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RESEARCH ON THE POSSIBILITY OF INTENSIFICATING THE PROCESS OF RICTION OF ZINC CONCENTRATE IN A FLUIDIZED BED USING MATHEMATICAL MODELING METHODS

МЫРЫШ КОНЦЕНТРАТЫН МАТЕМАТИКАЛЫҚ МОДЕЛЬДЕУ ӘДІСТЕРІН ПАЙДАЛАНҒАН СҮЙІКТІ КӨРСЕТКІДЕ РИКЦИЯЛАНДЫРУ ПРОЦЕСІН ҚАРШЫТУ МҮМКІНДІГІН ЗЕРТТЕУ

ИССЛЕДОВАНИЕ ВОЗМОЖНОСТИ ИНТЕНСИФИКАЦИИ ПРОЦЕССА ОБЖИГА ЦИНКОВОГО КОНЦЕНТРАТА В КИПЯЩЕМ СЛОЕ С ИСПОЛЬЗОВАНИЕМ МЕТОДОВ МАТЕМАТИЧЕСКОГО МОДЕЛИРОВАНИЯ

Аңдатпа. *Бұл жұмыста цинк концентратын математикалық модельдеу әдістерін қолдана отырып, сұйық қабаттағы пештерде күйдіру процесін күшейту мүмкіндігі қарастырылады. Зерттеудің мақсаты мырыш оксидінің шығымдылығын арттыру және энергия шығындарын азайту үшін күйдіру шарттарын оңтайландыру болып табылады. Реакция кинетикасын және масса және жылу алмасу процестерін сипаттайтын математикалық модельдерді пайдалана отырып, температура, күйдіру уақыты және бастапқы материалдың құрамы сияқты негізгі параметрлер талданады. Аэрацияның және реагенттерді қосудың реакция жылдамдығы мен тиімділігіне әсері қарастырылады. Жұмыстың эксперименттік бөлімі математикалық модельдерді растауға және теориялық болжамдарды растауға мүмкіндік беретін зертханалық сынақтарды қамтиды. Нәтижелер көрсеткендей, ұсынылған интенсивтендіру әдістері қуыру процесінің тиімділігін айтарлықтай жақсартады, шығарындыларды азайтады және тұрақты өндіріске ықпал етеді. Алынған мәліметтер өнеркәсіпке енгізу және мырыш концентраттарын өңдеу саласында жаңа технологиялық шешімдерді әзірлеу үшін пайдалы болуы мүмкін.*

Түйін сөздер: *Мырыш концентраттарын күйдіру, интенсификациялау, аэрациялау, математикалық модельдеу, сұйық қабат, масса алмасу.*

Аннотация. *В данной работе исследуется возможность интенсификации процесса обжига цинкового концентрата в печах кипящего слоя с применением методов математического моделирования. Целью исследования является оптимизация условий обжига для повышения выхода оксида цинка и снижения энергетических затрат. Используя математические модели, описывающие кинетику реакций и процессы переноса массы и тепла, анализируются ключевые параметры, такие как температура, время обжига и состав исходного материала. Рассматривается влияние аэрации и добавления реагентов на скорость и эффективность реакции. Экспериментальная часть работы включает лабораторные испытания, которые позволяют валидировать математические модели и подтвердить теоретические прогнозы. Результаты показывают, что предложенные методы интенсификации значительно улучшают эффективность процесса обжига, уменьшают выбросы и способствуют более устойчивому производству. Полученные данные могут* *быть полезны для внедрения в промышленность и разработки новых технологических решений в области переработки цинковых концентратов.*

Ключевые слова: *Обжиг цинковых концентратов, интенсификация, аэрация, математическое моделирование, кипящий слой, массовый обмен.*

