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# Evaluating the efficiency of metallized siderite concentrate electric melting

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***Abstract***. The Bakal siderites belong to low-grade refractory carbonate iron ores. The low content of phosphorus and non-ferrous metals makes siderites a valuable raw material for obtaining highly metallized concentrate suitable for use in steelmaking processes. Reduction of siderites in a rotary furnace at 1300 – 1350 °C followed by magnetic separation of waste rock allows to obtain a concentrate with metallization degree over 90 % and a content of waste rock of about 5 % suitable for steelmaking as raw materials. The purpose of this work is to evaluate the efficiency of the process aimed at obtaining metal from siderite ore including obtaining of highly metallized siderite concentrate in a recovery furnace, as well as its hot loading into ore-thermal furnace and melting process itself. To do this, the electric melting was calculated in the electric ore melting furnace providing for determination of a large number of parameters including the electricity consumption required for melting. As raw materials we used a highly metallized siderite concentrate ($\varphi_{met}$ = 92.3 %) containing 35 % of waste rock and, for comparison, a briquetted metallized siderite concentrate obtained from a lump concentrate in which a significant amount of waste rock was removed by wet magnetic separation. The results analysis shows that increase in concentrate temperatures from 25 to 1000 °C decreases specific energy consumption and at the same time increases the furnace productivity to values comparable to the parameters of melting briquetted concentrate. This confirms the efficiency of the developed process. To reduce the melting point of high-magnesium slag, it is proposed to use colemanite as flux.

***Keywords:*** iron ore raw materials, Bakal siderites, ore benefication, metallization, concentrate, electric melting, colemanite

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# Оценка эффективности электроплавки металлизованного сидеритового концентрата

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***Аннотация***. Бакальские сидериты относятся к бедным, труднообогатимым карбонатным железным рудам. Низкое содержание фосфора и цветных металлов делает сидериты ценным сырьем для получения высокометаллизированного концентрата, пригодного для использования в сталеплавильных процессах. Восстановление сидеритов во вращающейся печи при 1300 – 1350 °С с последующим отделением пустой породы методом магнитной сепарации позволяет получить в качестве сырья концентрат со степенью металлизации более 90 % и содержанием пустой породы около 5 %, пригодный для выплавки стали. Цель данной работы – оценить эффективность процесса получения металла из сидеритовой руды, включающего получение высокометаллизованного сидеритового концентрата в восстановительной печи, а также его горячую загрузку в руднотермическую печь и сам процесс плавки. Для этого произведен расчет электроплавки в электрической руднотермической печи, позволяющий определить большое количество параметров, в том числе расход электроэнергии, необходимый для плавки. В качестве исходных материалов использовали кусковой металлизированный сидеритовый концентрат ($\varphi_{мет}$ = 92,3 %), содержащий 35 % пустой породы. Для сравнения взят брикетированный металлизированный сидеритовый концентрат, полученный из кускового концентрата, в котором значительное количество пустой породы удалено методом мокрой магнитной сепарации. Анализ результатов показывает, что повышение температуры кускового концентрата от 25 до 1000 °С снижает удельные энергозатраты и одновременно увеличивает производительность печи до значений, сравнимых с параметрами плавки брикетированного концентрата. Это подтверждает эффективность предлагаемого процесса. Для снижения температуры плавления высокомагнезиальных шлаков в качестве флюса предложено использовать колеманит.

***Ключевые слова:*** железорудное сырье, бакальские сидериты, обогащение руды, металлизация, концентрат, электроплавка, колеманит

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## Introduction

The Bakal group of deposits, situated in the Chelyabinsk region, holds siderites categorized as low-grade refractory carbonate iron ores. Predominantly composed of sideroplesite and pistomesite, these ores comprise iron, magnesium, and manganese carbonate solid solutions. Complementing these minerals are barren components such as quartz-clay slates, dolomites, dolomitized limestones, diabases, and quartzites [1 – 4].

