ABSTRACT

FOR PHD THESIS "KINETICS ANALYZING OF DIRECT METAL REDUCTION IN MULTICOMPONENT OXIDE SYSTEM AND DEVELOPMENT OF ALLOY STEEL TECHNOLOGY"

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The assessment of the current state of a scientific or scientific-technological problem under the question. The industrial development of any country depends on the level of production of structural materials. In particular, the development of new advanced technologies for the production of iron and steel is part of the fundamental science.

Traditional methods of metallurgical production have become multistage, more complicated. The technology of the metallurgical method for the production of iron and steel consists of two stages: 1) reduction melting of the prepared charge in blast furnaces with the release of cast iron; 2) oxidative smelting of cast iron in oxygen converters at which all the alloying elements are completely oxidized and the crude steel is discharged, followed by secondary treatment of crude steel and alloying it with ferroalloys to produce alloyed steel of a given chemical composition. Processing of a complex iron ore is of great practical importance due to the need and possibility to recover from it not only iron but also other valuable impurity metals.00

The problem topicality: Kazakhstan has large reserves of ilmenite and titanomagnetite ores being explored and developed now. Russia like Kazakhstan has a large metallurgical complex Evraz "NTMK" and the Kachkanarsky MPP in the Urals producing on the basis of a large titanomagnetite deposit a titanomagnetite concentrate with the content of iron 56.0-62.0%; TiO_2 4.0-5.0%, V_2O_5 0.50-0.6% and Mn 0.12-0.15%. At the same time, the most important problem is the development of new advanced technologies that provide direct production of natural alloy steels by processing the complex, hematite, magnetite and complex iron ore raw materials of the given chemical and mineralogical composition. For this, it is necessary to develop the scientific basis for new technologies that allow leaving valuable alloying elements contained in raw materials in the composition of steel in the required quantity.

Among complex iron ore raw materials Titanomagnetite and Ilmenite occupy a special place due to containing in their composition such valuable metals as vanadium, titanium, partly manganese and chromium. Titanium in the form of oxide TiO_2, like iron, is a wide-spread metal but unlike iron oxides, titanium dioxide has a very high chemical strength. Consequently scientific research on sequential recovery of iron, vanadium, titanium, the development of the reduction-melting technology for titanomagnetite and ilmenite concentrates is ***an actual problem***.

The goal of research is the experimental study of the sequential reduction of metals from a multicomponent oxide system, the study of the kinetic characteristics of direct reduction of metals - iron, vanadium, manganese, chromium, titanium and obtaining samples of natural alloy steels.

Research objectives included:

- Preparation of special lab coked charge specimens from multicomponent oxide materials like ilmenite and titanomagnetite concentrates;
- Analysis of strength characteristics of metal oxides based on thermodynamic properties of chemical bonding of metal oxide and the amount of gasified oxygen in metal oxides in the result of reduction reactions;
- Stoichiometric calculations for determination and regulation of the solid carbon flow rate needed for metal reduction;
- Preparation of ore-coal mixture specimens to be used in the direct metal reduction processes and in production of metallized materials;
- Organization of a melting-recovery process, using laboratory melting plants and instrumentation. Carrying out the analysis of the results obtained and their publishing in scientific journals.

Theoretical foundations of research

The scientific research organization of metal recovery from complex ore materials, such as ilmenite and titanomagnetite concentrates, is based, on using solid carbon as a reducing agent. The theoretical foundations of the research arise from the analysis of metal reduction mechanisms based on fundamental scientific statements.

The well-known and widespread adsorption-autocatalytic mechanism (AAM) proceeding from the theory of adsorptionbility of gaseous reducing agents recommends to use a hot reducing gas (HRG) usually consisting of CO and H_2 gases. The use of this mechanism is associated with the need to organize a countercurrent motion of the charge and the HRG mainly in shaft furnaces. The implementation of this process presupposes the presence of some technical conditions (TC) of preparation of agglomerated iron ore raw materials and sorting them by size which is caused by the formation and accumulation of small waste materials.

The use of solid carbon as a reducing agent has certain limitations due to the fact that the contact-diffusion interaction of carbon atoms with metal oxides does not give a tangible result.

The practical realization of the reduction of metals in the HRG stream in the layer of agglomerated raw material is carried out in diffusion mode from the outer surface of a large piece and spreads to its central part. Therefore, in practice, the duration of the processes of metallization of ore raw materials in a shaft furnace and reduction melting in blast furnaces is 6-7 hours.

Based on the analysis of known metal reduction mechanisms, we have proposed a new "dissociation-adsorption mechanism" (DAM), the reduction of metals, which is based on the provisions of the fundamental sciences.

The DAM mechanism of the process should be explained at the level of electron flows and not of molecular motions of interacting reagents.

The interaction of oxide and reducing agents, first of all, begins with the transfer of electron flows according to the “donor-acceptor mechanism” in which the reducing agent always acts as a donor, and the metal oxide as an acceptor. This enables to estimate the reduction potential of both HRG and solid carbon, depending on the presence of valence and free electrons. This estimation shows that the HRG components - CO and H_2 - have only two valence electrons, and the solid carbon atom has 4 valence electrons plus a greater number of composite electrons located in the interplanar distances of the crystal lattice. Here, the main role in recovery reactions, is played by the motion of electron flows and not by the motion of molecules. Therefore the opinion that the solid carbon effect is limited by the contact-diffusion mass transfer is a simplistic view having no scientific basis.

On the basis of this new DAM mechanism there are currently being developed the processes of direct metal reduction and production of high-quality steels and alloys.

