

## ANNOTATION

Dissertation for the degree of Doctor of Philosophy (PhD) in the educational program 8D07201 – Metallurgy

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### **RESEARCH AND DEVELOPMENT OF FERROUS SAND AGGLOMERATION TECHNOLOGY FOR ALUMINA PRODUCTION AND THE SINTER USAGE IN THE PRODUCTION OF FERROALLOYS**

**Relevance of the dissertation work's topic.** In the Republic of Kazakhstan, alumina production is carried out from bauxites using the combined sequential Bayer-sintering method with preliminary enrichment of the bauxites at JSC Aluminum of Kazakhstan with an annual capacity of 1.5 million tons per year.

The main raw material for this process is Kazakhstani bauxites, which are characterized by a high iron content. Consequently, at the initial stage of hydrometallurgical processing, the ferruginous part is removed from them, forming what is known as ferruginous sands. These wastes, containing up to 65 %  $\text{Fe}_2\text{O}_3$ , are not utilized in metallurgical processing stages and, under the current scheme, are stored in the enterprise's sludge dumps. Despite the high iron content, the direct use of ferruginous sands is problematic. This is hindered by their unfavorable particle size distribution (granulometric composition), the presence of alkali, and the absence of clay components. However, the application of agglomeration technology, specifically sintering, makes it possible to convert this waste into an iron ore sinter, suitable for smelting pig iron and ferrosilicon.

**The aim of the dissertation work.** Investigation of the physicochemical principles and development of a technology for the sintering (agglomeration) of ferruginous sands – waste from alumina production – and the use of the resulting sinter (agglomerate) for smelting pig iron and ferrosilicon.

**Scientific novelty of the results obtained:** In this work, for the first time:

– the dynamics of the phase composition change in the sinter fluxed with magnesium oxide were established; the formation of intermediate phases of magnesioferrite ( $\text{MgFe}_2\text{O}_4$ ), forsterite ( $2\text{MgO}\cdot\text{SiO}_2$ ), and monticellite ( $\text{CaMgSiO}_2$ ) in the fluxed sinter during the agglomeration process was identified; the presence of these new phases allowed for the substantiation of the mechanisms for increasing the melting temperature of the final slags during pig iron smelting;

– a comprehensive analysis of the influence of magnesium oxide (MgO) on the physicochemical characteristics and phase composition of the fluxed sinter was conducted for the first time; the study allowed for the substantiation of the optimal MgO consumption, equal to 3.0 %, for sintering ferruginous sands, which opens the possibility for more rational utilization of technogenic raw materials in metallurgy;

– it was shown for the first time that the processes of thermal decomposition of minerals in ferruginous sands – waste from alumina production – during their

sintering (agglomeration) follow a specific sequence and are accompanied by the formation of magnesioferrite ( $\text{MgFe}_2\text{O}_4$ ), forsterite ( $2\text{MgO}\cdot\text{SiO}_2$ ), and monticellite ( $\text{CaMgSiO}_2$ ), which expands the understanding of the principles of phase formation in multicomponent oxide systems.

**Novelty of the research work results:** The patentability of the scientific and technical developments has been established by the research. The novelty is confirmed by the receipt of a patent: Utility Model Patent 8362. Republic of Kazakhstan. C22B B1/16 (2006.01). Charge for the production of iron ore sinter [Text] / Zhunusova A.K., Bykov P.O., Zhunusov A.K., Kenzhebekova A.E. – No. 2023/0322.2; appl. (applied) 31.03.2023; publ. (published) 18.08.2023, Bull. (Bulletin) No. 33.

**Main theses submitted for defense:**

– results of the analysis of thermodynamic data and phase equilibrium modeling in multicomponent oxide systems, performed using thermodynamic-diagrammatic analysis;

– results of computer thermodynamic modeling in Chemistry 9.0 for the reactions of flux interaction with metal and inclusions;

– research results, including the analysis of derivatograms, rentgenograms, petrographic data, and microanalysis to determine the qualitative and quantitative elemental composition of both the iron ore sinter and the fluxed sinter.

– results of the experimental study on the influence of dolomite screenings ( $\text{MgO}$ ) on the sintering process of ferruginous sands – waste from alumina production – and on the metallurgical properties and strength of the sinter, studies conducted during the sintering of ferruginous sands;

– results of large-scale laboratory tests of the ferrosilicon smelting technology in an 80 kVA ore-smelting furnace using sinter as a substitute for steel scrap.