Abstract. *This paper examines the possibility of intensifying the process of roasting zinc concentrate in fluidized bed furnaces using mathematical modeling methods. The purpose of the study is to optimize firing conditions to increase the yield of zinc oxide and reduce energy costs. Using mathematical models describing reaction kinetics and mass and heat transfer processes, key parameters such as temperature, firing time and composition of the starting material are analyzed. The effect of aeration and the addition of reagents on the speed and efficiency of the reaction is considered. The experimental part of the work includes laboratory tests that allow us to validate mathematical models and confirm theoretical predictions. The results show that the proposed intensification methods significantly improve the efficiency of the roasting process, reduce emissions and contribute to more sustainable production. The data obtained can be useful for implementation in industry and the development of new technological solutions in the field of processing zinc concentrates.*

Keywords: *Roasting of zinc concentrates, intensification, aeration, mathematical modeling, fluidized bed, mass exchange.*

Introduction. In the modern world, metallurgy plays an important role in the development of economy and industry. One of the key processes in metallurgical production is the fluidised bed roasting of zinc concentrate. This process is of great importance for obtaining quality zinc product.

The operation of the fluidised bed furnace is based on the circulation of gas, which is fed from below through a bed of loose particles. The gas creates a lifting force, lifting and agitating the particles, which ensures a uniform distribution of temperature and reactant concentration. The pipework ensures reliable movement of both gas and solids, maintaining stable process conditions.

Ensuring the efficient operation of fluidised bed furnace pipework is important to ensure the safety and efficiency of the production process. One of the ways to improve the efficiency of pipework is stabilisation and uniform mixing of the air mixture. This raises the need to investigate the possibilities of intensification of the firing process using mathematical modelling methods (Alkatsev et al., 2022).

Mathematical modelling allows to analyse and predict the behaviour of the system, identify patterns and optimise its operation (Alkatsev et al., 2020). In this case, mathematical modelling of the process of oxygen-air mixture supply for zinc concentrate roasting in the fluidised bed will help to determine the optimal process parameters, such as temperature, air flow rate and others, to achieve maximum productivity and product quality.

Object and methods of research. The object of the study was pipework designed to mix oxygen with air in certain proportions. A fluidised bed furnace pipeline is a system of pipes designed to transport gases and/or particles (e.g. bulk materials) during fluidised bed firing (Krasheninnikov and Savchenko, 2013). The main characteristics of the pipeline are:

1. Materials: The pipework can be made of various materials such as steel, stainless steel or special alloys resistant to corrosion and high temperatures.
2. Diameter: The diameter of the pipework is determined according to the flow volume and material characteristics. Generally large diameter pipes are used to ensure efficient movement of gaseous mixtures.
3. Design: The pipework is available in a variety of configurations including straight sections, elbows and connections, allowing for optimum system organisation depending on the project requirements.
4. Insulation: In some cases, pipework may be insulated to reduce heat loss or prevent condensation.
5. Monitoring systems: Pipelines can be equipped with pressure, temperature and flow sensors to monitor process status.

The basic schemes (existing today) of mixing of two gas streams of oxygen and air for blower machines are shown in Figure 1. Blower #1 with oxygen supply in the centre of the pipeline (Figure 1a) and Blower #2 with oxygen supply near the sector elbow (Figure 1b).

Since mixing of air and oxygen is usually carried out in a short period of time on a path of relatively small dimensions, the resulting oxygen-air mixture entering the blowers will be inhomogeneous and local formation of zones with higher oxygen content (more than 40%) is possible. From the material presented in (Safety Instructions for Production and Consumption of Air Separation Products [Electronic Resource]) it follows that blower fans can safely operate in a gas environment with an oxygen concentration of less than 40%.

In order to achieve a more uniform mixing of oxygen and air flows, we modelled the reconstruction of the pipeline by installing a conical confuser nozzle. A confuser nozzle (confuser) is a part of a technical device, which is a channel that smoothly tapers into a smaller diameter pipe. Confusors are used to accelerate the flow of gas or liquid by reducing the cross-sectional area of the channel, thus increasing the flow velocity and pressure. Depending on the application, confuser nozzles can have different shapes and sizes. They are widely used in various technical devices and systems such as:

• internal combustion engines;
• jet engines;
• gas turbines;
• wind tunnels;
• ventilation and air conditioning systems;
• pumps and compressors.

