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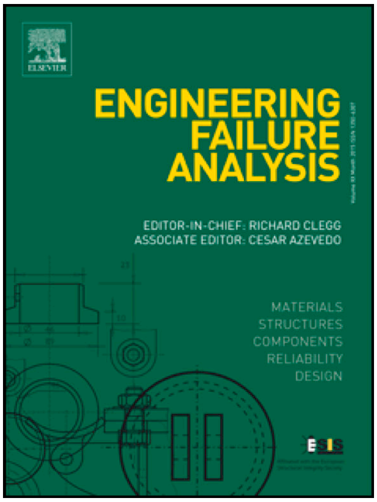

Failures and a concept of corrosion protection system for spiral classifiers at KGHM Polska Miedź S.A. Ore Concentration Plant

M. Czekajło, K. Żakowski

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KGHM Polska Miedź S.A. Ore Concentration Plant

M. Czekajło[1], K. Żakowski [2]

1) KGHM Polska Miedź S.A. – KGHM Polska Miedź S.A. Ore Concentration Plant
ul. Kopalniana 1, 59-101 Polkowice
e-mail: *marcin.czekajlo@kghm.com*

2) Gdańsk University of Technology - Department of Electrochemistry, Corrosion and Materials Engineering
ul. G. Narutowicza 11/12, 80-233 Gdańsk,
e-mail: *krzysztof.zakowski@pg.edu.pl*
ORCID*: orcid.org/0000-0002-9242-3152*

Abstract

The Ore Concentration Plant, where the process of flotation is carried out as well as the final production of copper concentrate, plays a key role in the entire production line of KGHM Polska Miedź S.A. Majority of operations related to the run-of-mine preparation to copper flotation enrichment are carried out in a water environment. The maintaining of production process continuity requires to pursue minimisation of many production limitations. The corrosive action of the technological medium, being a salted water suspension of ground copper ore, is one of them. The concept of spiral classifiers cathodic protection presented in this paper may become an alternative to the anti-corrosion protection methods of machinery and equipment used now at the KGHM.

The obtained results of research indicate a possibility of significant reduction of classifiers corrosion rate at the application of cathodic protection and of a few times extension of the period of spiral classifiers operation, which replacement generates substantial operating costs.

Keywords:
corrosion; cathodic protection; copper ore enrichment; spiral classifiers

Introduction

A multi-stage process of copper ore enrichment is carried out at the KGHM Polska Miedź S.A. Ore Concentration Plant (OCP), to a large extent in a water environment [1,2,3]. The main source of water consists of mine water resources, containing substantial amounts of chloride and sulphate ions.

The 2018 figures originating from the system of chlorides and sulphates monitoring show the presence of chloride ions (Cl^-) at a level of 2.1 g/dm^3, which together with mine waters go to the Lubin OCP Region; 10.3 g/dm^3 to the Polkowice OCP Region, and 106.1 g/dm^3 to the Rudna OCP Region. In the case of return waters from the 'Żelazny Most' OUOW the chlorides concentration exceeds 27 g/dm^3.

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Also sulphate ions (SO_4^{2-}) are another component of salts dissolved in water. Their current concentration in mine waters directed to Lubin and Polkowice OCP Regions amounts to 1.3 g/dm^3, and 2.2 g/dm^3 to the Rudna OCP Region, while the return waters contain approx. 3.2 g/dm^3. The corrosive aggressiveness of water with such a content of chlorides and sulphates is very high [4,5].

Also the atmosphere in the industrial shops is very aggressive in terms of corrosion. The above factors cause fast corrosion of equipment in the Ore Concentration Plants [6]. At the lack of preventive actions this can result in stopping the machinery and equipment and in the necessity for their repair, generating significant costs [7].

