ABSTRACT

to the thesis on «**Extraction technological development of non-ferrous and precious metals from RPS-process from collector matte**», Submitted for the Degree of Doctor of Philosophy PhD Majoring in Metallurgy - 6D070900

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The relevance of research.

Production of gold is one of the most important problem among the most pressing problems of the development of non-ferrous metallurgy in Kazakhstan. Currently, neither quantitative nor qualitative indicators of the gold mining industry in Kazakhstan meet the needs of our state. Limited proven reserves of metal, the use of obsolete, imperfect, low-productivity, multi-operational and environmentally hazardous technologies for the extraction, processing and metallurgical processing of gold-bearing ores at the main gold mining enterprises are the main constraining factors for the growth and intensification of gold production in Kazakhstan today. As a result, large losses of gold are allowed, especially at the stages of beneficiation of refractory ores with tailings, in which up to 1.5-2.5 g/t of gold remains. For this reason, its total end-to-end extraction into marketable products from such raw materials does not exceed 60-70 %, and ores of this type are classified as refractory.

As known, more than 50 % of the available active reserves of gold ores are characterized as difficult for beneficiation, contain harmful impurities - arsenic, antimony and carbon. According to experts, the share of such ores accounts for about 60% of the current reserves. In gold metallurgy, these ores are classified as refractory. According to experts, the ore base of Kazakhstan in terms of the average grade of gold in the ore (6.3 %) is promising for development. However, a significant part of ore occurrences is poorly studied, and the reserves of many deposits require clarification.

For Kazakhstani fields of sulphide gold-bearing ores, the presence of a large amount of the above harmful impurities in the ore is characteristic. In this regard, a certain part of the reserves is characterized as stubborn and refractory raw materials. For many of these fields, there are currently no effective beneficiation and metallurgical processing technologies. For this reason, these gold fields are currently not exploited on an industrial scale.

The development and development of new technologies for processing gold-bearing raw materials are one of the most pressing problems of non-ferrous metallurgy in the world. At the same time, one of the unsolved and fundamental tasks of the gold mining industry is the organization of highly efficient processing of complex refractory base ores of gold.

The main modern problems of gold mining enterprises in world industrial practice are also associated with a change in the raw material base towards the deterioration of the quality of ores and concentrates using traditional technologies that do not meet modern requirements of metallurgical production. This is the case

in both pyrometallurgical and hydrometallurgical methods for extracting these metals. The applied technologies do not provide the required level of environmental protection and require an increase in the scientific and technological indicators of production.

Complete pyrometallurgical smelting by the RPS-process and the extraction of gold and other metals from collector mattes may be promising for large refractory gold field located in hard-to-reach and waterless regions of our country and a number of foreign countries (South Africa, Russia, China, USA, Kyrgyzstan, etc.).

The relevance of this work is due to the fact that, both in world practice and in Kazakhstan, there are currently no fundamentally new technologies for efficient processing of refractory base gold ores with high rates of extraction of precious metals into marketable products.

At many enterprises of the gold processing industry in Kazakhstan, producing gold concentrates, there is no pyrometallurgical technology for their processing. The results of this work will make it possible to process gold-bearing ores, bypassing the stage of their beneficiation, by pyrometallurgical methods to obtain intermediate products suitable for further processing. Therefore, the topic of this work is relevant.

The aim of the thesis is to develop a comprehensive technology for the processing of refractory base ores of gold and sulfide copper concentrates to obtain a metallized phase enriched in gold and silver.

The objects of research were mattes and slags obtained by the RPS-process during direct smelting of refractory gold ores, matte processing products - cinders and volatile components - sulfur, arsenic and carbon, - metal melts, gold collectors.

Research subject - physical and chemical properties and compositions of research objects; pyrometallurgical processing of indigenous refractory gold ores and sulfide copper concentrates; the process of oxidative roasting of mattes; matte cinder recovery process.

Research aims, their place in the implementation of research work in general.

The main objectives of the thesis are:

– detailed experimental study of physical and chemical properties and compositions of research objects;

– carrying out laboratory crucible smelting of refractory gold ores with sulfide copper concentrates with the determination of the optimal yields and compositions of gold-bearing copper mattes and the study of their physicochemical and thermal properties and structure;

– development of technological parameters for the roasting process of sulfide gold-collecting systems;

– development of processes for liquid-phase reduction of gold-bearing cinders with obtaining a metallized phase.

Research methods.

