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To cite this article: M Czekajło and K Żakowski 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **427** 012032

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Increasing efficiency of technological process by limiting impact of corrosive environment on operation of spiral classifiers

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Abstract. Most of the technological operations related to the preparation of the output to be enriched and to the production of the final copper concentrate take place with the use of water environment. Water management, besides using innovative technical and technological solutions, is a significant factor in the whole copper ore enrichment process. Mine water resources and surface water of the tailing pond named “Żelazny Most” are the two sources of technological water. Its physico-chemical composition is not insignificant for both the flotation process and the machinery and equipment maintenance. The concept of electrochemical protection of the spiral classifier presented in this article is the supplement and alternative for anti-corrosion protection of the machinery and equipment used in KGHM Polska Miedź S.A. Ore Enrichment Plant. The adequate appreciation of the spiral classifier characterisation and the working conditions will allow for the optimal adjustment of cathodic protection installations with the anode polarization system. Research into the development of an effective protection method will combine two complementary types of anti-corrosion protection systems, that is the passive (a protective coating) and the active (a cathodic protection). The effect of the planned research will be the evaluation of the potential possibilities of the corrosive and erosive impact limitation of the spiral classifier working condition. And, moreover, it will lead to an extension of working hours and the reduction in the costs of the technological circuit.

1. Introduction

The Ore Concentration Plant (OCP/ZWR) is a single organizational unit of KGHM Polska Miedź S.A. and consist of three production areas: Lubin, Polkowice and Rudna which fulfils a special role in the technological lines of copper ore processing. The basic task of the plants is to maximize metal recovery and produce the concentrates with the quality parameters required for effective smelting at the lowest possible cost.

The copper ore deposits mined by KGHM in Poland comprise three lithological types: shale, dolomite, sandstone, which contain, on average, 1.50 % of the actual copper used. The copper ore is



subject to process whose main operation is the flotation enrichment, which, in turn, results in the obtaining of the concentrate with the copper content enabling its metallurgical processing while smelting. The remaining part of the output, with a small metal content, constitutes the floatation waste, which is further transported to the tailing pond named “Żelazny Most”. The technics and technology that are used in concentration plants ensure a very effective recovery of copper, silver and other elements, even up to 90 % of copper with high copper content in the concentrate up to 26 %. The Concentration Plants operating at each of KGHM’s three mines are able to process an average of 33 million tonnes of ore per year.

The basic production processes in OCP/ZWR include: sieving, crushing, grinding and classification, flotation, concentration, filtration and thermal drying of the concentrate. The implementation of the above tasks requires that enrichment processes should be carried out in a manner that is safe for employees, as smooth as possible and effective. That is why, it is vital to keep machines and devices in good technical condition. It should be understood as carrying out all the planned maintenance and repairs as well as applying modern and effective methods of their protection.

This could be achieved by using the proper anti-corrosion protection system, that is the passive (a protective coating) and the active (a cathodic protection) or by combining both methods.

2. The conditions of the technological process

The grinding and classifying processes are the stages which prepare ore to flotation enrichment. Starting with this stage, all subsequent operations of the production stages are carried out using water.

The main source of water used in the technological process is the surface water of the tailing pond and the mine water. The amount of water pumped to all the ore enrichment plants is variable and results directly from ore throughput. This relationship is determined by water usage per one tonne of ore dried mass, m^3/Mg (figure 1, figure 2).

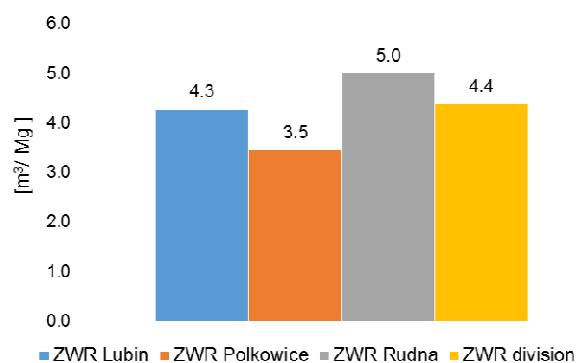


Figure 1. The process water usage indicator of one tonne of ore dried mass on average in 2017.