Bi-spiral steel classifiers [8,9] are one of strategic components of the OCP plants. Altogether in three OCP production regions 29 pieces of such equipment are in operation. Their task is to separate grains in terms of size and weight in a water environment due to the gravity force action [10,11]. Classification products comprise: overflow (directed to the overflow trough through an overflow threshold, featuring a finer grain) and outflow (brought by so-called spiral to the outflow trough, featuring a coarser grain). Photographs 1÷2 present an operating classifier, which is approx. 12 m long, and the spiral is 2.6 m in diameter.

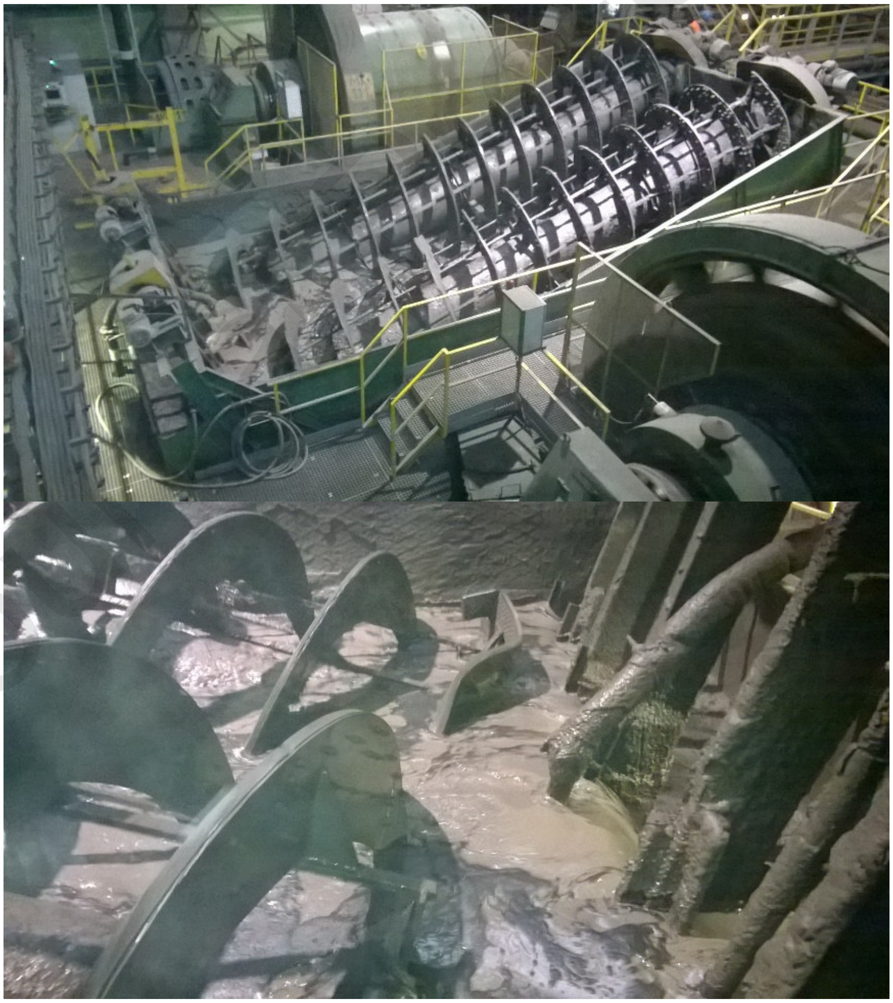

Photo 1÷2. Spiral classifier used in the process of copper ore classification.

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another 3 years the shaft regeneration is carried out as well as the spiral replacement, then the maximum time of its operation at the technological stand is 12 years. Each classifier standstill is related to a standstill of the processing section, i.e. mills and the classifier. The stoppage causes specific difficulties in the enrichment process performance, results in productivity reduction, and generates high costs [12]. Reasons of quick classifiers degradation comprise corrosion and erosion (friction, wear of classifier's spiral by the ground ore contained in the feed). Photograph 3 illustrates the spiral ready to be installed in the workplace, whereas photographs 4÷5 illustrate the view of worn spirals.

Photo 3. The new spiral of classifier.