Experimental test procedures

- there on the basis of the analysis of modern theoretical provisions about the mechanism and kinetics of metal reduction processes have been organized a number of successive experimental test procedures or techniques;
- a technique for preparation of ore-coal charge, consisting of titanomagnetite, ilmenite concentrates and carbon-containing reductant;
- a technique for producing a dispersed ore-coal charge in electric-vibration attritors with fractions of less than 1.0 mm;
- a technique for the consumption regulation of carbon-containing reducing material per unit of oxide part of the charge;
- a technique for solid-phase metal reduction by regulation of the temperature-thermal regime of the process and application of two methods for direct metal reduction - by free carbon and by carbon dissolved in metal.

Scientific novelty of research

- Establishment of the regularity of a successive reduction of iron, vanadium, manganese, chromium, and titanium depending on chemical strength of the oxides of corresponding metals and the temperature of the system;
- Obtainment of kinetic characteristics of each recoverable metal basing on sequential-phase transformations from their higher oxides up to the metallic state;
- Update on the basis of the analysis of experimental study results of the concept of direct metal reduction by carbon accompanied not only with the formation of CO gas but also with CO_2;
- Determination of series of changes in gas composition i.e the appearance of CO, CO_2, as products of direct metal reduction, depending on phase transitions, which is important in terms of regulation of charge composition and resulting metallic phases.

Provisions submitted for PhD thesis defence:

- The results of research into the scientific foundations of direct reduction of metals by solid carbon from multicomponent oxide systems;
- Experimental data of direct metal reduction from ilmenite and titanomagnetite concentrates by free carbon;

- Experimental data of direct metal reduction from ilmenite and titanomagnetite concentrates by dissolved carbon;
- Data of the reduction melting and obtainment of steel samples doped with manganese, titanium and vanadium;
- Technology of processing titanomagnetite concentrate and organization of a recovery-melting process for the production of naturally-alloyed steel.

Scientific and practical significance of research results.

The first ever preparation of a dispersed ore-coal charge from titanomagnetite and ilmenite concentrates and of the carbon-containing reagent in such stoichiometric ratios at which direct reduction of iron, valuable impurity metals, and partially of titanium was realized without significant carbonization and metal carbides. Direct kinetics studies displayed the possibility of additional reduction of titanium and regulation of its concentration in the metal within the range of 0.3-5.0%.

Practical significance of research results. Based on the analysis of experimental results, there was developed a technology for the complex processing of titanomagnetite and ilmenite concentrates by continuous reduction-melting the concentrates without any intermediate redistributions and with the production of special steel doped with manganese, chromium, vanadium and titanium.

The first ever preparation of vanadium-containing steel samples with the vanadium concentration [V] = 0.06-0.13 %. The method of microstructural analysis enabled to establish a very important factor at the reduction melting of natural alloy steel - unlike melting in an oxygen converter here steel composition has no oxide inclusions which is a very important practical value in terms of the output quality.

Level of the R&D. The research of kinetics of a direct metal reduction from a multicomponent oxide system i.e. from ilmenite and titanomagnetite concentrates was based on the analysis of current research carried out in this field and published in the world press in terms of the latest achievements including their positive and negative aspects. There were organized theoretical and experimental research as for finding kinetics regularities of metal reduction from complex oxide systems, confirmation of the results by concrete experimental studies. Preparation of alloy steel samples characterizes a high level of R&D and confirms the attainment of this goal.

Publications related thesis topics. According to thesis topic results there were published 13 papers and articles, **3** of them in Web of Science Core Collection journals (Scientific and Production Technical Journal Metallurgist (Russia) **IF-0.243**) and Scopus (Steel in Translation (United Kingdom) (**IF-0.232**) - International Journal of Chemical Sciences (**IF-0.229**), four of them in journals recommended by the RK Committee for Control in Education and Science sphere (article "Bases and prospects for the development of steel smelting reduction" is accepted for publication in the journal. Metals, №2, 2018. There is a confirmation certificate from the publishing house - Appendix G). Basic thesis research provisions and results were presented at the International Scientific and Practical Conferences of the XIV International Scientific Congress Machines. Technologies. Materials: Year I, Issue 4 (4), Vol. IV, Technologies. Varna, Bulgaria. 13-

16.09.2017; Science and innovation in the 21st century: Current issues, discoveries and achievements: V International Scientific and Practical Conference: International Research Cooperation Centre "Science and Education" – Russia, Penza, 5 August 2017; International Scientific and Practical Conference "Scientific and Personnel Support of Innovative Development of Mining and Metallurgical complex", April 27-28, 2017, Almaty, Kazakhstan; VII International Scientific and Practical Conference "Fundamental and Applied Scientific Research: Current Issues, Achievements and Innovations", November 15, 2017, Penza, Russia.

Received a patent for a new tubular furnace for metallization (- No. 31705, declared on March 13, 2015. published on December 22, 2016, No. 18. The method for metallization of iron ore raw materials in a tubular furnace and a device for its implementation).

Relationship of work with government programs and research projects:

Dissertational work was carried out within the framework of the state grants of the science fund of the Ministry of Education and Science of the Republic of Kazakhstan for a project on the development of a technology for deep processing of iron ore raw materials (Research work No. 2213 / GF4, contract No. 74 of 12.02.2015 for 2015-2017), funded by the Ministry of Education and Science of the Republic Kazakhstan within the framework of the subprogram "Grant financing of scientific research" on the priority "Rational use of natural resources, processing of raw materials and products."

Structure and volume of the dissertation. The Thesis Work consists of the introductory part, 5 chapters, conclusion and annexes. The Work is written on 119 typed text pages, contains 21 tables and 34 figures. The List of References includes 110 sources.