ANNOTATION

of the dissertation work

«DEVELOPMENT AND IMPLEMENTATION OF RESOURCE–SAVING TECHNOLOGY FOR SMELTING MEDIUM-CARBON FERROMANGANESE FROM DOMESTIC RAW MATERIALS»,

submitted for the degree of Doctor of Philosophy (PhD)

under the educational program 8D07203 – «Metallurgy of ferrous and non-ferrous metals»

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Relevance and Novelty of the Dissertation Work. The primary focus of the development in ferrous metallurgy is improving the quality of metal products, particularly in the production of alloyed steel, where medium-carbon ferromanganese plays a critical role.

Currently, there is no operational production of medium-carbon ferromanganese in the country. As a result, domestic foundries are forced to purchase ferromanganese from China, Ukraine, and the Russian Federation. Despite the shortage of manganese ferroalloys, around 0.2 million tons of manganese concentrates are exported annually to China and the Russian Federation. For example, the manganese ore from the Zhezdy deposit, part of the Zhairem Mining and Processing Plant and the Kazmanganese holding, is exported to the Chelyabinsk Electrometallurgical Plant. This is advantageous for countries importing domestic manganese concentrates due to low tax and transportation costs.

However, the declining quality of domestic manganese ores, along with the rising cost of raw materials and electricity, makes the improvement of technology for producing medium-carbon ferromanganese alloys a pressing issue, requiring theoretical, laboratory, and industrial research.

The object of the study

The Dzhezdinsky deposit of manganese, low-phosphorous advanced silicomanganese, ferrosilicomanganese and medium-carbon ferromanganese.

The subject of the study is the technology of smelting medium-carbon ferromanganese using various reducing agents.

The purpose of the work is to develop a resource-saving technology for smelting medium-carbon ferromanganese from domestic manganese ores.

Research objectives. In accordance with the stated goal, the following scientific tasks have been identified for this work:

- conducting physicochemical research to assess the qualitative and quantitative characteristics of the studied manganese ore and determine its metallurgical suitability;
- determining the optimal composition of charge materials using thermodynamic and mathematical modeling for the smelting of medium-carbon ferromanganese;
- conducting laboratory experiments on the smelting of medium-carbon ferromanganese;

- performing large-scale laboratory experiments on the smelting process of medium-carbon ferromanganese in an electric arc furnace with a transformer capacity of 100 kV·A to develop a technological regulation;

- carrying out industrial tests of the medium-carbon ferromanganese smelting process using low-phosphorus refined silicomanganese in an electric arc furnace with a transformer capacity of 0.25 MV·A.

Scientific Novelty of the Work. For the first time in this study:

- a complete thermodynamic modeling of the Mn-Fe-Si-Al-Ca-C-O system was carried out to select the optimal composition of the charge mixture using non-standard silicon-aluminum reductants necessary for smelting medium-carbon ferromanganese. The optimal composition of the charge mixture, %: manganese ore - 33; refined silicomanganese - 36; aluminum scrap - 2; and lime - 30.

- using the six-factor experimental design method, a mathematical model was developed to determine manganese recovery, taking into account the manganese and silicon content in the reductant, the proportion of fine ore (particle size up to 5.0 mm), slag basicity, manganese content in the ore, and the proportion of aluminum scrap in the charge mixture:

$$\hat{y} = -17.777 + 0.420x_1 + 0.396x_2 - 0.164x_3 + 19.843x_4 + 0.157x_5 + 2.758x_6.$$

- a mathematical model was developed to determine the manganese content in medium-carbon ferromanganese based on the manganese and iron content in the ore, as well as manganese recovery.:

$$\hat{y} = 52{,}307 + 0{,}053x_1 - 0{,}786x_2 + 0{,}530x_3.$$

- a technology for smelting medium-carbon ferromanganese was developed and refined using silicon-aluminum reductants-silicomanganese and aluminum scrap-in a 100 kVA electric arc furnace. An experimental batch of medium-carbon ferromanganese was produced with the following chemical composition, %: Mn - 85-88; Si - 0.33-0.7; C - 1.6-1.8; S - 0.01-0.03; P - 0.03-0.05; Fe - other. High manganese recovery rates of 65-69% were achieved due to the use of aluminum scrap and slag basicity of 1.7-1.9.

- technological trials were conducted under industrial conditions for smelting medium-carbon ferromanganese using refined silicomanganese in a 0.25 MVA electric arc furnace. As a result, the average chemical composition of the medium-carbon ferromanganese produced was, %: ; Si - 0.04-0.35; C - 1.86-2.0; S - 0.01-0.03; P - 0.03-0,05; Fe- other.

Practical Value of the Work.