The main research methods and analyzes used in the implementation of the dissertation work include:

– critical analysis of patent information sources;

– researches were carried out by methods of chemical, X-ray phase, thermal analyzes;

– performance of chemical analysis of samples on an optical emission spectrometer with inductively coupled plasma Optima 2000 DV (USA, PerkinElmer);

– X-ray phase analysis of samples using the D8 Advance device (Bruker AXS GmbH) using the EVA software, Search / match and the ASTM card database;

– mineralogical analysis of the samples was carried out under a MIN-8 microscope, OLYMPUS, Leica DM 2500P using the Stream BasicR program;

– thermal analysis of samples was carried out using the STA 449 F3 Jupiter synchronous thermal analysis device using the NETZSCHProteus software;

– the study of the composition of the samples and their constituent natural and artificial formations was carried out on an electron probe microanalyzer brand JEOL JXA 8230 Electron Probe Microanalyzer;

– experiments were carried out on an induction melting unit UIP-16-10-0.005, and a high-temperature chamber furnace NTS 08/16 Nabertherm GmbH was also used;

– to study the process of oxidative roasting of gold-bearing matte, an installation was created on the basis of a tubular laboratory furnace SUOL-0.25.1 / 12-M1 with a nichrome heater;

– the study of the composition of the gas phase was carried out using a PEM-2M gas analyzer.

Main provisions for the defense.

The following provisions are submitted for the defense of the dissertation work:

– the process of processing of indigenous refractory ores of gold and sulfide copper concentrates;

– the results of experiments on the study of the process of firing the investigated mattes in the temperature range 600-900 °C without circulating the flow of the oxidizing gas phase;

– the results of experiments on the study of the process of recovery of gold-bearing cinders;

– the process of experimental study of the effect of coke consumption on the degree of cinder recovery;

– the results of experimental smelting of gold-bearing cinders.

Main results of research:

– For the first time, the features of the structure and properties of mattes of direct smelting of ore from the Bakyrchik field of the following composition were investigated: $Cu_9Fe_9S_{16}$ (mooihoekite), $Cu(OH)_2 \cdot H_2O$ (copper hydroxide hydrate),

FeS (troilite), CaS (oldhamite), $Cu_{1,1}Fe_{1,1}S_2$ (talnakhite), $CaFe_2O_4$ (calcium Iron Oxide), ZnS (sphalerite), CuAsS (lautite), PbS (galena), $CuFe_2S_3$ (isocubanite) for the purpose of their further pyrometallurgical processing;

– for the first time, differential thermal studies have established polymorphic transformations of matte from direct smelting of ore with phase transitions of medium and low intensity with maximum development at 140, 686, 761 °C corresponding to FeS, Fe_2O_3 and Fe^0;

– the melting temperature of matte of direct smelting of ore was set in the range of 900-1200 °C;

– obtained compositions of mattes by direct smelting of ore provide extraction up to: 98 % Au, 97% Ag and 95 % Cu;

– the optimum temperature of matte firing is set – 800 °C, which ensures a decrease in the content of sulfur and carbon in the cinders to 4.89 and 1.50 %, respectively, due to the oxidizing potential of the gas phase;

– electron probe studies of cinders have shown that they are formed by new formations in the form of FeO_2 compounds, which is about 75-77 %, and the newly formed mineral aldgamite with the CaS formula, which is 10 %;

– differential thermal analysis found that the melting temperature of the cinders with the appearance of the liquid phase was – 1241 °C, which determined the temperature of further reduction smelting;

– during the reduction smelting of cinders, it was determined that with a decrease in the yield of the metallized phase, it is naturally enriched with metals: gold from 189.2 to 808.1 g/t, silver from 139.75 to 544.8 g/t and copper from 2.19 up to 6.82 %, which indicates the possibility of regular regulation of the content of these metals in the metallized alloy by changing the degree of cinder reduction;

– experimentally, using the method of liquid-phase reduction smelting of cinder, the optimal slag composition was determined: SiO_2 - 33-35 %; CaO – 20-25 %; about Al_2O_3 – 10 %; Au - 0.1 g/t and Ag - 2.0 g/t, which provides low loss of metals when obtaining metal alloys containing%: 70-75 Fe; 1-2 Cu; 145-150 ppm Au and 100-120 ppm Ag.

Justification of the novelty and importance of the results obtained.

The novelty of this work is due to the fact that in the world practice of gold mining there are no examples of the opening of refractory carbonaceous-arsenic base ores of gold by methods of their direct smelting for the purpose of their contractile pyrometallurgical selection (RPS-process). At the same time, the high recovery of gold from refractory base ores into reservoir products, characteristic of the RPS-process, is based on new physicochemical approaches, when, under conditions of high temperatures and liquid-phase interactions in the melt, almost complete opening of refractory gold-bearing raw materials takes place. At the same time, such gold-containing alloys obtained under the conditions of the RPS-process, collecting 95-98% of gold and silver are also new intermediate products in gold metallurgy.

A highly efficient technology for processing refractory base gold ores with high rates of extraction of precious metals has been developed. From the

technological scheme, the processes of fine grinding, beneficiation and, accordingly, the loss of gold with tailings, ineffective for refractory gold-arsenic-carbonaceous gold ores, were completely excluded. From the charge in the process of its melting in the form of dump slags sent to the production of building materials, all minerals of the waste rock, which make up 70-80 % of the weight of the charge, are completely removed, and arsenic, carbon and other volatiles are almost completely transferred to the gas phase in the process of pyroselection of the charge components. In the region of high temperatures and during liquid-phase interactions under the conditions of the reduction-sulfiding process, a negative effect on the opening of base gold ores of all refractory forms is excluded. 95-98 % of gold, silver and copper pass into the collector melt, the yield of which from the weight of the charge will be 5-15 % because of almost tenfold reduction in the volume of the initial charge. The absence of special gold recovery processing in the technological cycle and the possibility of processing large volumes of refractory ores and produced mattes.

