CRUSHING CIRCUIT OPTIMISATION IN A LEAD-ZINC PROCESSING PLANT

Irena Grigorova, Marin Ranchev, Ivan Nishkov

University of Mining and Geology "St. Ivan Rilski"; 1700 Sofia; irena_mt@abv.bg

ABSTRACT. A mineralogical study in order to determine the mineral composition of the ore entering the Rudozem concentrator have been carried out. Polished sections of ore samples from the three hydrothermal Pb-Zn deposits - Petrovitsa, Varba-Batantsi and Kroushev dol have been prepared. The studies were performed using a MEIJI MT 9430 optical microscope equipped with a DK 3000 digital camera. Compared to the ores from the other lead-zinc deposits in the Madan ore field, the ore processed in Rudozem plant contains harder to grind components, resulting in poor plant performance and limited production capacity. Therefore, it was recommended to improve the old crushing and screening circuit (three stage crushing in closed circuit) with new modern equipment comprising of two stage crushing and screening, including – jaw and cone crushers and one high throughput vibrating screen operated in open circuit. This study therefore sets out to assess the benefits of the new equipment for the downstream processes.

Keywords: crushing, screening, open circuit, equipment

ОПТИМИЗИРАНЕ СХЕМАТА НА ТРОШЕНЕ ПРИ ПРЕРАБОТКАТА НА ОЛОВНО-ЦИНКОВИ РУДИ

Ирена Григорова, Марин Ранчев, Иван Нишков
Минно-геоложки университет "Св. Иван Рилски", 1700 София

РЕЗЮМЕ. За определяне минералния състав на рудата, постъпваща на преработка в ОФ „Рудозем“ бяха проведени микроскопски изследвания. Бяха изготвени полирани микроскопски препарати (аншлифи) от три осреднени, квартовани рудни проби от находищата Петровица, Върба-Батанци и Крушев дол. Микроскопските изследвания на препаратите са проведени с помощта на поляризационен микроскоп MEIJI MT 9430, окомплектован с дигитална камера. В сравнение с рудите от другите оловно-цинкови находища в Маданското рудно поле, рудата преработвана в ОФ „Рудозем“, съдържа трудно смилаеми компоненти, което води до ниски технологични показатели и ограничена производителност. Поради това, беше препоръчано старата схема на трошене и пресяване (тристадиална схема на трошене в затворен цикъл) да бъде подменена с ново модерно оборудване, включващо челюстна и конусна трошачка и високо производително вибрационно сито, работещи в отворен цикъл и два стадия на трошене и пресяване. В това изследване се прави оценка на предимствата на новото оборудване върху последващите процеси в технологичната верига на фабриката.

Ключови думи: трошене, пресяване, отворен цикъл, оборудване

Introduction

The largest, economically most important deposits of Pb-Zn ores in Bulgaria are located in the Central Rhodopes, in the Madan ore field. The polymetallic ore mineralisation in Madan ore field is controlled by major six several steep ore fault zones, with length to 10-15 km and more, with NNW- SSE trending (Fig. 1). The Pb-Zn mineralisation has been represented by three morphogenetic types of ore bodies – steep to subvertical ore veins (1 to 3 km wide, up to 7 km long), marble-hosted metasomatic ore bodies and disseminated stockworks. The metasomatic (skarn) ore bodies are developed by hydrothermal replacement at intersections of the ore-controlling faults with the marble horizons.

The main ore minerals in the deposits are represented by galena, sphalerite, pyrite and subordinate amount of chalcopyrite, and non-metallic minerals - mainly of quartz, carbonates, johannsenite-hedenbergite skarns (in metasomatic ores bodies) and others.

The hydrothermal Pb-Zn deposits in Madan ore field are hosted in the Rhodopean metamorphic complex, consisting mainly of high grade metamorphic rocks of the Madan Tectonic Unit (Madan Allochton) and Arda Unit. The Pb-Zn ore deposits Petrovitsa, Varba-Batantsi and Kroushev dol are hosted in the rocks of the Madan Unit - various gneisses, schists, amphibolites and marbles.

The predominant metamorphic rocks are represented by biotite and amphibole-biotite gneisses, containing amphibolite bodies (metagabbro), irregularly alternating with marbles packages containing graphite and phlogopite. A characteristic feature of the Madan Unit is the abundance of quartz-feldspar veins, located both in parallel and crosscut on the metamorphites. Among the migmatised biotite and amphibole-biotite gneisses, biotite gneiss-schists with and without garnet are established, forming irregular layers.