Photo 4÷5. Classifier's spirals degraded due to corrosion.

Depending on the industrial plant type and its operation conditions and environment, the corrosion degradation of a metal may be reduced by choosing structural materials, applying protective coatings, and applying cathodic protection. The cathodic protection consists in lowering

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technologies for cathodic polarisation current supply: 1) application of galvanic anodes (so-called sacrificial anode cathodic protection) [13], 2) impressed current cathodic protection, i.e. the use of an external source of polarising current, so-called cathodic protection stations supplied from the power network, working with polarising anodes [14]. Galvanic anodes, made of zinc or aluminium alloys, are used in the environment of salty water. In the fresh water environment aluminium anodes are passivated and should not be used [15].

At a greater demand for the cathodic protection current it is more convenient to use an impressed current protection. Most frequently these are polarising devices, automatically adjusting the polarising current intensity in order to maintain the set value of the structure's potential, although it is also possible to control parameters of galvanic anodes operation [16,17]. Polarising anodes are made of materials difficult to solubilise (e.g. high-silicon cast iron), of non-soluble (e.g. titanium, platinum), or exist in the form of a polymer-based conducting coating [18].

A concept of classifiers protection, by the application of cathodic protection together with appropriately chosen protective coating, featuring a high mechanical strength, has been introduced. The coating would work with the cathodic protection - the better the barrier properties of the coating, the lower the demand for cathodic protection current [19,20].

The fact, that coils are not entirely immersed in the electrolyte, could raise some doubts related to the application of cathodic protection to protect the classifier spirals. Spirals make approx. 4 rotations per minute, so individual spiral coils periodically emerge from the electrolyte. However, in the classical application of cathodic protection technology the protected surface of the metal structure is in permanent contact with electrolyte, like at the cathodic protection of underground pipelines and tanks, vessel hulls, or offshore platforms [21]. In addition, the cathodic protection of a classifier would not be 'supported' by calcareous deposits, forming on cathodically polarised structures in the environment of salty process water or sea water. Such deposits are non-conducting, hence they support the protective coating action, resulting in reduced demand for the cathodic protection current [22]. However, in classifiers the feed continuously abrades the surface of classifier components, so the forming carbonates and hydroxides cannot deposit on the cathodically protected metal surface (they are abraded).

The studies presented in this paper were aimed at the assessment of possibilities to apply cathodic protection of classifiers. The protection effectiveness was estimated based on laboratory tests, and also on the basis of trial cathodic polarisation of a classifier operating in one of OCPs.

Material and methods

1) Laboratory tests

The tests were carried out in the environment of feed collected from a classifier operating in a OCP. Rotating wheels, 15 cm in diameter and 2 mm thick, made of carbon steel S235JR were the tested samples. They were so cut and bent as to obtain the effect of friction with particles of crushed

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cleaned with abrasive paper to Sa 2½ degree of cleanness and weighed with accuracy to 0.0001 g.

During the experiment samples were partially immersed in the corrosion medium, as visible in photograph 5, and were rotating with a speed of 4 rotations per minute. Two samples were exposed, each in a separate vessel. One of samples was not protected against corrosion (reference sample). The second sample was cathodically polarised in potentiostatic mode: a potential of +90 mV was maintained vs. a zinc electrode situated at a distance of 2 cm from the sample surface, to minimise the IR drop of potential. In accordance with standard EN-12473: 'General principles of cathodic protection in sea water' the potentials of full cathodic protection of structural steel in salty water environment range from +250 mV to -50 mV vs. zinc electrode. A potentiostat with connected anode made of platinised titanium, with 10x2 cm dimensions, was used for the cathodic polarisation. The exposure time was 4 weeks. Tests were carried out at room temperature.

Photo 5. Samples exposed during laboratory tests of cathodic protection effectiveness. On the left - the sample with cathodic protection, on the right - the unprotected sample.