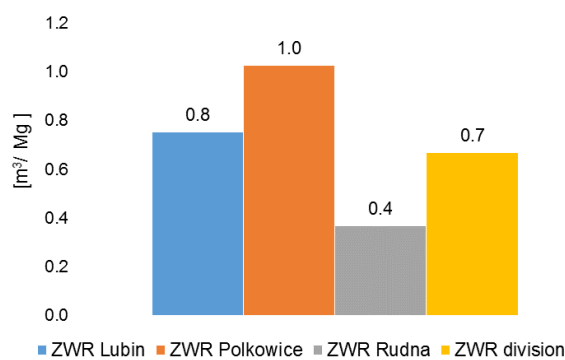


Figure 2. The mine water usage indicator of one tonne of ore dried mass on average in 2017.

Currently the largest participation of the water used in the technological process is the surface water from the tailing pond (86 %). The mine water amounts to about 14 %. In addition to monitoring the amount of water directed to the process, another important aspect is water quality. In the last few years dissolved substances in the processed water has been monitored especially for sodium chloride (NaCl). It is estimated that mine water salinity over the next few years will be slightly, but gradually, increasing [1].

Current data from the monitoring system of chlorides and sulphates created for the needs of KGHM Polska Miedź S.A. has shown the presence of chloride ions (Cl^-) at around $2.0 \text{ g}/\text{dm}^3$, which along with mine water are directed to OCP/ZWR Lubin, $7.8 \text{ g}/\text{dm}^3$ to OCP/ZWR Polkowice and $100 \text{ g}/\text{dm}^3$ to OCP/ZWR Rudna. In the case of tailing pond’s surface water the concentration of chlorides nears $25 \text{ g}/\text{dm}^3$.

Another component of water-soluble salts is sulphate ions (SO_4^{2-}). Their current concentration in the mine water directed to OCP/ZWR Lubin and Polkowice is 1.3 g/dm^3 and 2.3 g/dm^3 to OCP/ZWR Rudna, whereas the tailing pond's surface water contains about 3.1 g/dm^3 . For many years the sulphate concentration in water directed to OCP/ZWR has been maintained at a similar level and occasionally exceeded 3.0 g/dm^3 .

3. The influence of industrial water on the technological process

Industrial water quality is not without significance for the flotation process, where the hydrophobicity of the mineral surface is essential. The flotation reagents usage regime can affect not only the hydrophobicity of the grains, but also the foam formation and stability. The effect of stable foam is obtained mainly by adding foaming agents, which also improve gas dispersion and accelerate the flotation process [2]. When using saline technological water, a similar effect is observed. The water affects the quality of the air bubbles produced, as well as the mineral particles surface wettability and the interaction between the air bubble and the grain [3]. Smaller bubbles are generated themselves better in high salinity solutions, which may lead to a reduction in reagent consumption [4].

The research on commission of KGHM's Ore Enrichment Plants carried out by the University of Technology in Wrocław has shown that the addition of sodium chloride usually does not change the selectivity of copper and organic carbon flotation, but slightly affects the selectivity of silver and lead flotation. In turn, conducted research as part of a doctoral thesis entitled "The enrichment of output in KGHM Polska Miedź S.A." showed an increase in the efficiency of copper and organic carbon enrichment as the concentration of salt in the water added to the flotation process increases [5]. Other attempts to determine the influence of salinity of technological water on the flotation process were made in the past by Żmudziński, Lekki [6] and Karpisz [7]. They showed an adverse effect of salinity increase on flotation of sandstone ore in the concentration range from 6.0 to 14 g/dm^3 in relation to flotation in tap water. In the case of shale ore, the most favorable enrichment was obtained with salinity of water with concentrations of 6 and 40 g/dm^3 , while worse for tap water. On the other hand, in the case of carbonate ore a linear improvement in flotation results is observed along with the increase in sodium chloride content in water.

The influence of salt on the efficiency of the copper flotation process has not been yet clearly defined and described in the literature. Therefore, it is necessary to acquire knowledge and carry out further research in this area.

Taking into account all the above, it can be stated, with some simplification, that the observed changes in the concentration of chloride ions do not involve technological problems in achieving the assumed quality parameters of the final copper concentrates. Their presence, within certain concentration limits, can have a positive effect on the flotation process course. The control and carrying out of the flotation enrichment process are the easier the smaller variability of process water quality is observed.