Comminution processes such as crushing and grinding constitute a significant proportion of capital and operating costs in mineral processing plants (Napier-Munn et al., 2005).

Crushing circuits are an essential part of most mineral processing plants, with various production units such as crushers, screens, bins, conveyors and feeders. There are numerous configuration and number of units in each processing plant, as the main purpose of crushing is to prepare the ore for further processing, i.e. to produce a certain amount of material of a certain size per day so that the grinding circuit has sufficient feed.

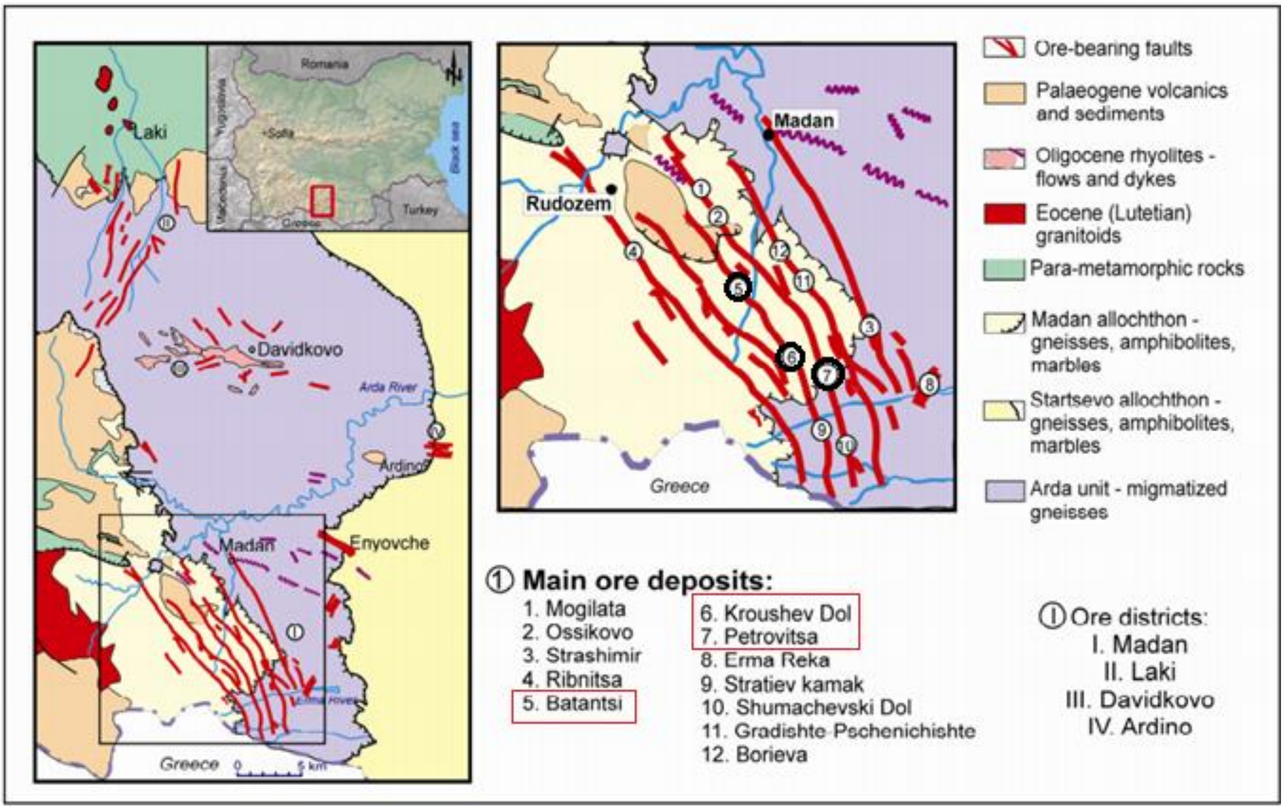

Fig. 1. Simplified geological map of the ore deposits in the Central Rhodopes and location of the main Madan ore deposits (modified from Vassileva et al., 2009, after Ivanov, 2000)

According to Napier-Munn et al. (2005), the criteria for a comminution optimisation campaign are usually determined by the following objectives:

- Maximise throughput and maintain the existing final product size specification;
- Change final product size and maintain the existing throughput;
- Maintain existing throughput and final product size, but minimise working costs.

Following the above mentioned objectives, the optimisation of the old crushing and screening circuit will enable the ball mills to take advantage of the finer feed (change of the final product size) that is produced from the new crushing and screening equipment.