Comparative values during the experiment:

- potential of unprotected sample: +390 mV vs. the zinc electrode,
- potential of protected sample: +90 mV vs. the zinc electrode,
- the cathodic protection current intensity: on average approx. 12 mA (depending on instantaneous current demand to maintain the set potential value), which taking into consideration the size of surface immersed in the electrolyte gives the protective current density of approx. 200 mA/m^2.

The corrosion rate of samples was determined by the gravimetric method [23]. After testing the samples were rinsed with tap water. Then the corrosion products were removed by means of 10% solution of hydrochloric acid mixed with 9 g/dm^3 of corrosion inhibitor - $(CH_2)_6N_4$. The sample

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corrosion rate was determined from the following relationship:

$$V = \Delta m / (S \cdot t)$$

where: Δm is the mass loss of the studied sample [g], S is the total surface area of the tested sample [cm^2], and t is the time of sample exposure [years].

Then the corrosion rate (V) was divided by the metal density to obtain a linear corrosion rate expressed in a universally used unit [mm/year].

2) Trial cathodic polarisation of a spiral classifier

Tests were carried out on two objects: a non-operating classifier (spirals were not rotating) and on an operating classifier (spirals were rotating). Because of that additional information was obtained about the impact of the feed flow on the object's demand for the cathodic protection current. During the experiment the cathodic protection current was flowing from anodes not only to spirals, but also to the metal tank of the classifier, covered with a few centimetre thick layer of concrete, because all those components are galvanically connected. The measured value of resistance between the tank and the spiral was 0.2 Ω.

Cathodic polarisation of the classifier was carried out by means of a portable microprocessor cathodic protection station with maximum output parameters of 50V/10A and two polarising anodes made of a magnesium alloy in a form of a cylinder weighing 5 kg. Anodes were placed in the corners of a shorter side of the classifier tank, like it is schematically shown in Fig. 1. The negative pole of the station was connected to the classifier tank (cathodic bond). The obtained protective effect was evaluated based on the potential measurements of spirals and of classifier tank under various polarisation conditions. The potential was measured around the whole internal surface of the tank and along both spirals by means of portable zinc reference electrodes and digital multimeters. Measurements of the potential were taken 1 hour after switching on the polarising current flow.

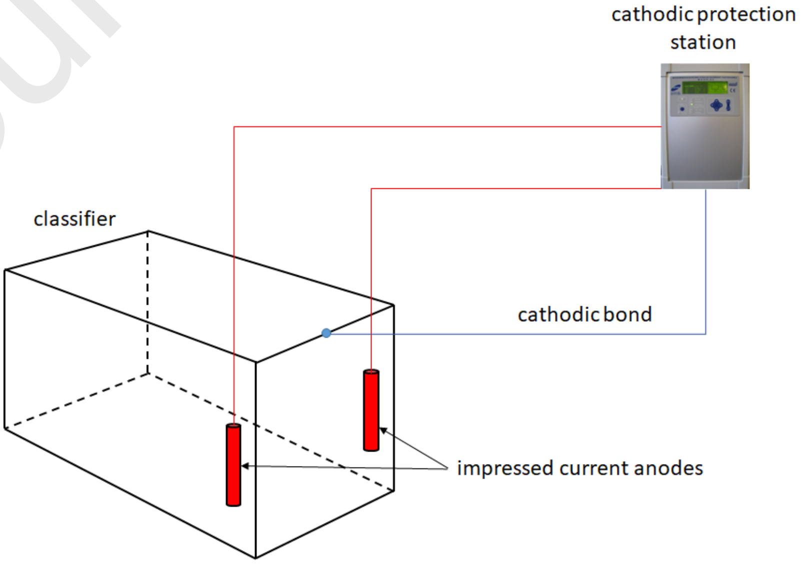

Fig. 1. Diagram of trial cathodic polarisation of classifier.

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1) Laboratory tests

Physical and chemical parameters of the electrolyte, in which the exposure was carried out (i.e. the feed taken from OCP) are specified in Table 1.

