

ABSTRACT
of dissertation work
**«DEVELOPMENT OF A TECHNOLOGY FOR PROCESSING
A MIXTURE OF CONVERTER SLUDGE AND SLAG TO OBTAIN A
METALLIZED PRODUCT»,**
submitted for the degree of Doctor of Philosophy (PhD)
specialty 6D070900 – «Metallurgy»
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The purpose of the dissertation is to develop a technology for processing converter production waste – slag and sludge to obtain a metallized product for steel smelting.

Objectives of the research:

- determine the chemical and phase composition of iron-containing converter slag and sludge of JSC «ArcelorMittal Temirtau»;
- to investigate the peculiarities of pelletising of BOF slag and slime mixture and select the optimal method of pelletising;
- to evaluate the possibility of direct reduction of metals and harmful impurities included in BOF slag and slime by solid carbon with the help of HSC Chemistry software package (Outokumpu, Finland);
- investigate the reducing properties of different types of carbonaceous materials (coal sludge, coal) in the process of metallisation of iron ore raw materials.
- to investigate the processes of metallisation of ore-coal raw materials and smelting of iron-containing alloys from metallised products;
- to develop technological scheme of processing of iron-containing converter slag and sludge of JSC «ArcelorMittal Temirtau» in order to obtain low-carbon steel;
- to conduct laboratory tests of processing of iron-containing converter slag and sludge of JSC «ArcelorMittal Temirtau» with the production of iron-containing alloys.

Methods of the research:

The main methods of research and analysis used in the performance of the dissertation work include:

- critical analysis of patent information sources;
- planning an experiment for pyrometallurgical processing of iron-containing waste by a probabilistic-deterministic method;
- mathematical planning of the metallization process of a mixture of converter sludge and slag during solid-phase reduction using the method of Professor Malyshev V.P.;
- carrying out thermodynamic calculations of reduction processes using the HSC Chemistry software package;
- solid-phase reduction of briquettes in the electric furnace SUOL-0,44 / 12-M2-U4 with the production of metallized briquettes;

- melting of iron-containing alloys in Tamman electric furnaces and GW-MF-25 induction furnace.

To study and analyze the phase compositions and structure of the initial charge materials, the following were used:

- vacuum multichannel emission spectrometer DFS-71;
- X-ray diffractometer Empyrean, company PANalytical, series 2;
- FEG SEM scanning electron microscope (TESCAN MIRA3) with a field emission cathode;
- differential scanning calorimeter TGA/DSK2 (METTLER TOLEDO, Switzerland).

The highlights (proven scientific hypotheses and other conclusions that are new knowledge) submitted for protection:

- results of analysis of chemical and phase composition of iron-containing BOF slag and sludge of JSC «ArcelorMittal Temirtau»;
- the results of research of pelletising of BOF slag and slime mixture peculiarities and establishment of optimal pelletising method;
- results of estimation of possibility of direct reduction of metals and harmful impurities included in slag and slime by solid carbon with the help of HSC Chemistry software package;
- results of research of reducing properties of different types of carbonaceous materials (coal sludge, coal) in the process of metallisation of iron ore raw materials;
- results of research of metallisation processes of ore-coal raw materials and smelting of iron alloys from metallised products;
- on the basis of the results of experimental studies the technological scheme of processing of iron-containing converter slag and sludge of JSC «ArcelorMittal Temirtau» with the production of iron-containing alloys was developed;
- results of laboratory tests of processing of iron-containing converter slag and sludge of JSC «ArcelorMittal Temirtau» with obtaining iron-containing alloys.

Description of the main results of the study:

- according to the results of physical and chemical analysis BOF sludge contains iron mainly in the form of oxides ($\approx 70\%$), part of iron in metallic form ($\approx 4,6\%$), and also in sludge contains manganese in the form of oxides ($\approx 5\%$) and CaO up to 13% . The content of phosphorus $\approx 0,3\%$, sulphur $0,4\%$.

- according to the results of physico-chemical analysis in converter slag iron is contained mainly in the form of oxides ($\approx 15\%$) or the total content of Fe total $\approx 21\%$. In addition, the slag contains manganese in the form of oxides ($\approx 5\%$) and CaO up to 45% . The content of phosphorus $\approx 1,497\%$, sulphur $0,156\%$.

- according to the results of the research the optimal composition of the ratio of components in the charge mixture of converter sludge and slag (sludge/slag below 90/10), the degree of metallisation does not exceed 80% , which is associated with low iron content.

– preliminary evaluation of thermodynamic parameters showed that the reaction of direct reduction of hematite by solid carbon can theoretically proceed already at a temperature of 400°C.

The reduction of magnetite with solid carbon is theoretically possible at temperatures above 700°C. The reduction reaction of magnetite with carbon monoxide is theoretically possible at T above 600°C.

The reaction of reduction of iron oxide with carbon is theoretically possible at T above 800 °C.

Phosphorus in the form of compound $\text{Ca}_3(\text{PO}_4)_2$ begins to be reduced at temperatures above 1200°C. Sulphur is completely rigidly bound to calcium oxide (CaO) in the form of CaS, of which sulphur cannot be reduced in reductive smelting. At heating up to 1100°C full solid-phase reduction of iron is possible, without reduction of sulphur and phosphorus.

