology of special materials», Mining and Metallurgical Institute, Satbayev University, (Almaty, Kazakhstan), [k.manyrbayeva@satbayev.university](mailto:k.manyrbayeva@satbayev.university); <https://orcid.org/0000-0002-1094-5345>

**Brajendra M.**, Professor and Director of MPI Mechanical and Materials Engineering, Worcester Polytechnic Institute (Worcester, USA), [bmishra@wpi.edu](mailto:bmishra@wpi.edu); <https://orcid.org/0000-0001-7897-1817>

**Авторлар туралы мәліметтер:**

**Чепуштанова Т.А.**, кафедра меңгерушісі, техника ғылымдарының кандидаты, PhD, Сәтбаев университеті, Тау-кен металлургия институты, «Металлургиялық процестер, жылу техникасы және арнайы материалдар технологиясы» кафедрасының қауымдастырылған профессоры (Алматы қ., Қазақстан)

**Мартыулы Д.**, магистр, Сәтбаев университеті, Тау-кен металлургия институты, «Металлургиялық процестер, жылу техникасы және арнайы материалдар технологиясы» кафедрасының PhD докторанты, Satbayev University, (Алматы қ., Қазақстан)

**Мамырбаева К.К.**, PhD, қауымдастырылған профессор, Сәтбаев университеті, Тау-кен металлургия институты, «Металлургиялық процестер, жылу техникасы және арнайы материалдар технологиясы» кафедрасының қауымдастырылған профессоры (Алматы қ., Қазақстан)

**Бражендра М.**, Вустер политехникалық институтының MPI механикалық және материалдар инженериясының профессоры және директоры (Вустер, АҚШ)

**Сведения об авторах:**

**Чепуштанова Т.А.**, заведующая кафедрой, канд. техн. наук, PhD, ассоциированный профессор кафедры «Металлургические процессы, теплотехника и технология специальных материалов», Горно-металлургический институт, Satbayev University, (г. Алматы, Казахстан)

**Мартыулы Д.**, магистр, PhD, докторант кафедры «Металлургические процессы, теплотехника и технология специальных материалов», Горно-металлургический институт, Satbayev University, (г. Алматы, Казахстан)

**Мамырбаева К.К.**, PhD, ассоциированный профессор кафедры «Металлургические процессы, теплотехника и технология специальных материалов», Горно-металлургический институт, Satbayev University, (г. Алматы, Казахстан)

**Бражендра М.**, профессор и директор MPI Машиностроение и материаловедение, Вустерский политехнический институт (г. Вустер, США)

**ВСЕРОССИЙСКАЯ НАУЧНО-ТЕХНИЧЕСКАЯ КОНФЕРЕНЦИЯ  
С УЧАСТИЕМ ИНОСТРАННЫХ СПЕЦИАЛИСТОВ  
«ЦИФРОВЫЕ ТЕХНОЛОГИИ В ГОРНОМ ДЕЛЕ»**



**ОСНОВНЫЕ НАПРАВЛЕНИЯ РАБОТЫ КОНФЕРЕНЦИИ:**

- Цифровые технологии и компьютерное моделирование объектов и процессов горного производства для решения задач рациональной и безопасной отработки месторождений полезных ископаемых
- Цифровые технологии в геомеханическом обеспечении горных работ
- Цифровые технологии для решения задач повышения полноты и комплексности извлечения полезных ископаемых из рудного и техногенного минерального сырья
- Цифровые технологии и компьютерное моделирование в решении экономических и экологических проблем горной отрасли

Заявки на участие принимаются по электронной почте [conf2023@ksc.ru](mailto:conf2023@ksc.ru)

Горный институт Кольского научного центра Российской академии наук, 184209 г. Апатиты Мурманской обл., ул. Ферсмана, д.24  
Телефоны: (81555) 79567, (81555) 79268, факс: (81555) 74625