A technology for smelting medium-carbon ferromanganese using ore from the Zhezdy manganese deposit, low-phosphorus refined silicomanganese as a reducing agent, and aluminum scrap under large-scale laboratory conditions has been developed. Based on the results of this work, the issue of silicate disintegration of the final ferromanganese slags has been resolved, allowing for an increase in manganese recovery up to 69%.

Experiments on the smelting of medium-carbon ferromanganese were conducted in an electric furnace with a transformer capacity of 100 kVA, resulting in an experimental batch of medium-carbon ferromanganese.

Part of the experimental batch of medium-carbon ferromanganese was sent to «Temirtau Foundry» LLP for testing in the alloying of 110G13L steel grade.

A technological regulation for smelting medium-carbon ferromanganese in an electric furnace with a transformer capacity of 100 kVA was developed.

Research Methods. In the dissertation, various methods were employed to study complex metallurgical processes, including: chemical analysis, spectral analysis, granulometric analysis, X-ray phase analysis, differential thermal analysis of materials, complete thermodynamic modeling using the comprehensive program "HSC Chemistry 10.0", process diagram analysis using FactSage software, mathematical planning, experimental modeling of medium-carbon ferromanganese smelting technology in a laboratory high-temperature Tammann furnace and in an electric arc furnace.

Key Results to be Defended:

- results of granulometric, X-ray phase, and spectral analyses of the Zhezdy manganese ore;
- results of complete thermodynamic modeling of the medium-carbon ferromanganese smelting process;
- results of equations for determining manganese recovery and the manganese content in the metal through multifactor mathematical modeling;
- results of laboratory tests of the medium-carbon ferromanganese smelting process;
- results of large-scale laboratory tests for medium-carbon ferromanganese smelting;
- results of industrial tests for medium-carbon ferromanganese smelting.

Place of Research. The research was conducted at the Department of "Metallurgy and Materials Science" of the Karaganda Industrial University, as well as at the experimental site of the Z.Abishev Chemical-Metallurgical Institute in the "Ferroalloys and Reduction Processes" laboratory. Complete thermodynamic studies were carried out at the Department of "Metallurgy and Materials Science" at Istanbul Technical University (Istanbul, Turkey).

Description of the main results of the study.

- the capabilities and current state of production utilizing domestic manganese ores for the smelting of manganese ferroalloys have been presented. The production dynamics and traditional technologies for smelting medium-carbon ferromanganese are discussed. The demand for ferromanganese in domestic steel foundries has been determined.
- using a JSM-7001F scanning electron microscope, the chemical and microstructural composition of Zhezdy manganese ore was determined. The ore has the following chemical composition: Mn_{tot}-48,23; Fe-5,6; SiO_2-12,48; CaO-2,1; MgO-1,47; P-0,01; S-0,01; LOI-8. Granulometric analysis showed that the manganese content in ore with a particle size of +5 mm was Mn_{total} – 49-53%, and iron content Fe_{total} – 0.47-2.06%. For particle sizes of -5 mm, the manganese content was Mn_{total} – 19-30%, and iron content Fe_{total} – 20-30%. X-ray phase analysis revealed that manganese ore with a particle size of +5 mm contains phases of pyrolusite (MnO_2) and manganese hydroxyoxide ($MnO_2(H_2O)_{0,15}$). For particles of

-5 mm, the ore contains phases of lamontite ($CaAl_2Si_4O_{12}(H_2O)_2$), gibbsite ($Al(OH)_3$), and potassium aluminosilicate ($KAlSi_3O_8$). Differential thermal analysis determined that the softening temperature of manganese ore with a particle size of +5.0 mm begins at T = 1105°C and ends at T = 1305°C, while for particle size -5.0 mm, the softening temperature begins at T = 925°C and ends at T = 1115°C.

- as a result of the complete thermodynamic modeling of the Mn-Si-Fe-Al-Ca-Mg-C-O system, 69 phases were identified. Of these, 41 phases are oxides, and 28 phases are metals. The metallic phases include intermetallics, carbides, and pure metals. Optimal charge materials for smelting standard grades of medium-carbon ferromanganese were determined as follows: manganese ore - 110 kg, silicomanganese - 100 kg, limestone - 90 kg, and aluminum - 5.0 kg.

- through multifactorial mathematical modeling, expressions were developed to determine manganese input and the amount of manganese in the metal. The first mathematical model allows for the determination of manganese recovery based on the manganese and iron content in the manganese ore and reducing agent, slag basicity, the proportion of aluminum scrap in the charge mixture, and the proportion of "fines" (particle size -5.0 mm) ore. The second mathematical model estimates the manganese content in the metal based on the manganese and iron content in the ore and the manganese recovery from the ore. The resulting models are characterized by high correlation coefficients (R = 0.965 and 0.891).