The purpose of this research paper is to assess the benefits of changing the three-stage crushing and screening circuit to two-stage, by replacing the original (old) equipment with new state of the art crushing and screening units.

Original three-stage crushing and screening circuit of the Rudozem concentrator

The original crushing and screening circuit includes a primary KKD-500/75, secondary KSD 1750 and tertiary KMDT 2200 cone crushers manufactured in Uralmash, the Ural Heavy Machine Building Plant, Yekaterinburg, Russia, and the vibrating screens type SB-350 manufactured in Monek-Yug (former Komsomolec plant) Kardzhali, Bulgaria, have been in operation for more than 50 years. The flowsheet of the original Rudozem crushing and screening circuit is shown in Figure 2.

Materials and Methods

Mineralogical studies

In order to determine the mineral composition of the ore, polished sections of representative ore samples from the three hydrothermal Pb-Zn deposits - Petrovitsa, Varba-Batantsi and Kroushev dol have been prepared. Mineralogical studies of the polished sections were performed using a MEIJI MT 9430 optical microscope equipped with a DK 3000 digital camera.

Particle size distribution of ball mill feed

Particle size analysis of the ball mill feed have been conducted, in order to assess the performance of the old (original) and the new crushing and screening circuit. The laboratory sieve analysis was carried out with sieve shaker Retsch AS 200 using the following test sieves (200 x 50 mm): 45, 40, 35, 20, 16, 14, 10, 5, 2 and 1 mm. Furthermore, the total reduction ratio for both crushing circuits has been calculated.

Reduction ratio

The reduction ratio of a crushing stage can be defined as the ratio of maximum particle size entering to maximum particle size leaving the crusher (Wills, Napier-Munn, 2006). All crushers have a limited reduction ratio meaning, that the size reduction will take place in stages (*Metso Minerals®*, 2002). In order to compare the total reduction ratio for both circuits, data from a plant survey conducted after the installation of the new equipment have been analysed and the results are presented below.

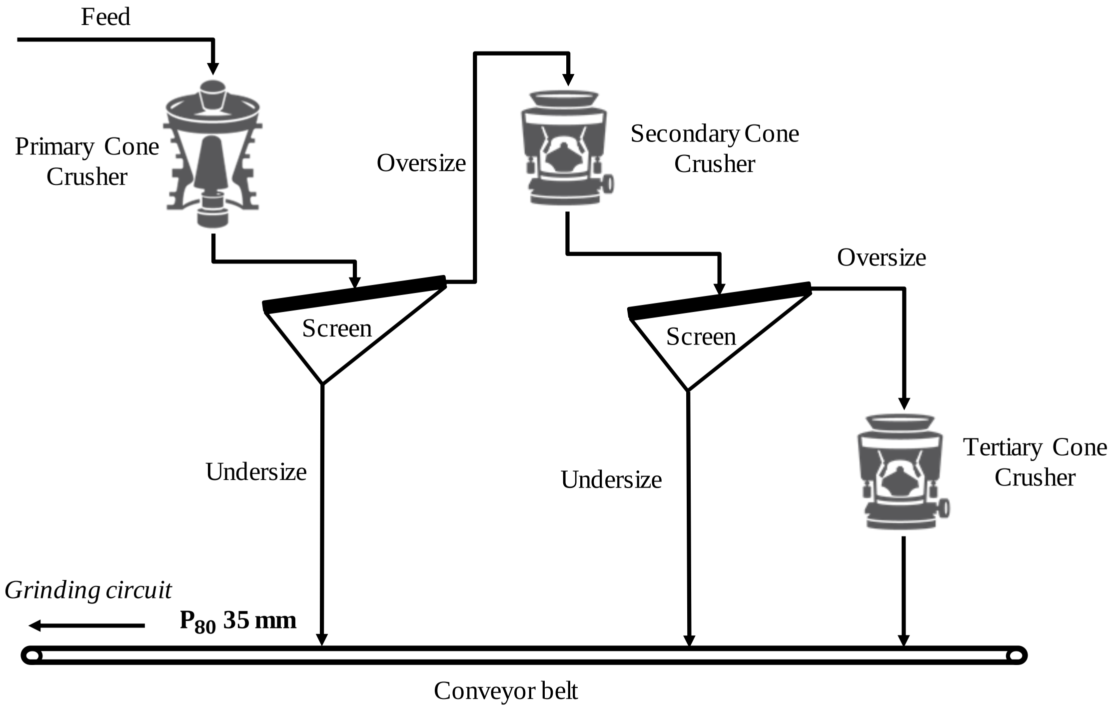

Fig. 2. Original crushing and screening circuit of the Rudozem concentrator

Results and Discussions

Mineralogical studies

The data from the conducted studies in polished sections by reflected light microscopy show that in the samples examined there are fragments from both the quartz-sulphide ore veins and the metasomatic ore bodies, formed in the skarns and in the marbles, present among the host metamorphic rocks.

