ABSTRACT

of the dissertation work on the topic:

"DEVELOPMENT OF A TECHNOLOGY FOR PROCESSING TAILINGS FROM CHROMITE AND MANGANESE ORE BENEFICIATION TO OBTAIN PELLETS FOR FERROALLOY PRODUCTION",

submitted for the degree of Doctor of Philosophy (PhD) in the specialty 8D07204 – "Metallurgical Engineering"

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The aim of the dissertation research is to develop combined technological schemes for the beneficiation of chromite and manganese tailings dumps to obtain composite fired pellets for the production of standard grades of ferroalloys.

Research objectives:

- critical analysis of scientific and technical publications and patent information to justify the research direction for selecting technological solutions for processing chromite and manganese industrial waste;
- physicochemical studies of representative samples of fine tailings from chromite and manganese ore processing at JSC "TNC Kazchrome" enterprises;
- investigation of the effect of preliminary size classification of chromite and manganese tailings on the results of gravity beneficiation;
- study of the process of thermal sulfate-ammonium sulfation of chromite sludges and their chemical beneficiation;
- study of the effect of natural ferruginous diatomite as a new fluxing component during the roasting of raw chromite and manganese pellets and the determination of various factors affecting their strength characteristics;
- study of smelting composite fired chromite and manganese pellets to produce standard grades of ferroalloys;
- techno-economic evaluation of composite fired chromite and manganese pellet production for obtaining standard ferroalloy grades.

Research Methods

The main research methods and analyses applied in the dissertation work include:

-critical analysis of scientific, technical, and patent literature;

-a set of modern methods of physicochemical analysis, such as:

1. X-ray phase analysis using a Bruker D8 Advance apparatus with copper radiation at an accelerating voltage of 35 kV, current 25 mA;
2. X-ray fluorescence analysis carried out on a wavelength dispersive spectrometer Venus 200 PANalyical B.V. (PANalytycal B.V., Netherlands);
3. Chemical analysis of solid samples and solutions performed on an optical emission spectrometer with inductively coupled plasma Optima 2000 DV (USA, PerkinElmer);
4. Study of solid sample surfaces through elemental and phase composition mapping using a JEOL JXA-8230 electron probe microanalyzer (Japan);

5. Thermogravimetric analysis of the studied compositions of raw pellet mixtures conducted on a synchronous thermal analysis device STA 449 F3 Jupiter;

- thermodynamic calculations of carbothermic reduction of the main components of composite chromite and manganese pellets performed using the HSC Chemistry 5 software package by Outocumpu.

Main points (proven scientific hypotheses and other conclusions representing new knowledge) submitted for defense:

- results of physicochemical studies of reference samples of chromite and manganese fine-grained tailings from beneficiation of chromite and manganese ores at TNK Kazchrome JSC enterprises;
- results of various options of combined beneficiation schemes of chromite and manganese tailings with production of marketable fine-grained concentrates suitable for producing standard grades of ferroalloys;
- results of studies on synthesis of composite fired chromite and manganese pellets using a new natural fluxing component – ferruginous diatomite from the Zhalpak deposit in the Aktobe region;
- results of thermodynamic calculations of carbothermic reduction of chromium and manganese in composite fired chromite and manganese pellets;
- results of smelting studies of composite chromite and manganese fired pellets into ferroalloys;
- results of techno-economic assessment of producing chromite and manganese pellets from concentrates obtained by beneficiation of corresponding fine-grained tailings.

Object of research – fine-grained tailings from beneficiation of chromite and manganese ores.

Description of main research results

The first section of the dissertation provides a general overview of the current state of the raw material base for both global productions of chromium and manganese ferroalloys and in Kazakhstan, along with further development prospects. A general description of accumulated man-made mineral formations generated during gravity beneficiation of chromite and manganese ores at operating mining and processing plants of TNC Kazchrome JSC is given. Based on analysis of scientific, technical, and patent literature, technological approaches for processing fine-grained chromite and manganese tailings to increase overall recovery of valuable minerals from processed raw materials were formulated.

The second section examines the chemical, granulometric, and phase composition characteristics of reference samples of chromite and manganese tailings provided by the Donskoy and Zhairem mining and processing plants of TNC Kazchrome JSC. Using granulometric, X-ray fluorescence, and X-ray phase methods, patterns of distribution of chromium oxide and manganese across particle size classes in tailings from gravity beneficiation of respective ores were established and processing conditions were determined.