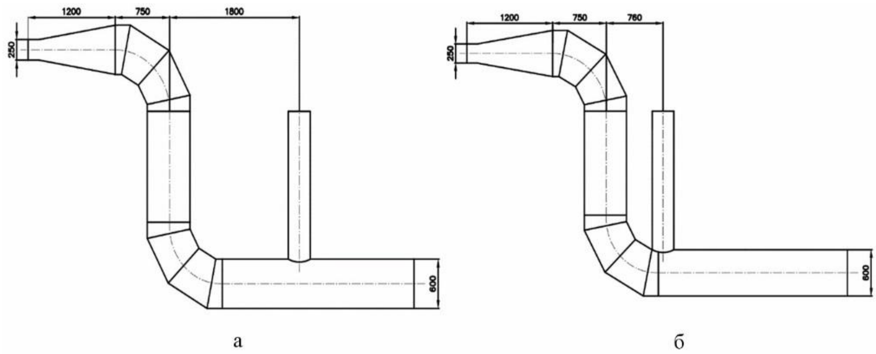

Figure 1. Basic schemes (existing today) for mixing the two gas streams oxygen and air for blower machines: a – blower No.1 with oxygen supply in the centre of the pipeline; b – blower No.2 with oxygen supply near the sector elbow

Note – compiled by the authors

The principle of operation of the confuser is based on the law of conservation of energy, according to which the flow velocity increases as the cross-sectional area decreases. At the same time, the potential energy of pressure is converted into kinetic energy of motion. The use of confusers allows optimising the operation of various systems and devices, ensuring more efficient use of energy and increased productivity.

Peculiarities of pipelines operation in conditions of mixing of two gas flows of oxygen and air can be determined by the method of computational modelling (Borodin, 2008). The possibility of inhomogeneous oxygen-air mixture formation at different initial parameters (temperature, flow rate and pressure) was assessed using the developed mathematical model in Ansys software and calculation complex. Ansys is a powerful tool for solving complex engineering problems and helps to improve the efficiency and reliability of designs. Ansys is designed for numerical modelling of various physical processes, which allows solving problems in deformable solid mechanics, hydrodynamics, heat transfer and other areas of physics (Krivtsov and Shabliy, 2013).

Numerical modelling methods have an advantage over experimental studies, as they can be used to obtain more complete information about the process under study. (Minkov and Moiseeva, 2017). In contrast to experiment, practically the whole area under study is available for calculation. It is very difficult when conducting experiments to measure the distribution of all variables affecting the process in the entire study area. (Salich, 2017).

Therefore, obtaining images of the processes occurring in the pipelines at mixing of two gas streams, obtained as a result of numerical modelling, allows to promptly identify design deficiencies and develop ways to eliminate them in further design (Mukhametdzhanova et al., 2021).

Results and their discussion. The process of formation of a homogeneous gas mixture when mixing two gas streams with different thermodynamic parameters is of great importance. (Ivakina et al., 2021). When mixing air and oxygen streams, it is possible to form air-oxygen mixture streams with increased oxygen concentration, which is a highly undesirable phenomenon because it can lead to negative consequences. (Xu et al., 2023).

Oxygen is known to be an active oxidising agent and many substances as well as materials in oxygen or oxygen-rich air environments form systems with increased fire and explosion hazards. (Liu et al., 2021; Harris, 2020). Therefore, the issues of ensuring trouble-free operation of pipelines under different oxygen and air streams are very important. Since the oxygen content in the oxygen stream supplied for mixing varies up to 96%, a nomogram was constructed (Figure 2) showing the dependence of air flow rate on the flow rate and oxygen content in it under normal conditions.

At oxygen supply with concentration equal to 96%, no exceeding of critical values of oxygen concentration in the mixture is observed. Optimum values can be seen at air supply of 16000-33000 Nm^3/h and oxygen supply of 4000-5000 Nm^3/h respectively. The oxygen concentration in the mixture may exceed the critical values at air and oxygen supply readings between 16000-19000 Nm^3/h and 5500-6000 Nm^3/h respectively. It follows from the data obtained that the oxygen content in the mixture depends on the flow rate of the mixed streams and the oxygen content in the supplied oxygen stream and may approach or exceed the critical value.