The results obtained show that the main ore minerals in the ores are represented by galena, sphalerite, pyrite and subordinate amount of chalcopyrite and non-metallic minerals - mainly of quartz, carbonates, johannsenite-hedenbergite skarns, flaky phyllosilicate minerals (sericite, chlorite), clayey phases and others (Fig. 3). The presence of pyrrhotite and pyrite-marcasite pseudomorphoses after primary pyrrhotite is also found in the ore from the Varba-Batantsi deposit.

Data on temperature of forming, distribution of main ore minerals within quartz-sulphide mineralization and content of trace elements in separate ore minerals suggest dome-like type of zoning in the Madan ore field (Kolkovski, Dobrev, 2000). In the upper (outer) zone the mineralisation is quartz–sulphide with a sphalerite prevailing over the galena, the galena showing high content of Ag and Sb. In the intermediate zone mineralisation is quartz-sulphide again, but galena prevails over the sphalerite, with the galena being enriched with Bi, as well as with Ag and Sb. At the lowest level of the deposits barren quartz is found.

The host rocks, including the lead-zinc deposits in the Madan ore field, also differ in lithological composition. Some of the deposits such as Varba - Batantsi, Kroushev Dol and Petrovitsa are located in the Madan Unit (Madan allohton), occupying the upper parts of the metamorphic complex in the Central Rhodopes. The Madan Unit is made up of a variety of high grade metamorphic rocks – biotite and amphibole-biotite gneisses, amphibolites, mica-schists, marble packages containing graphite and phlogopite, etc. A characteristic peculiarity of the Madan Unit is the presence of abundant quartz-feldspar bodies and veins. Skarns and sulphide mineralisation are often developed on the contact of pegmatite bodies with the marbles included among the gneisses.

According to Grigorova et al. (2017), it has become increasingly popular in large scale mineral exploration surveys to use non-invasive geophysical methods for collecting more accurate information about the location and the geological properties of the ore bodies and surrounding area. This information can be particularly important when presence of components such as gneisses and other high grade metamorphic rocks occur in the area of interest.

It is well known that the presence of components, such as gneisses and garnet-containing gneiss-schists, amphibolites (metagabbro), pegmatites, mica, chlorites, graphite etc., will cause difficulties during ball mill grinding, due to the higher bond work index (kWh/t) values, which they possess. Therefore, in order to reduce the size of the ore particles entering the ball mill grinding circuit and to decrease the energy consumption required for ball milling, it was suggested that a replacement of the obsolete crushing and screening machinery should be realized.

Particle size distribution of ball mill feed

The results from the laboratory particle size analysis clearly demonstrate the higher efficiency of the new crushing and screening equipment, providing a product in the size range of -16.00 +0.00 mm, which will favourably affect the performance of the downstream processes, i.e. the ball mill grinding and flotation. It is important to highlight the fact that despite the contrast in P80 for both products, there is no significant difference in the amount of finer sizes (-2.00 mm) as a result of which the slime production in the circuit will be reduced. The ball mill feed size distribution curve is shown on Figure 4.