- Laboratory experiments were conducted on the smelting of medium-carbon ferromanganese in a high-temperature Tamman furnace. The results of these experiments showed optimal distribution of metal and slag within a slag basicity range of 1.6–1.8. Large-scale laboratory trials were carried out for smelting medium-carbon ferromanganese using low-phosphorus refined silicomanganese and aluminum scrap in an electric arc furnace with a transformer capacity of 100 kVA. The chemical composition of the resulting metal was as follows, %: Mn – 85-88; Si – 0.33-0.7; C – 1.6-1.8; S – 0.01-0.03; P – 0.03-0.05; Fe – other. The optimal slag basicity was 1.7-1.9. The resulting manganese slags consisted of two calcium silicates (Ca_2SiO_4), gehlenite ($Ca_2Al_2SiO_7$), and manganosite (MnO). Manganese recovery from the ore increased to ≥ 69%, preventing the slag from self-grinding. In industrial conditions at NPO Manganese LLP, trials were conducted for smelting medium-carbon ferromanganese in an inclined electric arc furnace with a transformer capacity of 0.25 MVA. The average chemical composition of the medium-carbon ferromanganese produced was as follows, %: Mn – 86-88; Si – 0.04-0.35; C – 1.86-2.0; S – 0.01-0.03; P – 0.03-0.05; Fe – other.

Personal Contribution of the Doctoral Candidate to the Dissertation. The author fully accomplished the objectives and tasks outlined in the dissertation. They conducted practical tests using modern laboratory setups and comprehensive programs. Based on the results of these tests, articles were published in journals indexed in Scopus and Web of Science. Additionally, as a result of large-scale laboratory and industrial trials, a technological regulation, test report, and a patent for a utility model in Kazakhstan for the technology of smelting medium-carbon ferromanganese were obtained.

Approval of the Work. At the Z. Abishev Chemical-Metallurgical Institute, a large-scale laboratory test report for smelting medium-carbon ferromanganese in an electric arc furnace with a transformer capacity of 100 kV·A was prepared, and a technological regulation was developed.

A technological regulation for smelting medium-carbon ferromanganese in an electric arc furnace with a transformer capacity of 100 kV·A has been developed.

A patent for a utility model in the Republic of Kazakhstan, KZ 8180, was obtained on June 16, 2023, for «Charge for Smelting Medium-Carbon Ferromanganese».

Results of the Dissertation for Bachelor and Master Students of the Metallurgy Program at Aktobe Regional University named after K. Zhubanova the theoretical and practical results of the dissertation work have been incorporated into the educational process for the disciplines "Theory and Technology of Ferroalloy Production" and "Recycling Technologies in Ferroalloy Production." An implementation report has been prepared for this integration into the academic curriculum.Результаты научных исследований и разработок внедрены в ТОО «НПО Марганец». Акт имеется.

On the topic of the dissertation, 11 scientific works have been published, including: 2 articles in peer-reviewed scientific journals related to the dissertation topic, indexed in the Science Citation Index Expanded of Web of Science (Clarivate Analytics) and in CiteScore in Scopus (Elsevier), 3 articles in domestic metallurgy journals recommended by the Committee for Quality Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan, 6 articles in the proceedings of international and national scientific and practical conferences,1 patent for a utility model in Kazakhstan.

Information about the main publications of the Web of Science database (Clarivate Analytics) in scientific publications indexed by the Science Citation Index Expanded and CiteScore of the Scopus database (Elsevier), reviewed in the scientific field of the dissertation topic.

1 Abdirashit A., Makhambetov Y., Yerzhanov Y.A., Sarkulova Z., Aitkenov N., Aitbayev N. / Large-scale laboratory tests for smelting medium-carbon ferromanganese using Jezda manganese ore and SiMn17 silicomanganese fines / Metalurgija. – 2023. Vol 61, Iss. 1. – P. 139-141.

2 Nurumgaliev A., Makhambetov Y., Kuatbay Y., Yerekeyeva G., Abdirashit A., Mynzhassar Y. / Study of softening temperatures of manganese ores in central Kazakhstan// Metalurgija. – 2023. Vol. 62, Iss. 2. – 268-270.