**Practical significance of the work.** Based on the results obtained in the dissertation, a solution is proposed for the problem of metallurgical waste utilization by developing a rational sintering (agglomeration) technology, taking into account the specific composition and properties of ferruginous sands – waste from alumina production – to produce iron ore sinter and fluxed sinter. The technology for sintering ferruginous sands has been developed and is intended for two applications in ferrous metallurgy:

1) obtaining iron ore sinter for use in the reductive smelting of ferrosilicon in an ore-smelting furnace;

2) obtaining fluxed sinter by introducing 3 % dolomite screenings ( $\text{MgO}$ ) into the charge composition for pig iron smelting.

Cast iron grade L-6 was produced under laboratory conditions (muffle furnace *SX2 Series High*, up to 1700 °C).

Large-scale laboratory smelts of ferrosilicon were conducted using iron ore sinter as a substitute for steel scrap. Replacing 50 % of the steel turnings with iron ore sinter allows for the improvement of techno-economic indicators and the technological regime of ferrosilicon smelting, while saving on expensive steel turnings.

**Publications and approbation of the work.** The results of the dissertation work are published in five articles, including:

– one article in a journal indexed in the Web of Science database (Quartile Q3):

1) Zhunussova A., Bykov P., Zhunusov A., Kenzhebekova A. Research of the production of iron ore sinter from bauxite processing waste. *Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources*. 2024; 329(2):73-81.

– one article in a journal indexed in the Scopus database (Percentile 53):

2) Zhunusova A., Bykov P., Zhunusov A., Bakirov A., Zayakin O., Kenzhebekova A. Research of physicochemical properties of ferrous sands from alumina production. *Acta Metallurgica Slovaca*. 2024. 30(4).161-166.

– three publications in journals from the list of editions recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan for the publication of the main results of scientific activity:

3) Zhunusova A.K., Bykov P.O., Zhunusov A.K., Zayakin O.V., Kenzhebekova A.E. Issledovanie fiziko-khimicheskikh svoystv zhelezorudnogo aglomerata. *Science and Technology of Kazakhstan*, 2024, No. 1, pp. 162-174..

4) Bykov P.O., Zhunusova A.K., Kuandykov A.B., Mukanov R.B., Siemens E. Sravnitel'nye issledovaniya po doizvlecheniyu zheleza iz boksitov Kazakhstana al'ternativnymi vosstanovitel'yami (vosstanovlenie uglerodom). *Science and Technology of Kazakhstan*, 2024, No. 3, pp. 153–161.

5) Zhunusova A., Bykov P., Zhunusov A., Zayakin O., Bakirov A., Kenzhebekova A. Features of mineral formation in the structure of iron ore materials from the position of the state diagram of the system  $\text{CaO-Fe}_2\text{O}_3\text{-SiO}_2$ . *Engineering Journal of Satbayev University*, 2025. 147 (3). 14-19.

– a patent for a utility model of the Republic of Kazakhstan was obtained:

6) Utility Model Patent 8362. Republic of Kazakhstan. C22B B1/16 (2006.01). Charge for the production of iron ore sinter [Text] / Zhunusova A.K., Bykov P.O., Zhunusov A.K., Kenzhebekova A.E. – No. 2023/0322.2; appl. (applied) 31.03.2023; publ. (published) 18.08.2023, Bull. (Bulletin) No. 33.

– The main theses and results of the work were approbated and reported at two International conferences in the form of reports:

7) Zhunusova A.K., Bykov P.O., Zhunusov A.K., Kenzhebekova A.E. Otrabotka optimal'nogo parametra po vlazhnosti shikhty pri spekanii zhelezistykh peskov // Collection of reports on the materials of the International scientific-practical conference "XIV Toraighyrov Readings" (October 28, 2022). – Pavlodar: Toraighyrov University, 2022. – Vol. 3. – P. 273-278.

8) Zhunusova A.K., Bykov P.O., Zhunusov A.K., Zayakin O.V. Otkhody metallurgicheskogo proizvodstva kak al'ternativnye mineral'no-syr'evye resursy // Materials of the International scientific-practical conference dedicated to the 40th anniversary of the founding of the "Metallurgy" department: "Problems and prospects of the metallurgical industry: theory and practice". – Pavlodar: Toraighyrov University, 2023. – P. 106-112.

**Structure and scope of the dissertation.** The dissertation work comprises 150 pages, which allowed for a detailed presentation of the results across five chapters, supplemented by an introduction and a conclusion. The informativeness of the work is emphasized by an extensive bibliographic list (183 sources), 69 figures, 50 tables, and 8 appendices.