Siderites, characterized by their low phosphorus content, absence of non-ferrous metals like copper and zinc, and inclusion of manganese, stand as valuable resources for yielding high-metal concentrates suitable for steelmaking processes [5; 6]. Various process solutions have been devised for their production.

Pyrometallurgical techniques for processing low-grade iron ores, involving metallization with a solid reducing agent within rotary furnaces followed by waste rock separation through grinding and magnetic procedures, are widely employed in global industrial practice [7 – 11]. The refractory nature of siderite waste rock permits operation at temperatures ranging from 1300 to 1350 °C. This facilitates the enlargement of iron grains and significantly enhances their extraction into the concentrate through magnetic separation. In this process, a product boasting a metallization degree exceeding 90 % is achieved, containing approximately 5 % waste rock primarily composed of magnesium oxide [12; 13]. The preliminary removal of easily fusible slates enables processing in heavy media [14], where during separation, the lighter fraction of waste rock floats atop the suspension and is subsequently removed.

The metallurgical plants in the Ural region are currently facing a severe shortage of iron ore resources, necessitating their importation from other regions of the country [15 – 17]. Consequently, ensuring steelmaking production with a high-quality metal charge becomes a crucial objective. Therefore, there is an urgent need to evaluate the potential utilization of metallized concentrate derived from Bakal siderites through direct reduction as a resource for electric steelmaking furnaces.

In the majority of coke-free metallurgy technologies, the final product designated for electric steelmaking typically consists of 90 – 93 % iron with a metallization degree ranging from 92 – 95 %, alongside 3 – 5 % waste rock [18; 19]. As the proportion of waste rock increases, furnace yield and productivity decline, while power consumption rises. However, it is recognized that elevating the temperature of the loaded resources leads to a significant reduction in power consumption of the arc furnace, electrodes, and refractory materials, while simultaneously enhancing furnace productivity [19].

Hence, the objective of this study is to assess the efficiency of utilizing metallized siderite concentrate within an ore-thermal furnace.

## Materials and methods

The methodology for calculation and the software module developed for determining the technical and economic indicators of smelting in an ore-thermal furnace comprise a data input block, encompassing:

– chemical composition of charge materials;

– fluxing and fuel additives;

– furnace operation settings.

The electric smelting calculation in an ore-thermal furnace entails:

– determining metal and slag yield;

– assessing the chemical composition of the final slag with specified basicity or iron monoxide content;

– estimating the final metal temperature;

– designing sulfur content in the metal;

– analyzing the composition of flue gas;

– calculating mass and heat balances of the process;

– evaluating process production costs.

The developed software module, accessible in interactive mode, enables the user to:

– enter and edit information, as well as input data for calculations, with the ability to select and sort based on displayed edit fields;

Table 1

**Chemical composition of metallized siderites, wt. %**

*Таблица 1.* **Химический состав металлизованных сидеритов, % (по массе)**

| Description | C | $Fe_{met}$ | S | P | CaO | $SiO_2$ | MgO | MnO | FeO | $Al_2O_3$ | $\varphi_{met}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Metallized concentrate (lump) | 0.90 | 57.07 | 0.14 | 0.03 | 3.49 | 12.89 | 14.34 | 3.28 | 6.12 | 1.77 | 92.3 |
| Metallized concentrate (briquette) | 0.21 | 83.58 | 0.12 | 0.04 | 0.44 | 0.92 | 3.01 | 0.38 | 11.06 | 0.24 | 90.7 |

– quickly add new input data by copying and editing existing records;

– archive and print both input data and calculation results, while also providing authorized access to the software module.

To determine the chemical composition of the initial materials used in the calculations, experimental modeling of the siderite metallization process in a rotary furnace was conducted. A graphite crucible containing raw siderite lumps ranging from 10 to 40 mm in size, along with breeze coke filler sized between 0 and 5 mm, was placed in a Tamman furnace heated to a temperature of 1300 °C. The setup was maintained under specified conditions for 2 h before being cooled down with the furnace. This process resulted in the formation of a metallized concentrate (in lump form). Subsequently, a portion of the metallized concentrate lumps underwent grinding and wet magnetic separation to produce a product suitable for smelting in an electric furnace in the form of briquettes, referred to as metallized concentrate (briquette). The compositions of these materials are outlined in Table 1.