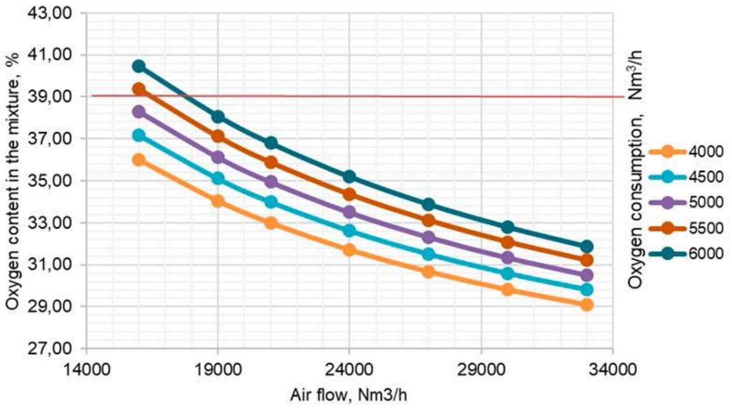

Figure 2. Dependence of oxygen content in air-oxygen mixture on air and oxygen flow rates under normal conditions (96% oxygen concentration)

Note – compiled by the authors

Mathematical modelling has been performed and results of the process of mixing of oxygen and air streams for blowers No.1 and No.2 have been obtained at average oxygen concentration in the stream – 96% and air and oxygen flow rates of 20000 and 5000 Nm^3/h. Figure 3 shows the mathematical model of the field of oxygen concentration distribution within the cross-section of the calculation area at the existing method of mixing of air and oxygen streams at the following parameters: volume flow rate of oxygen stream 5000 Nm^3/h and air 20000 Nm^3/h; initial temperature of oxygen 20ºC, air 25ºC.

In the investigated mixing units for blowers #1 and #2, the merging of two streams (air and oxygen) at 90° angle provides a rectangular tee that introduces very strong perturbations, and an uneven distribution of oxygen concentration can be seen.

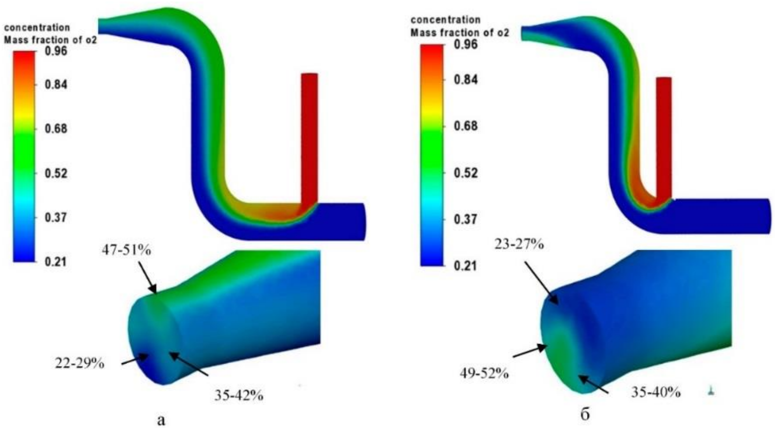

Figure 3. Oxygen concentration distribution field within the cross-section of the design area under the existing method of mixing air and oxygen flows: a – for blower machine No.1; b – for blower machine No.2

Note – compiled by the authors

One way of eliminating the non-uniform distribution of oxygen concentration fields when mixing two gas streams of air and oxygen is to make design changes to the mixing units themselves, and the other is to act on the non-uniformity that already exists. This can lead to changes in the resistance in the system. (Peng et al., 2020; Berdiyarov, Kim, & Nasyrov, R. 2021). In this case, the main objective is that the resistance does not change, and if it does, it does not change to a very large extent.