The third section presents results of various combinations of beneficiation of fine-grained chromite and manganese tailings, leading to the production of marketable concentrates suitable for smelting ferroalloys. New data were obtained on gravity beneficiation of fine-grained chromite and manganese tailings with preliminary separation into narrow particle size classes, resulting in marketable concentrates. This allowed an increase of 8–10% in total recovery of chromium and manganese from processed raw materials. For synthesis of composite fired chromite and manganese pellets, a new universal natural fluxing component, ferruginous diatomite from the Zhalpak deposit in the Aktobe region, was proposed and studied. The pellet mixture included calculated amounts of ferruginous diatomite (4-10 %), calcium-containing components (up to 5 %), special coke screenings (1.5-3.0 %), and the corresponding fine-grained concentrates. In fired composite chromite and manganese pellets, analyzed by gravimetric and X-ray phase methods at temperatures above 1000 ℃, formation of hedenbergite $CaFeSi_2O_6$ – a ferrosilico-calcium binder – was established. This increased pellet strength and reduced their thermal agglomeration temperature by 100–120 ℃.

The fourth section provides data from thermodynamic calculations of interactions between components of composite fired chromite and manganese pellets under carbothermic reduction conditions at ferroalloy smelting temperatures. Results of smelting composite fired chromite and manganese pellets made from concentrates obtained by various beneficiation methods of tailings are presented. The high levels of chromium and manganese oxide reduction achieved correspond to high smelting indicators for chromite and manganese raw materials and confirm the optimal compositions of composite fired pellets obtained from enriched fine-grained tailings.

The fifth section, based on laboratory and semi-industrial studies, develops process flow diagrams and provides techno-economic assessments of producing composite fired chromite and manganese pellets from concentrates obtained by different beneficiation methods of respective tailings. Among the examined options, the most cost-effective was production of composite fired chromite pellets obtained by gravity beneficiation of tailings. The estimated cost for this option shows an NPV of about 660 million tenge, an IRR of about 47 %, and a payback period (PBP) of 2 years 10 months.

Justification of novelty and importance of results

The novelty of the research lies in the development of a technology for processing chromite and manganese ore tailings into composite fired strong pellets suitable for smelting standard ferroalloy grades. New data were obtained on increasing total recovery of chromium and manganese during gravity beneficiation of fine-grained chromite and manganese tailings with preliminary separation into narrow size classes. Phase transformations during thermal synthesis of composite chromite and manganese pellets using the new fluxing material – natural diatomite – were established, and structures of ferroalloys and slags formed during smelting were described.

The importance of the obtained results is explained by the involvement of man-made mineral formations, namely chromite and manganese tailings, into the production cycle. This extends the operational life of mining enterprises, improves their technical and economic indicators, and contributes to solving environmental problems of production.

Compliance with directions of science development or state programs

The dissertation topic corresponds to the priority scientific direction "Rational use of natural resources, including water resources, geology, processing, new materials and technologies, safe products and structures," specifically the subpriority "Comprehensive and waste-free use of mineral raw materials."

The dissertation was carried out within the framework of grant funding for scientific and (or) scientific-technical projects of the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan under the following topics:

- "Development and testing of an improved technology for producing strong chromite pellets from fine-grained chromite concentrate with smelting into ferrochrome" (No. AP08856229 for 2019–2022);
- "Development of a technology for producing manganese pellets for production of ferrosilicomanganese and high-carbon ferromanganese from fine-grained tailings" (No. AP09258880 for 2020–2023);
- "Improvement of technology for producing chromite pellets from fine-grained tailings for production of high-carbon ferrochrome" (No. AP09259594 for 2020–2023).

The personal contribution of the author consists of physicochemical studies of initial reference samples of fine-grained chromite and manganese tailings, conducting laboratory experiments described in the dissertation, including experimental methodologies, participation in semi-industrial tests, analysis and presentation of results in the form of publications and scientific reports at international conferences.

Based on the dissertation materials, with direct participation of the author, 14 publications were issued, including 8 articles in international peer-reviewed scientific journals indexed in Scopus/Web of Science, 2 articles in other scientific journals and publications, and 4 presented at international scientific-practical conferences.