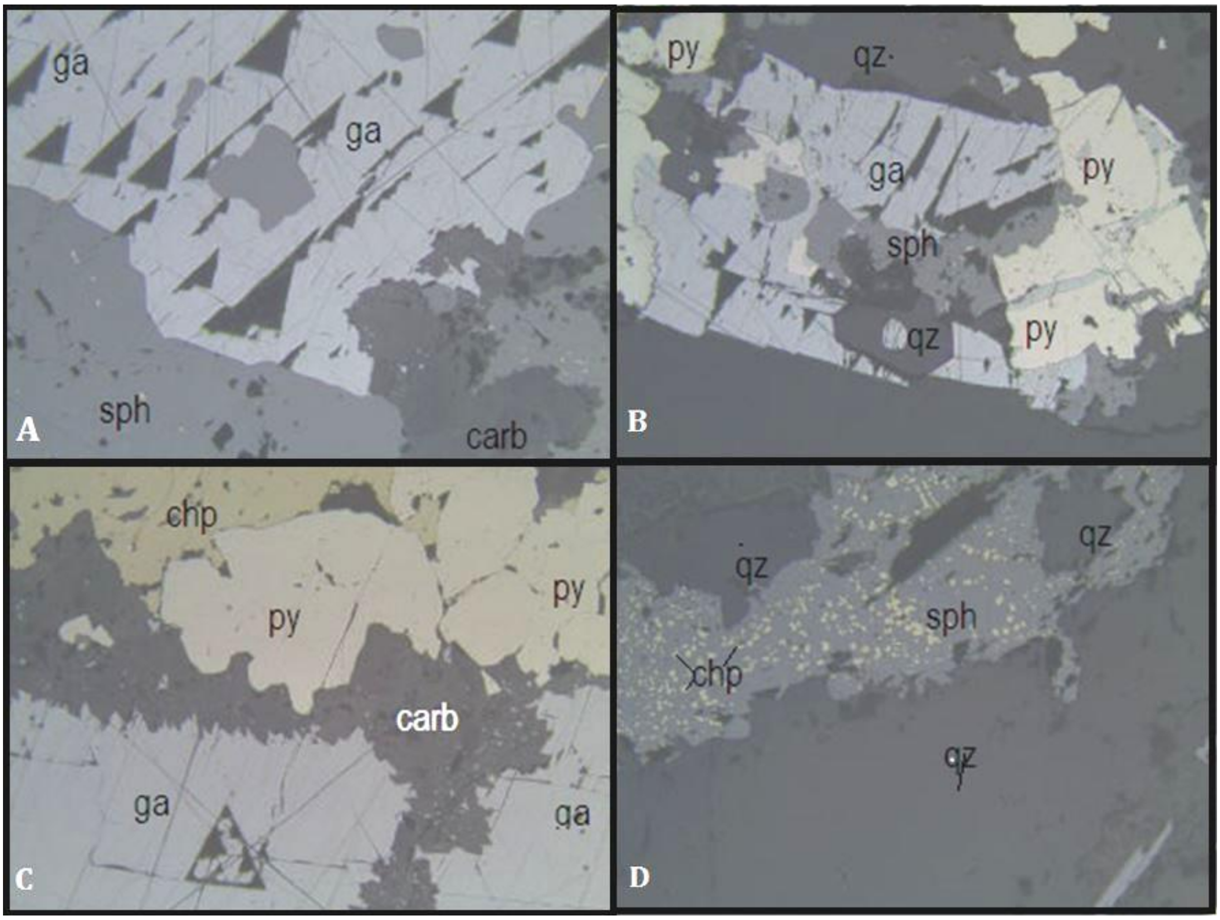

Fig. 3. Photomicrographs of the mineral assemblages from the Pb-Zn ores, processed in the Rudozem concentrator. Reflected light, N II, width of view – 820 µm: A) Galena (ga) and sphalerite (sph), corroded by carbonate (carb); B) Galena (ga), pyrite (py), sphalerite (sph) and quartz (qz). C) Galena (ga), pyrite (py) and chalcopyrite (chp), corroded by carbonate (carb) veinlets; D) Sphalerite (sph) with disseminated fine-grained inclusions of chalcopyrite (chp) among quartz (qz)

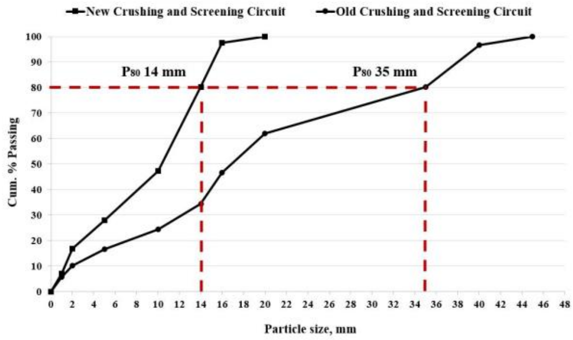

Fig. 4. Comparing the ball mill feed particle size distribution

Reduction ratio

The results from the sampling campaign, involving a simple size analysis of the crushed products from the original and the new crushing and screening units are presented in Table 1 below:

Table 1. *Size analysis of the crushed products*

Product	Old crushing and screening circuit:	New crushing and screening circuit:
Feed ore, mm	600	600
Primary crushed Product, mm	250	70
Secondary crushed product, mm	120	P_{80} 14 mm
Tertiary crushed Product, mm	P_{80} 35 mm	-

The estimated total reduction ratio (R) for both circuits is shown below:

- Old crushing and screening circuit: R1 = 2.4; R2=2.1; R3=3.43;
  - ○ **Total reduction ratio: R1xR2xR3 = 17.3**
- New crushing and screening circuit: R1 = 8.57; R2=5.0
  - ○ **Total reduction ratio: R1xR2 = 42.85**

The results show that a higher reduction ratio with less crushing equipment has been achieved, which is a prerequisite for lower operating costs i.e. saving energy, mechanical reliability, easy and safe maintenance.