– the evaluation of the possibility of direct reduction of metals, included in converter slag and slime, by solid carbon and research of reducing properties of different types of carbonaceous materials (coal slime, coal) in the process of metallisation of iron ore raw materials showed that coal slime can be used as a carbon-containing reducing agent after preliminary enrichment. When using coal sludge as a reducing agent, the degree of iron recovery was 99%, and when using unburnt coal of Shubarkol deposit, the degree of recovery increases to 99,6%.

– the results of laboratory melting with the use of metallised briquettes and pellets confirm the possibility of their use as a substitute for the metal part of the charge in steelmaking. The yield of metal at melting of metallised briquettes in the induction furnace is 92,0 %. The content of harmful impurities of sulphur and phosphorus meets the technical requirements of quality steel.

Based on the results of experimental studies the technological scheme of processing of iron-containing converter slag and sludge of JSC «ArcelorMittal Temirtau» with the production of iron-containing alloys is proposed.

Substantiation of the novelty and importance of the results obtained.

The need for research work is associated with large volumes of man-made waste of ferrous metallurgy already accumulated and newly generated on the territory of the Republic of Kazakhstan. New approaches in this direction should reduce the burden on the environment and have an economic justification.

In the development of steelmaking technology using metallised products from technogenic waste converter sludge, slag, coal slime and unburnt coal of Shubarkol deposit optimal parameters of the technological process are established. Development of the technology allows to reduce the deficit of scrap metal, expand the raw material base, obtain high quality products due to the reduction of non-ferrous impurities.

Relevance to the directions of science development or state programmes

Dissertation work is aimed at the implementation of the Strategy «Kazakhstan-2050», the message of the Head of State» The third modernisation of Kazakhstan: global competitiveness» dated 31 January 2017.

Description of the doctoral student's contribution to the preparation of each publication

The personal contribution of the author is to carry out the bulk of the theoretical and experimental works presented in the dissertation, including the development of theoretical models, methods of experimental research, conducting experiments, analyzing and formalizing the results in the form of publications and scientific reports.

5 scientific papers have been published on the topic of the dissertation, including: 2 (two) articles in peer-reviewed scientific journals on the scientific direction of the dissertation topic, indexed in CiteScore in the Scopus (Elsevier) database, 3 (three) articles in the domestic publication in the field of metallurgy, recommended by CQAFSHE MSHE RK on the topic of the dissertation:

Information about the main publications indexed in the Science Citation Index Expanded of the Web of Science (Clarivate Analytics) database in a peer-reviewed scientific journal that has a CiteScore percentile in the Scopus (Elsevier) database on the topic of the dissertation:

1. Tleubagulov S.M., **Aitkenov N.B.**, Koishina G.M. and Tazhiev E.B. Technology Production of Ore Coal Pellets from Converter-Coal Slag Mix and Reduction Smelting of Steel. Steel in Translation, 2021, Vol. 51, No. 1, pp. 65–67. © Allerton Press, Inc., 2021. Russian Text © The Author(s), 2021, published in Stal', 2021, No. 1, pp. 78–80.

2. Tleugagulov S.M., Nurumgaliev A.Kh., Koishina G.M. and **Aitkenov N.B.** Steel Production from Metal-Bearing Waste Steel in Translation, 2019, Vol. 49, No. 3, pp. 217–221. © Allerton Press, Inc., 2019. Russian Text © The Author(s), 2019, published in Stal', 2019, No. 3, pp. 65–69.

Information about publications, in domestic publications in the field of metallurgy, recommended by the CQAFSHE MSHE RK on the topic of the dissertation:

1. Tleugagulov S.M., Velichko A.G., **Aitkenov N.B.**, Zhabalova G.G., Ulyeva G.A. Metallurgicheskaya pererabotka konverternogo shlaka [Metallurgical processing of converter slag]. Kompleksnoe Ispol'zovanie Mineral'nogo Syr'a. = Complex Use of Mineral Resources = Mineraldik Shikisattardy Keshendi Paidalanu. - 2021. № 2 (317), pp. 40-49. (In Rus.).

2. **Aitkenov N.B.**, Smailov S.A., Zhabalova G.G., Mongolkhan O. Металлургия өндірісінің құрамында темір бар қалдықтарынан металданған өнімді алу // University of Economics No. 4 (87) • 2022 80- 85 bet

3. **Aitkenov N.**, Smailov S., Zhabalova G., Aitbayev N. Analysis of different types of carbonaceous reductants and methods of slag and sludge recovery at converter production // Труды университета №1 (90) 2023, с. 73-78.

Information about the report, reported and discussed on the results of the dissertation work at the International Scientific and Republican scientific and practical conferences:

1. Айткенов Н.Б. Металлургиялық өндіріс қалдықтарынан металл алу үрдістерін зерттеу / Труды Международной научно-практической онлайн конференции «Формирование интеллектуального капитала в условиях цифровой

трансформации: опыт, вызовы, перспективы» Ч.2. 29-30 14 декабря 2022. РК. г. Темиртау: КарТУ. 2022, стр. 27-29.