The temperature at which the concentrate (metallized concentrate in lump form) was loaded into the furnace after reducing roasting varied within the range of 25 to 1000 °C. The concentrate (metalized concentrate in briquette from) was loaded at 25 °C.

## Results and discussion

Variants of calculations of melting indicators in an ore-thermal furnace with the use of lump metallized siderite concentrate loaded into the furnace at temperatures of 25 – 1000 °C as an initial resource, all other conditions being equal, are given in Table 2.

Graphical interpretation of the effect of temperature of the lump metallized siderite concentrate loaded into a furnace on the productivity and specific power consumption for melting is given in the Figure.

The analysis of the obtained results shows that the use of highly heated lump metallized siderite concentrate is one of the important process measures to increase the efficiency of its electric smelting. When the temperature of the material increases in the range from 25 to 1000 °C, the specific power consumption decreases and the furnace productivity increases.

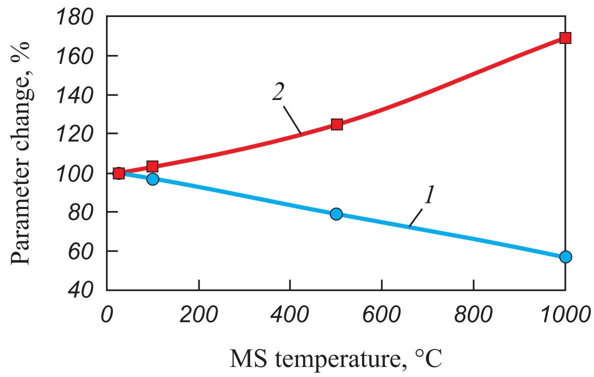
Table 3 presents calculations comparing the melting indicators in an ore-thermal furnace using a briquetted metallized siderite concentrate loaded at a temperature

Table 2

**Indicators of melting in ore-thermal furnace**

*Таблица 2.* **Показатели плавки в руднотермической печи**

| Indicator | 25 °C | 100 °C | 500 °C | 1000 °C |
|---|---|---|---|---|
| Furnace capacity, MVA | 16.5 | | | |
| Consumption of iron-ore components, kg/t metal | 1681.8 | 1681.8 | 1681.8 | 1681.8 |
| Metallized concentrate (lump), kg/t metal | 1681.8 | 1681.8 | 1681.8 | 1681.8 |
| Dust output, kg/t metal | 46.8 | 46.8 | 46.8 | 46.8 |
| Metal losses, kg/t metal | 10.0 | 10.0 | 10.0 | 10.0 |
| Electrode consumption, kg/t metal | 20.2 | 20.2 | 20.2 | 20.2 |
| Metal composition, % | | | | |
| Si | 0.40 | 0.40 | 0.40 | 0.40 |
| Mn | 1.24 | 1.24 | 1.24 | 1.24 |
| P | 0.03 | 0.03 | 0.03 | 0.03 |
| S | 0.005 | 0.005 | 0.005 | 0.005 |
| C | 0.10 | 0.10 | 0.10 | 0.10 |
| Metal temperature, °C | 1600 | 1600 | 1600 | 1600 |
| Slag output, kg/t metal | 579.8 | 579.8 | 579.8 | 579.8 |
| Slag composition, % | | | | |
| $SiO_2$ | 34.58 | 34.58 | 34.58 | 34.58 |
| MgO | 40.36 | 40.36 | 40.36 | 40.36 |
| $Al_2O_3$ | 4.89 | 4.89 | 4.89 | 4.89 |
| MnO | 5.32 | 5.32 | 5.32 | 5.32 |
| FeO | 5.00 | 5.00 | 5.00 | 5.00 |
| Basicity of slag, $CaO/SiO_2$ | 0.28 | 0.28 | 0.28 | 0.28 |
| Heat losses, % | 35.0 | 35.0 | 35.0 | 35.0 |
| Material balance, kg | | | | |
| Receipt | 1678.2 | 1678.2 | 1678.2 | 1678.2 |
| Consumption | 1678.1 | 1678.1 | 1678.1 | 1678.1 |
| Power consumption, kW·h/t sold | 1271.2 | 1229.2 | 1005.2 | 725.1 |
| Throughput capacity, t/day metal | 231.3 | 239.2 | 292.5 | 405.5 |