We propose to install a conical confusor nozzle in the duct cross-section in the area of connection with the oxygen pipeline. Figure 4 shows the geometric and calculation models of the proposed two-flow mixing unit for blower No. 2. Figure 5 shows the mathematical model of the field of oxygen concentration distribution within the cross-section of the design area at mixing of air and oxygen streams at installation of a conical confuser nozzle in the duct cross-section in the area of oxygen pipeline connection for blower machines No.1 and No.2 at the following parameters: volume flow rate of oxygen stream 5000 Nm^3/h and air 20000 Nm^3/h; initial temperature of oxygen 20ºC, air 25ºC.

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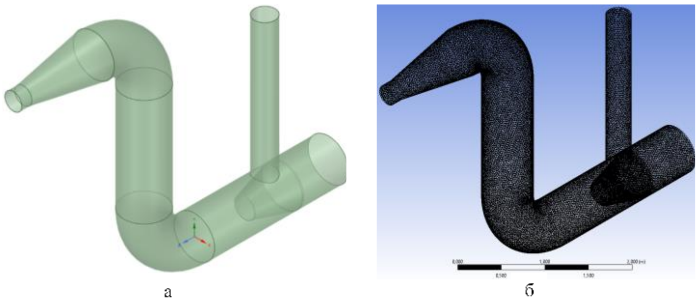

Figure 4. Three-dimensional model of the oxygen and air flow mixing unit when a conical confuser nozzle is installed in the duct cross-section in the area of connection with the oxygen pipeline for blower #1: a – geometric model; b – mesh model

Note – compiled by the authors

The computational modelling of the process of mixing of two streams, presented in Figure 4, showed that the introduction of a conical confusor nozzle into the flowing part of the duct initially eliminates direct contact of the oxygen stream with the air stream.

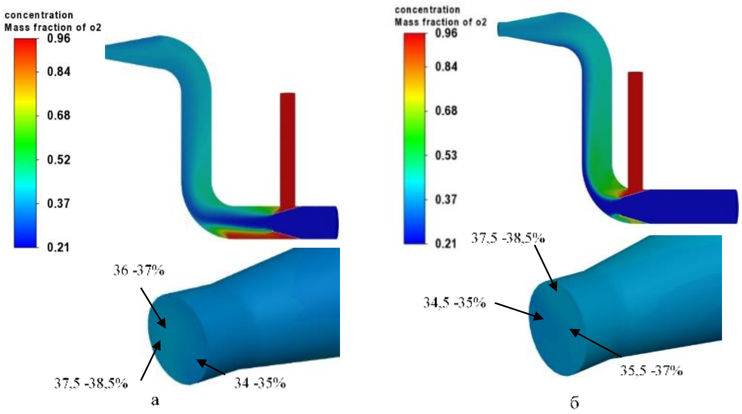

Figure 5. Oxygen concentration distribution field within the cross-section of the calculation area at mixing of air and oxygen flows when a conical confuser nozzle is installed in the duct cross-section in the area of oxygen pipework connection: a – for blower machine No.1; b – for blower machine No.2

Note – compiled by the authors

This leads to the fact that the oxygen flow, meeting on its way resistance in the form of a conical confusor nozzle, makes a 90° turn and presses against the walls of the duct, which is clearly seen in Figure 5 a, b, showing the distribution fields of oxygen concentrations within the cross-section of the calculation area at mixing of air and oxygen flows for blowers No. 1 and No. 2.

Conclusion. According to the results of the conducted research it was established that due to geometrical features of mixing units for blower machines No.1 and No.2, the resulting high-speed flow of oxygen-air mixture is characterised by a complex structure including swirl areas characterised by different pressure, velocity, temperature and oxygen concentration.

The installation of a conical confuser nozzle leads to the separation of the flow of streams and further their mixing at the same velocity direction, as a result of which the total volume of the gas mixture increases. As the nozzle presses on the direct air flow, there is a noticeable ejection effect, which favours the suction of oxygen from the side channel.

The main advantage of such organisation of mixing of two streams is to ensure uniform distribution of oxygen concentration at the outlet of the confuser, not exceeding 39%, at air flow rate of 20000 Nm^3/h and oxygen flow rate of 5000 Nm/h.3.

Conflict of interest. The authors declare that there is no conflict of interest.

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