Compliance with the direction of development of science or government programs.

The main prerequisites for the implementation of this work are directly related to the unresolved problems of the gold mining industry of the world and Kazakhstan on attracting large volumes of refractory base gold ores to extract precious and non-ferrous metals from them.

The analytical reviews carried out in recent years by many leading metallurgical scientists of the main gold producing countries in the field of critical analysis of the technological level of many operating gold mining enterprises in the world have shown the lack of highly efficient technologies and equipment for processing large volumes of refractory gold ores. For this reason, the share of gold production from such ores is only 8-10 %, while the gold reserves in refractory ores of the world in the total balance is 40-50 %. This situation is especially typical for Kazakhstan, where the richest gold deposits are not fully processed today.

Most of the technological processes used even at advanced gold production facilities do not completely solve the fundamental problems of efficient processing of refractory base ores of gold. Even modern technologies allow large losses of gold, ranging from ore dressing to cyanidation of products with tailings of these processing.

Based on this, direct smelting of refractory gold ores into gold-bearing mattes was proposed, bypassing all the processes of their beneficiation. The creation and development of a high-performance pyrometallurgical method for opening refractory gold-bearing raw materials - the RPS-process requires new methods for extracting precious and non-ferrous metals from collector products, which also provide high productivity of units, better technological indicators, efficiency and the possibility of more efficient development on an industrial scale.

This position, being the main rationale for this work, requires a significant amount of research to test new collector products and methods for extracting gold and other metals from them.

As studies on the study of the processes of direct smelting of refractory base gold ores of different composition, obtained during the RPS-processes of processing extra-resistant gold ores, have shown, collector mattes differed significantly in composition from mattes obtained during smelting of gold-arsenic concentrates, and especially in the content of precious metals. In addition, the literature lacks information and studies on the opening of such mattes by pyrometallurgical methods.

Proceeding from this, the first task of research in this work was a detailed study of the process of roasting collector mattes, obtained mainly by direct smelting of refractory base ores of gold, bypassing their beneficiation.

Previously, studies were carried out to determine the parameters of the matte formation process with the selection of a sulfidizer under the conditions of smelting gold-bearing ores and concentrates at 1500 °C and optimal slag compositions. At the same time, in the course of testing and development of the RPS-process for direct smelting of refractory ores of a number of deposits in Kazakhstan, the main attention was paid to the study of the concentration of gold and silver in ferruginous sulfide mattes, and to extract gold from them, as noted above, the method of oxyhydrochlorination was used.

In order to search for and develop other methods of gold concentration, the second task of the research was to study the possibilities of obtaining new types of collectors of precious metals and extracting gold and other metals from them.

A high scientific and technical level of the research performed has been achieved by studying the problem in the field of physical chemistry and technology of modern pyrometallurgical processes in non-ferrous metallurgy, in particular in the field of pyrometallurgy of precious metals. In addition, modern physicochemical methods of studying ores and new high-temperature pyroelectric installations were used.

The dissertation work uses the results of research on the processing of refractory gold-bearing ores and concentrates obtained during the performance of research work within the framework of grant funding for scientific research for 2015 - 2017 on the topic: "Research and development of technological parameters of new processes for the extraction of gold and non-ferrous metals from collector sulfide and metal melts of contractile pyrometallurgical selection of refractory gold ores."

This work is a continuation of the studies carried out under the project "Development of an integrated technology for pyrometallurgical selection of refractory gold-bearing ores and concentrates with the transfer of gold to matte by the method of contractile electric smelting and extraction of gold from mattes by the method of electromembrane oxyhydrochlorination (Zholbaristy field, Shovan Teriskei LLP, Mayatas Mayatas LLP ", Sayak-4, etc.)" of the program "Scientific

and technological support for the intensification of gold production in the Republic of Kazakhstan" for 2011-2014.

Contribution of the doctoral student to the preparation of each publication.

13 printed works were published on the topic of the thesis, including 2 articles in journals peer-reviewed by the Scopus database, 4 articles from the list of scientific journals recommended by the Committee for Control in the Sphere of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan, 5 abstracts, 2 patents were received.

The main provisions of the dissertation work were reported at 4 international conferences, including:

– International scientific and practical conference "Modern problems and innovative technologies for solving the issues of processing technogenic deposits of the Almalyk mining and metallurgical plant" (Uzbekistan, 2019)

– 2nd International Conference on Materials Science and Engineering ICMSE-2019 (Cairo, Egypt, 2019)

The structure and scope of the thesis. The dissertation consists of an introduction, 4 chapters, a conclusion and 4 annexes. The work is presented on 140 pages of typewritten text, contains 39 tables, 41 figures.