Influence of initial temperature of metallized siderite (MS) on parameters of ore-thermal smelting:
*1* – power consumption; *2* – furnace performance

Влияние начальной температуры металлизованного сидерита (МС) на параметры руднотермической плавки:
*1* – расход электроэнергии; *2* – производительность печи

of 25 °C as feedstock, with all other conditions held constant. Additionally, the data obtained, along with the calculated melting indicators of the lump metallized siderite concentrate loaded at 1000 °C, are provided.

An analysis of the data reveals that feeding a lump metallized siderite concentrate directly into an ore-thermal furnace immediately after discharge from the rotary furnace at temperatures exceeding 1000 °C (similar to the technology employed in processing titanomagnetites of the Bushveld complex in roasting furnaces with loading of a hot stub end into the ore-thermal furnace [20]), proves to be more efficient compared to melting a briquetted metallized siderite concentrate produced through the pyrometallurgical processing of siderites as described in [6; 12; 13].

Consequently, the pyrometallurgical processing technology eliminates the need for operations such as grinding, magnetic separation for waste rock removal, as well as drying and briquetting, thereby significantly reducing the product's overall cost.

The calculations demonstrate that the melting process yields slag with a high magnesium oxide content, characterized by a high melting temperature. However, the addition of material containing boron, such as colemanite [21], to high-magnesia steelmaking slags significantly reduces their melting point.

Table 3

**Comparative indicators of melting in ore-thermal furnace**

*Таблица 3.* **Сравнительные показатели плавки в руднотермической печи**

| Indicator | 1000 °C | 25 °C |
|---|---|---|
| Furnace capacity, MVA | 16.5 | |
| Consumption of iron-ore components, kg/t metal | 1681.8 | 1114.1 |
| Metallized concentrate (lump), kg/t metal | 1681.8 | 0 |
| Metallized concentrate (briquette), kg/t metal | 0 | 1114.1 |
| Dust output, kg/t metal | 46.8 | 27.2 |
| Metal losses, kg/t metal | 10.0 | 10.0 |
| Electrode consumption, kg/t metal | 20.2 | 20.2 |
| Metal composition, % | | |
| Si | 0.40 | 0.20 |
| Mn | 1.24 | 0.18 |
| P | 0.03 | 0.02 |
| S | 0.005 | 0.008 |
| C | 0.10 | 0.10 |
| Metal temperature, °C | 1600 | 1600 |
| Slag output, kg/t metal | 579.8 | 45.7 |
| Slag composition, % | | |
| $SiO_2$ | 34.58 | 12.30 |
| MgO | 40.36 | 66.07 |
| $Al_2O_3$ | 4.89 | 4.29 |
| MnO | 5.32 | 0.76 |
| FeO | 5.00 | 5.01 |
| Basicity of slag, $CaO/SiO_2$ | 0.28 | 0.89 |
| Heat losses, % | 35.0 | 35.0 |
| Material balance, kg | | |
| Receipt | 1678.2 | 1132.1 |
| Consumption | 1678.1 | 1132.0 |
| Power consumption, kW·h/t sold | 725.1 | 773.4 |
| Throughput capacity, t/day metal | 405.5 | 380.2 |

## Conclusions

The direct loading of lump metallized siderite concentrate into the electric furnace from the reducing furnace in a hot state (at temperatures exceeding 1000 °C) proves to be an effective method for melting and producing metal – a semi-product suitable for subsequent steel production. To ensure adequate fluidity of the high-magnesia slag at outlet temperatures, the addition of boron-containing materials, such as colemanite, to the charge becomes necessary.

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