The situation, however, is different in the case of the impact that salt has on machinery and equipment, as well as the technical and technological infrastructure. The research carried out by Gdańsk University of Technology [8] has confirmed the high corrosivity of the atmosphere as defined according to PN-EN ISO 12944-2 as C5-I (industrial) and C5-M (marine). Its aggressive character is observed both in the lower and upper parts of the production sites. Difficult climatic conditions, in particular, occur at the floor level, where the relative humidity nears or exceeds 80% . In addition to the corrosion conditions mentioned above, the corrosion and erosive character of the ore enrichment process should also be listed. Its negative impact is especially visible at the stage of classification in spiral classifiers. The significant amounts of the aqueous medium transporting the crushed and milled ore produce a clear mechanical effect, mainly through friction, cavitation and impact attack.

The inspection of the construction, installations and equipment operating in the plant showed the need for effective methods of corrosion protection.

Taking into consideration all the above, it is important to use the sources of technological water skilfully, supporting the flotation process on the one hand, and on the other limiting its negative impact on the maintenance of machinery and equipment in motion.

4. Initial tests for the possibility of using cathodic protection

The aim of the conducted research was to assess the degree of corrosivity of the feed - an aqueous slurry, which is the natural working environment of spiral classifiers.

The classifiers that classify output, pre-crushed and milled grains up to a grain size of less than 5 mm copper ores work under conditions that until recently have not been examined for corrosivity.

The presence of a large amount of both chloride and sulphate ions has also been confirmed in the conductivity (the inverse of resistivity) studies of classifiers feed. The knowledge of electrolyte conductivity, in this case an aqueous medium, is of great importance to the calculations of the amount and the size of anodes, as well as the location of the sources of protective current for the cathodic protection system.

The measurements of the feed conductivity (comminuted, ground ore in the form of an aqueous slurry) were carried out using a digital resistance meter, to which a "soil-box" vessel was connected (figure 3, figure 4).

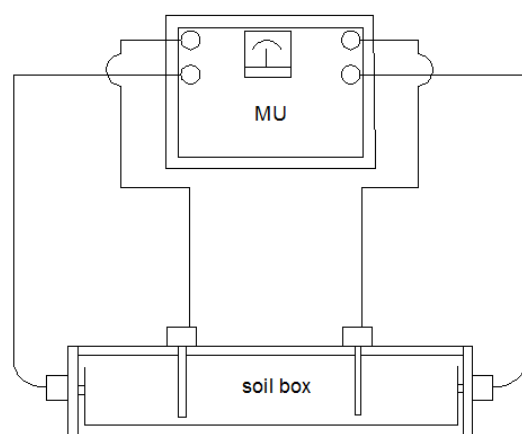


Figure 3. Diagram of the apparatus used to measure the conductivity of the feed.



Figure 4. A measuring set used to determine the conductivity of the feed. Digital earth resistance meter, type TELLUROHM C.A 2 and „soil-box” vessel.

The conductivity of samples of the feed taken from three regions: Lubin, Polkowice and Rudna were measured separately for decanted water and mixed feed containing solids.

The above results (table 1) indicate that the feed coming out of OCP/ZWR Rudna region is characterized by the lowest resistivity and thus the highest conductivity. Therefore, the use of cathodic protection in the case of OCP/ZWR Rudna classifiers will require providing the largest protection current. It confirms the presence of the largest amount of soluble mineral salts (mainly chlorides) and their corrosive nature as well.

Lower values of conductivity were achieved in the case of mixed feed, which is related to the influence of the output's suspended grains.

Table 1. The conductivity of the spiral classifier's feed.

Ore Enrichment Plant area	Decanted water conductivity (mS/cm)	Mixed feed conductivity (water + solids) (mS/cm)
Lubin	42.0	37.3
Polkowice	45.0	44.4
Rudna	70.4	61.0

Transferring the conductivity results into the amount of dissolved salts, the following figure 5 showing the dependence of seawater resistivity on salinity and temperature can be used. Reading the values from the graph, it can be concluded that the obtained resistivity results ($\sim 0,22 \Omega\text{m}$, measurement temperature $25 \text{ }^\circ\text{C}$) correlate with salt water salinity at 3.0 ‰. It means that in 1 dm^3 of sea water, 30 g of mineral salts is dissolved. Similar values are achieved for the tested samples, which confirms the high contents of soluble salts in technological waters. The result is a high corrosivity of the work environment of spiral classifiers, which determines the use of specific corrosion protection measures.