Table 1. Parameters of electrolytic environment, in which laboratory tests were carried out.

parameter	value
chlorides content	5960 mg/dm^3
sulphates content	148 mg/dm^3
pH	6.95
conductivity	61 mS/cm
resistivity	16.4 Ωm

Table 2 presents the obtained results of experiment: mass losses of the exposed samples, their corrosion rates, the obtained protective effect, and the cathodic protection effectiveness.

Table 2. Results of laboratory tests.

	unprotected sample	protected sample
initial mass	142.2884 g	133.8262 g
final mass	137.4920 g	133.5832 g
mass loss	4.7964 g	0.2430 g
corrosion rate	V_1 = 0.234 mm/year	V_2 = 0.012 mm/year
achieved protective effect	$V_1 / V_2 = 19.5$	
achieved protection effectiveness	$(V_1 – V_2)/V_1 = 94.9$ %	

2) Trial cathodic polarisation of a spiral classifier

Fig. 2 presents 3D distribution of classifier potential with stationary spirals. The view of potential distribution is presented in the same projection (angle of view) as in Fig. 1. Potential measurements were made under the following conditions:

- without cathodic protection (corrosion potential, reference level),
- at cathodic polarisation with a current of 5 A intensity,
- at cathodic polarisation with a current of 10 A intensity.

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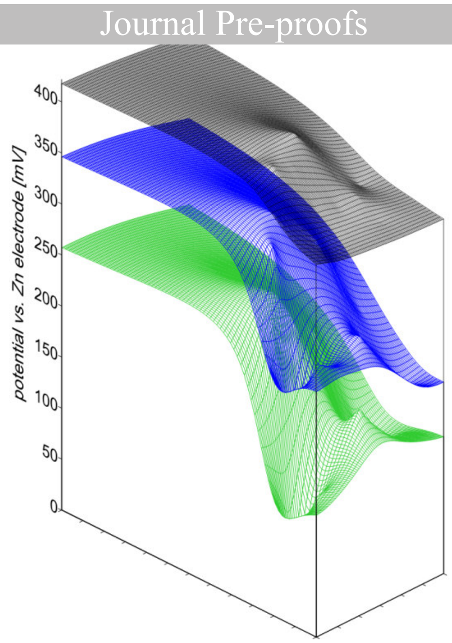

Fig. 2. Potential distribution of the classifier with stationary spirals during trial cathodic polarisation.
black *- without cathodic protection*
blue *- polarising current intensity of 5A*
green *- polarising current intensity of 10 A*

Fig. 3 presents the potential distribution of classifier, which spirals were rotating (normal classifier operation). Measurements were made under the same polarisation conditions as in Fig. 2.

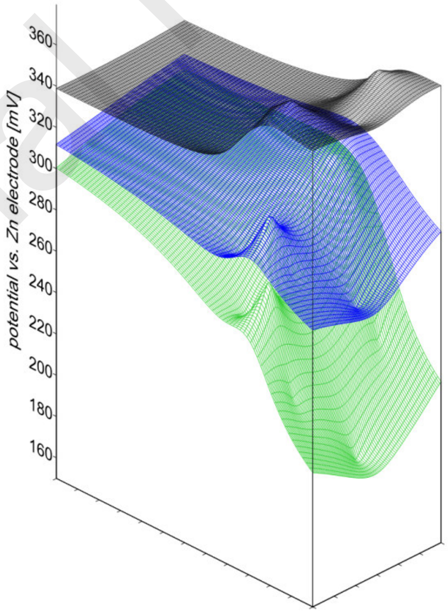

Fig. 3. Potential distribution of the classifier with rotating spirals during trial cathodic polarisation.
black *- without cathodic protection*
blue *- polarising current intensity of 5A*
green *- polarising current intensity of 10 A*

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1) Laboratory tests

The content of chlorides and sulphates in the electrolyte used for laboratory tests and its resulting low resistivity (Table 1) show, that the operating environment of classifiers is very aggressive in terms of corrosion.