New state of the art crushing and screening circuit

The original crushing and screening circuit includes a vibrating grizzly feeder, providing a continuous feed rate and scalping of the ROM. The primary crushing of the ore is carried out in a jaw crusher with actual feed opening depth of 700 mm and 1060 mm width, with throughput capacity of around 160 – 190 t/h. The size control of the circuit is accomplished by an incline double deck vibrating screen, with 30 mm top deck and 14 mm bottom deck apertures. The screen oversize and mid-size fractions are fed to the cone crusher, the undersize fraction combined with the cone crusher product is conveyed to an intermediate stockpile and then fed to the ball mills. The secondary crushing stage is carried out in a cone crusher with 14 mm closed side setting (stroke setting) and throughput capacity of 110 – 170 t/h. A simplified block flow diagram of the new crushing and screening circuit is shown in Figure 5.

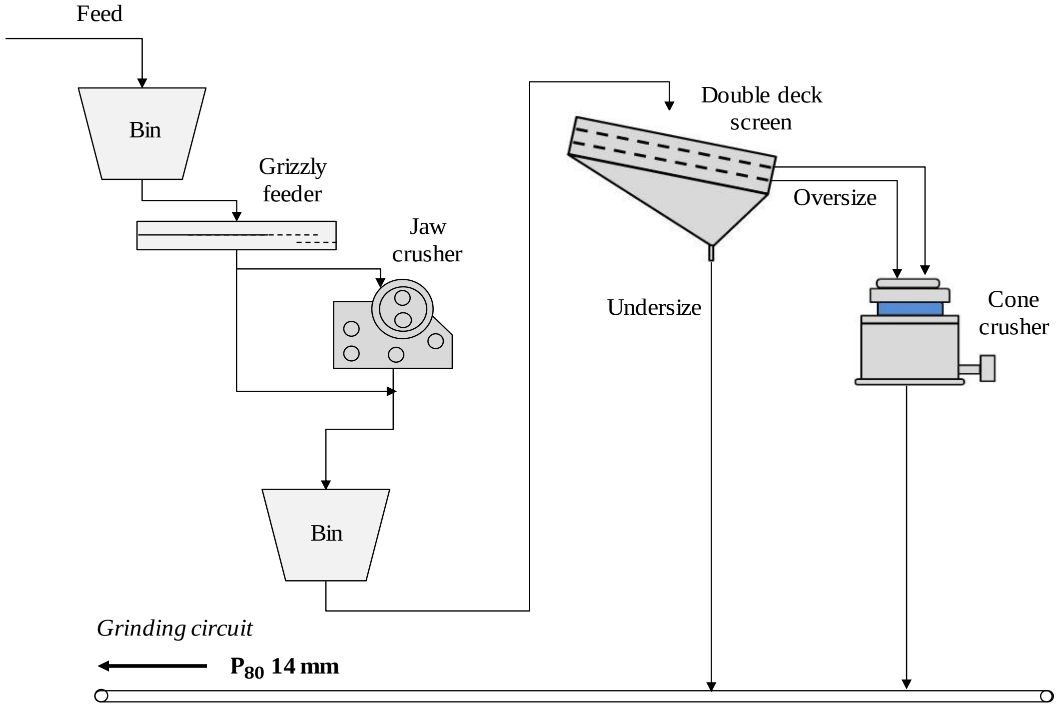

Fig. 5. New crushing and screening circuit of the Rudozem concentrator

Conclusions

Based on the results from the mineralogical studies, it can be concluded that the improvement of the crushing and screening circuit in the Rudozem concentrator, will provide a finer ball mill feed product, thus boosting the grinding efficiency of the harder to grind ore components and reducing the specific energy consumption. Furthermore, the higher reduction ratio, achieved by fewer machines, ensures an easy maintenance, cost efficiency and safe working environment. Taken together, the findings in this research highlight the benefits of the new crushing and screening equipment installed in the Rudozem concentrator.

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