VARIATION ANALYSIS OF THE TECHNOLOGICAL SCHEME FOR RECYCLING OF THE COPPER SLAG

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Abstract
This paper deals with an analysis of the variants of the technological scheme for recycling of the copper slag. Three variants of the process flow diagrams describing the recycling of pyrometallurgical copper slag were examined, analyzed and evaluated. The technological scheme must ensure the recycling of slag as a solid phase of iron oxides and silica. The main indicator for the evaluation and selection of the technological scheme is the composition of the obtained solid residue.

In indicator, composition of the products obtained as result of processing of the copper slag via the processes, described in technological schemes it was found that Variant III is the most appropriate for the application.

Introduction
The slag – a waste product from the pyrometallurgical production of copper, contains iron, silicon dioxide, aluminium oxide, calcium oxide, copper, nickel, cobalt, etc. It has been estimated that about 2.2 tons of slag are generated for each ton of produced copper and approximately 24.6 million tons of slag are accumulated every year [1-3]. Dumping or disposal of this slag causes wastage of certain amount of metal available in the raw material and leads to environmental problems [4]. Many efforts have focused on developing methods for the recycling of slag and the reduction of its quantity [5-7]. Various methods have been proposed for extracting copper and other precious metals from slag by treating it with solutions of acids, bases and salts under atmospheric pressure and under high pressure as well [8-23]. Using of these methods do not result in a significant reduction of the disposal slag because the quantity of the extracted copper and precious metals are negligible in comparison to the amount of slag [1-3, 5]. A new approach has been proposed in the EU patent No. 2 331 717 B1 [24], which is based on the decomposition of the fayalite presented in the slag into iron and silicate phases by oxidation and subsequent hydrometallurgical treatment. As a result, useful products could be obtained in the form of amorphous silicon dioxide and iron oxide and the slag can be completely utilized.

Development of the idea to a technology requires selection of a technological scheme. The technology creation begins with elaboration and selection of a technological scheme. The term technology is composed of the Greek words - "Technos" - art, craft, and „Logos” - science. Technology is the science studying the methods and processes for the processing of raw materials into consumer and capital goods. The task of the technology is to describe in the form of successive activities a scientific knowledge underlying the processes involved in the overall production process. The basis of technology are the science theories and different theoretical principles, knowledge of material properties and objective laws of the course of the chemical and physical processes. A technological process represent a set of physico-chemical or mechanical effects on basic raw materials used in processing them to obtain needed items and products. If the sequence of technological processes allows then different variations of the technological schemes are developed. In our case, it is possible to achieve the objective of the technology - recycling of slag from copper manufacturing by different variations of the process. A schematic block diagram corresponds of each variant describing the sequence of operations.

There are different approaches to the assessment of a technological scheme: energy; necessary machines and apparatus; yield; price; or product quality. In our case, the technological
scheme must ensure the recycling of slag as a solid phase of iron oxides and silica gel. The solid phase must not contain any residual silica exceeding 10% by mass and sodium more than 1% by mass. Therefore, the composition of the useful products is an indicator for selection of the optimal technological scheme.

The aim of the study is an analysis of the variants of the technological scheme for the recycling of slag from copper production and selection of the best.

Fig. 1 Variant I of the technological scheme
Variants of the technological scheme - description, analysis and evaluation

Variant I presented in Fig. 1 contains fourteen processing operations of the slag, which can be grouped in five main processes: 1) Thermal decomposition of the slag - sifting and oxidation. 2) Heat treatment of a mixture of slag with a hydroxide or an alkali metal carbonate - mixing, heat treatment and cooling; 3) Hydrometallurgical extraction of silicate phase - mixing, extracting, cooling, and filtration; 4) Processing of the solids - washing, filtering, drying and pelleting; 5) Processing of the liquid phase - hydrolysis filtration and separation, the separation of the leach liquor, and drying the gel. The chemical composition of the resulting residue in wt. % is: FeO- 67.92; SiO₂- 23.62; MgO- 0.71; CaO- 1.34; MnO- <0.01; Al₂O₃- 3.28; Na₂O- 1.98; K₂O- 0.78; TiO₂ -0.12. As can be seen from chemical composition of the solid residue the technological scheme Variant I does not reach the specified parameters and is not suitable for an application.
Variant II, presented in Fig. 2 contains twelve processing operations of the slag, which can be grouped in four main processes: 1) Thermal decomposition of the slag – sifting and oxidation; 2) Hydrometallurgical extraction of the silicate phase - mixing, extracting, cooling and filtering; 3) Processing of the solid phase - washing, filtering; drying and pelletizing; 4) Processing of the liquid phase - hydrolysis, filtration and separation, the separation of the leach liquor, and drying the gel. The chemical composition of the resulting residue in wt. % is: FeO- 75.02; SiO₂- 15.49; MgO- 0.01; CaO- 0.49; MnO- 0.01; Al₂O₃- 2.57; Na₂O- 0.01; K₂O- 0.1; TiO₂ -0.19. It is evident that Variant II gives better results with regard of silica content in the solid residue. However, it did not reach the required values. The content of residual silica in the solid phase is more than 10 mass%. After treatment of the slag with an alkaline solution, silica was dissolved partly or completely, thus the grain size is reduced.
Although it is applied vacuum, filtration a part of the sodium silicate remains onto the iron oxide grains as nano-layer. Further steps are needed to separate this sodium silicate from the solid residue.

Variant III, presented in Fig. 3 contains seventeen processing operations of the slag, which can be grouped in five main processes: 1) Thermal decomposition of slag - sifting and oxidation; 2) Hydrometallurgical extraction of the silicate phase - mixing, extracting, cooling and filtering; 3) Re-hydrometallurgical extraction of the silicate phase - mixing, extracting, cooling, and filtration; 4)
Processing of solids - washing, filtering, drying and pelletizing: 5) Processing of the liquid phase - mixing, hydrolysis, filtration and separation, the separation of the leach liquor, and drying the gel.

**Example for Variant III:** The oxidized slag was mixed with 60 g of NaOH and 1000 ml of water, placed in an autoclave and heated with continuous stirring to a temperature of 180 °C, at which is kept 6 h. After the end of the process, the solution was filtered.

The solid residue was returned to the autoclave with 1000 ml of water and heated with continuous stirring to a temperature of 180° C for 2 h. After the end of the process, the solution was filtered.

The chemical composition of the residue in wt. % is:

<table>
<thead>
<tr>
<th></th>
<th>FeO</th>
<th>MgO</th>
<th>CaO</th>
<th>MnO</th>
<th>SiO2</th>
<th>Al2O3</th>
<th>Na2O</th>
<th>K2O</th>
<th>TiO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>86.69</td>
<td>0.97</td>
<td>0.87</td>
<td>&lt;0.01</td>
<td>6.163</td>
<td>3.04</td>
<td>1.92</td>
<td>&lt;0.01</td>
<td>0.66</td>
</tr>
</tbody>
</table>

It is evident that the technological scheme Variant III provides reaching the preset values of silica as a residue in the solid phase.

**Conclusion**
In indicator, composition of the products obtained as result of processing of the copper slag technological scheme Variant III is the most appropriate for the application.

**Literature**
14. Yang Z, Rui-Lin M, Wang-Dong N, Hui W. Selective leaching of base metals from copper slag...
24. European Patent No. 2 331 717 B1. METHOD FOR RECYCLING OF SLAG FROM COPPER PRODUCTION.