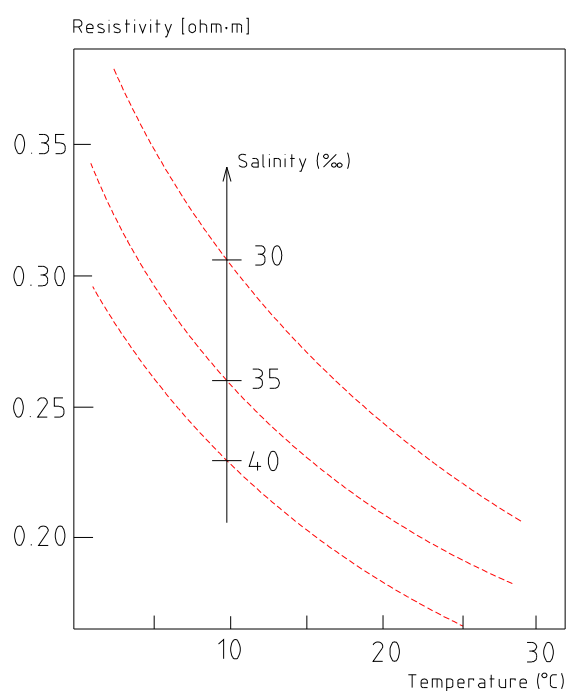


Figure 5. Resistance of sea water as a function of temperature for salinity in the range of 30 - 40 ‰ [9].

5. The concept of implementation of cathodic protection of spiral classifiers

Coatings which are currently used for classifiers protection are inadequate, which results in the necessity to carry out periodic repairs or replacements of complete helices.

Further research into the possibility of protecting these devices, planned for the future will be a combination of passive (a coatings protection) and active method of anti-corrosion protection (a cathodic protection). The selection of the appropriate abrasion resistant coatings will be carried out by the corrosion coupon (metal specimens) testing in the classifier's natural working environment. At the same time, impedance tests in the laboratory test stand will be conducted. The selection of

effective wear-resistant coatings will protect metal elements from the erosive impact of the feed and will significantly reduce the demand for protective current in the cathodic protection system.

Cathodic protection research will be based on the surface polarization of the protected element. The first method will involve the creation of a galvanic link, that is a combination of a structure with a metal of a lower potential, the so-called galvanic anode (protector), the other will entail the flow of protective direct current from an external source, the so-called cathodic protection station (SOK). The ultimate method of protection of the classifier's spiral will be determined on the basis of a detailed analysis of the device operating conditions and initial polarization measurements. With some probability, however, one can point out to the choice of cathodic protection technology using an external power source. This is due to the high current demand for the helix protection and the classifier bath. Presumably, galvanic anodes would not provide enough electricity, because each of them would have a relatively low current. Therefore, it would be necessary to install a large number of anodes, which would be difficult due to the limited space of their assembly.

Cathodic protection is probably the most effective method of preventing corrosion of underwater and underground constructions. At the appropriate assumptions, corrosion processes occurring on the metal surface can be practically stopped, for example up to 0.01 mm per year. At the current corrosion rate of the classifier spiral, which nears 0.3 mm per year [8], the search for effective protection methods seems to be indisputable.

When designing the cathodic protection, it will be necessary to collect data on the protected structure, its surface and the type of metal from which it has been made, as well as the surrounding of electrolytic environment and its corrosion potential. It will be equally important to properly assess the economic aspect of the device's life expectancy. It is significant to research the right selection of the anodes supplying cathodic protection current, as well as conducting a series of studies on the selection of wear-resistant protective coatings cooperating with electrochemical protection.

The scheme of the planned connection of cathodic protection with the use of an external source of protection current is shown below (figure 6). The system will be built from a cathodic protection station (SOK), a cathode and potential connection, an anode system and a reference electrode.