The corrosion rate of the reference sample (without protection) was very high and amounted to 0.234 mm/year. The obtained results have shown that the application of cathodic protection decreased this value many times (Table 2). The corrosion rate of the sample polarised to a potential of +90 mV relative to the zinc electrode was only 0.012 mm/year. So the unprotected sample was corroding approx. 20 times faster, than the protected sample. The effectiveness of cathodic protection calculated based on the obtained test results was nearly 95 % at the sample polarisation to a potential of +90 mV (with reference to the corrosion potential equal to +390 mV).

2) Trial cathodic polarisation of a classifier

Figures 2 and 3 show that the corrosion potentials (i.e. before switching on the cathodic polarisation) of both classifiers were different. This resulted, among other things, from a different level of both classifiers metal components corrosion and from various qualities of the concrete coating on the tank surface. The potential of non-operating classifier ranged from approx. 350 mV at the beginning of tank to 420 mV at the tank end (Fig. 2), while of the operating classifier from approx. 360 mV to 340 mV, respectively (Fig. 3).

The turning on of the polarising current flow caused a required change of classifiers potential to more electro-negative values, which resulted in a diminished corrosion rate. The potential change was highest close to polarising anodes (at the beginning of tank), which is typical of cathodic protection installations and results from the density distribution of the polarising current flowing to the surface of the protected object - in general the current density is the higher, the smaller is the distance from anodes.

The amount of classifier potential change was the bigger, the higher was the applied intensity of the polarising current. In the non-operating classifier (Fig. 2) at the beginning of tank (close to polarising anodes) a potential change of approx. 100 mV was obtained at a polarising current of 5 A, while at a current of 10A - approx. 200 mV. At the tank end, where the distance from anodes was the highest, the potential change was approx. 70 mV and 120 mV, respectively. In the operating classifier (Fig. 3) at the beginning of tank a potential change of approx. 100 mV was achieved at a polarising current of 5 A, and of approx. 180 mV at a current of 10 A. At the tank end under those conditions a potential change was obtained of approx. 30 mV and 40 mV, respectively. A slightly smaller change of the operating classifier potential was related mainly to the feed flow through the classifier, higher electrolyte oxygenation due to that, and an increased demand for the cathodic protection current due to that.

In the case of the non-operating classifier, the polarising current of 10 A intensity was sufficient to polarise the entire classifier to a protective potential, that is 250 mV against the zinc

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at these places to a potential of approx. 300 mV, that is the effect of incomplete cathodic protection was obtained. The problem may be resolved by the application of a larger number of polarising anodes situated around the entire classifier.

Conclusions

- The obtained results of laboratory tests show that the cathodic protection of classifiers can be effective even despite periodical emerging of spiral coils from the electrolyte.
- The application of cathodic protection provides a possibility to significantly extend the period of classifiers operation.
- Trial cathodic polarisation of classifiers has shown that it is practically possible to implement cathodic protection of such equipment. The obtained results have shown that it is possible to polarise a classifier to the potential of full cathodic protection.
- The target protective installation should have more polarising anodes situated around the whole classifier tank so as to achieve a more even distribution of the polarised object potential. The application of anodes made in the form of a cable placed on the tank bottom may be another solution, which will ensure even more uniform supply of polarising current to the protected surface.
- The application of protective coatings on the classifier spiral will reduce the demand for cathodic protection current and will facilitate cathodic protection of the protected object.

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Declaration of no conflict of interest

The authors declare that there are no conflicts of interest.

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Highlights

1. Cathodic protection increases the efficiency of the copper ore enrichment process.

2. The use of cathodic protection may extend the lifetime of the classifier several times.

3. The current demand for the bare (without coating) classifiers spiral is about 200 mA/m^2.

4. The cathodic protection system is effective despite the periodic ascent of the spiral.

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The authors declare that there are no conflicts of interest.

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