Information about publications in domestic publications in the field of metallurgy recommended by the KOKSNVO of the Ministry of Internal Affairs of the Republic of Kazakhstan on the topic of the dissertation:

1 Makhambetov Ye., Abdirashit A., Myngzhassar Ye., Baisanov A., Zhakan A./Thermodynamic and experimental simulation of the smelting process of medium carbon ferromanganese with the use of Zhezdinsky manganese ores // Қазақстан ғылымы мен техникасы. 2023. №3, P. 141-153. https://doi.org/10.48081/HHSN1365

2 Makhambetov Ye. N., Abdirashit A.M., Myngzhassar Ye. A., Burumbayev A.G., Zhakan A.M., Yucel O. / Research on the possibility of obtaining medium-carbon ferromanganese from the Djezdinskoe deposit. // Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources. 2024; Vol. 331. – Iss. 4. – P. 101-108. https://doi.org/10.31643/2024/6445.43

3 Махамбетов Е.Н., Әбдірашит А.М., Мыңжасар Е.А., Байсанов А.С., Юсел О. / Металлотермиялық тәсілмен орта көміртекті ферромарганецті балқыту процестерінің термиялық қасиеттерін зерттеу // Труды университета. 2024. Б.95. - №2., Р. 54-59. https://doi.org/10.52209/1609-1825_2024_2_54

Information about the report presented and discussed based on the results of the dissertation work at the international and republican scientific and practical conference:

1 Әбдірашит А.М., Мыңжасар Е.А. / Әлемдік және отандық марганец кендерді тұтыну мен талдау// Университеттің 70 жылдығына арналған «Қазақстан-2050» Стратегиясын жүзеге асырудағы жастар ғылымының үлесі» атты Республикалық студенттік ғылыми конференциясы ЕҢБЕКТЕРІ 2 – бөлім, (13-14 апрель) Қарағанда қ. 2023, 283-284 б.

2 Әбдірашит А.М., Махамбетов Е.Н., Мыңжасар Е.А., Нурумгалиев А.Х., Юджел О. / HSC Chemistry 6.0 бағдарламалық кешенін қолдану арқылы орта көміртекті ферромарганецті балқыту термодинамикалық модельдеу// «Металлургия» кафедрасының 40-жылдығына орай өтетін «Металлургия саласының мәселелері мен перспективалары: теория және практика» атты Халықаралық ғылыми-практикалық конференциясының материалдары (31 мамыр) Павлодар қ., 2023, 48-51 б.

3 Әбдірашит А.М., Махамбетов Е.Н., Мыңжасар Е.А., Нурумгалиев А.Х./ Қазақстандағы болат өндірісінің жағдайы мен тұтынылуы// Қарағанды индустриалды университетінің 60 жылдығына арналған «Инновациялық технологиялар және инжиниринг» атты XII халықаралық ғылыми-тәжірибелік конференциясының материалдар жинағы (19-20 қазан), Теміртау қ., 2023, 111-114 б.

4 Әбдірашит А.М., Махамбетов Е.Н., Мыңжасар Е.А., Нурумгалиев А.Х./ Қайта өңделетін силикомарганецті қолдана отырып, орта көміртекті ферромарганецті балқыту үрдісін эксперименттік модельдеу // Қарағанды индустриалды университетінің 60 жылдығына арналған «Инновациялық технологиялар және инжиниринг» атты XII халықаралық ғылыми-тәжірибелік конференциясының материалдар жинағы (19-20 қазан), Теміртау қ., 2023, 115-117 б.

5 Әбдірашит А.М., Нурумгалиев А.Х., Махамбетов Е.Н., Юсел О. / Әр түрлі тотықсыздандырғыштарды қолдана отырып, орта көміртекті ферромарганец технологиясын әзірлеу// Қарағанды индустриялық университетінің «Жастар, ғылым және технологиялар: жетілдіру және ықпалдасу жолдары» LIV Республикалық ғылыми-практикалық конференцияның материалдар жинағы,Теміртау қ., 2024, 62-64 б.

6 Әбдірашит А.М., Нурумгалиев А.Х., Махамбетов Е.Н., Юсел О./ Орта көміртекті ферромарганец технологиясын зерттеу және әзірлеу// Қазақстан

Республикасының Ұлттық Ғылым Академиясының (Қазақ ССР Ғылым Академиясы) негізін салушы, тұңғыш президенті Қ. Сатпаевтың 125 жылдығына арналған «өндірістегі және техникалық мамандарды дайындаудағы инновациялар» халықаралық ғылыми-практикалық онлайн-конференция материалдары (23 сәуір), Ақтөбе қ., 2024, 28-29 б.

Information about security documents for intellectual property objects:

1. Patent for a utility model of the Republic of Kazakhstan "Charge for smelting medium carbon dioxide ferromanganese" No. 8180, 06/16/2023.

The structure and scope of the dissertation. The dissertation consists of an introduction, a main part consisting of 4 sections, a conclusion and appendices. The volume of the dissertation is 118 pages of typewritten text, the work contains 37 figures, 23 tables, a list of sources used, including 82 titles.