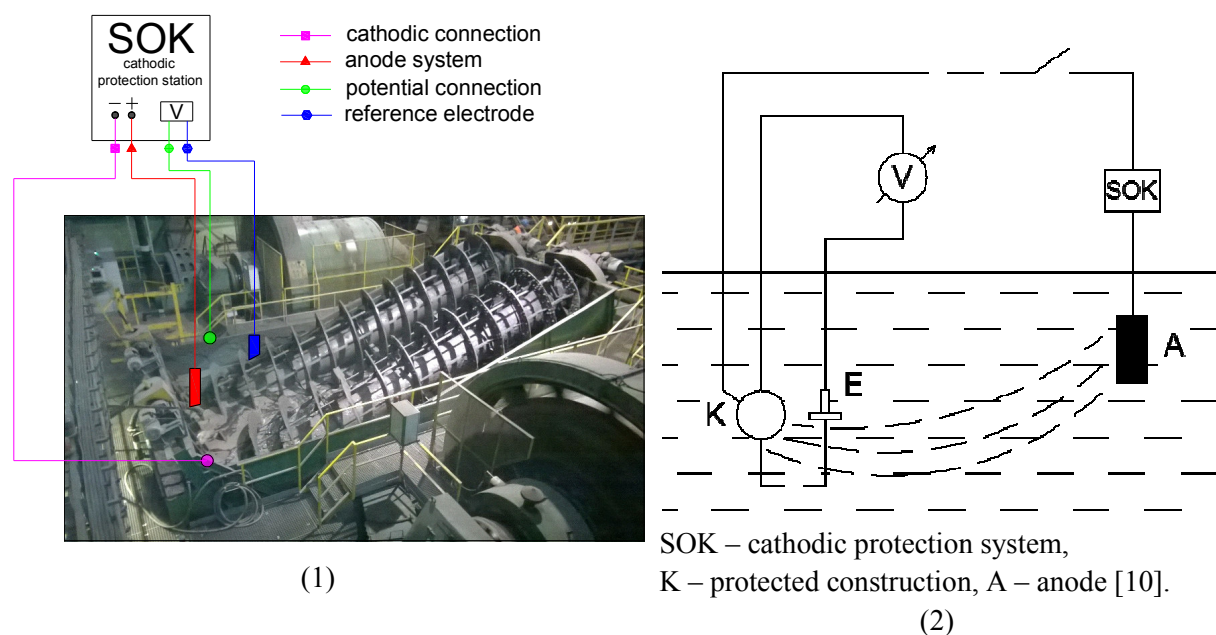


Figure 6. An overview of the planned cathodic protection of the classifier using an external current source – a cathodic protection station (SOK) - real view (1), a schematic diagram (2).

Any type of corrosion protection applied should offer a possibility of assessing its effectiveness in a simple, relatively cheap manner, not requiring long-term research. The first criterion for the effectiveness of electrochemical protection will be the potential measured in relation to the reference electrode, which is placed close to the protected structure. Using the potential measurement, the rate of reduction of the corrosion rate of metal can be predicted [11]. The value of the protective potential should be achieved for the entire surface of the construction, which in the case of spiral classifiers may be difficult due to the fact that the rotating rotor periodically emerges from the electrolyte. Preliminary studies [8] indicate that despite the periodic ascent of the spiral from the feed, the cathodic protection can reduce the corrosion rate of the classifier up to 5 times. Research in this area is due to continue.

6. Summary

The limitation of corrosion processes should be considered in the economic aspect, security issues as well as direct and indirect losses. The effective protection of structures and devices exposed to corrosion will reduce the costs associated with the replacement of the corroded elements, carry out renovation works and, above all, extend the machine and equipment cycles. The elimination of these factors will contribute to the reduction of material loss, improve the safety and comfort of work and allow for the rational management of natural resources.

Therefore, in ore enrichment plants a number of detailed tests should be carried out in order to determine the possibility of effective corrosion reduction through the use of cathodic protection. The choice of the method of protection implementation should be individually adapted to the existing corrosion risk and working conditions of the protected metal surfaces. In order to confirm the effectiveness of the application of the innovative method of machinery protection and processing equipment it is required to develop a detailed protection technology, as well as the implementation and launching of the pilot installation.

An extremely important issue in the application of cathodic protection is the ability to assess the correctness and effectiveness of the actions taken. In addition to periodic check-ups of the installation's operation parameters, it could be advisable to perform additional tests by using corrosive coupons, simulating electrodes, or even resistive corrosion resistance, which determines corrosion loss based on the determined increments of electrical resistance [12]. An excellent complement to control activities should be a comprehensive system of managing the corrosion protection process, in which one should define, among others, the areas of responsibility of cathodic protection personnel [13].

In addition to classifiers, potential devices that can be secured using the methods described in this article include Dorr thickeners and flotation machines. Both devices work in an electrically conductive environment.

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