MINISTRY OF EDUCATION

UNIVERSITY OF PETROȘANI

DOCTORAL SCHOOL

DOCTORAL THESIS

Theoretical and experimental researches concerning the equipment for treating and monitoring polluted waters evacuated from closed and greened mining perimeters and waste deposits

ABSTRACT

SCIENTIFIC COORDINATOR,
PROFESSOR Silviu Marin **NAN,** D. Eng.

PH.D. STUDENT,
ENG. Petrică Dorel **VITAN**

Petroșani 2019

CONTENTS

5.6. Designing monitoring programmes
5.7. Monitoring water bodies in vulnerable areas
5.8. Water bodies
5.9. Monitoring and BAT stipulations concerning the management of mining waste and of residual sediments having resulted from mining activities

VI. Experimental researches in the domain of polluted waters evacuated from the mining waste deposit of the former PREPARATION UNIT in LUPENI – BRANCH 1 (Case study)

6.1. General aspects concerning the geology of Lupeni mining perimeter
6.2. Characteristics of the soil on which the mining waste deposits in the area of Lupeni are located
6.3. Orohydrographical characteristics of Lupeni mining field
6.4. History of the mining waste deposits in the area of Lupeni mining perimeter
6.5. Theoretical and practical researches concerning the geological mapping of the Branch 1 Lupeni mining waste deposit
6.6. Physical and mechanical characteristics of the mining waste stored at Branch 1 Lupeni
6.7. Determining the chemical composition of the mining waste stored at Branch 1 Lupeni
6.8. Geophysical measurements of the mining waste deposit at Branch 1 Lupeni
6.9. Analysis of the data resulting from hydrological mapping
Conclusions

VII. Researches concerning the efficiency of the greening technology applied in the case of acid waters within the perimeter of the former mining exploitation at Boița Hateg. (Case study)

7.1. Process of forming mine waters and their characteristics
7.2. Acid mine waters (AMW)
7.3. Methods for determining acid potential
7.4. Present stage of the knowledge concerning the greening technologies of the waters containing metal ions
7.5. Presentation of the mine waters cleaning station at Boița Hațeg
7.6. Matching the quality of the effluents in emissary with the standards and greening efficiency of the mine waters treatment station at Boița Hațeg

CONCLUSIONS, PERSONAL CONTRIBUTIONS AND PROPOSALS

Final conclusions, original contributions

Romania is the country displaying the highest percentage of mining waste having resulted from the extractive industry, more than 85 % of the total waste (the average in Europe represents about 25 %), having as a source historic mining.

Before 1989, the mining industry in Romania owned a development strategy that relied on the concept of self-support. Its main objective was the providing of the economy with mineral resources with a view to decrease imports. The result of this policy consisted in the oversizing of the mining sector, which directly employed over 350,000 individuals and indirectly included another 700,000 individuals within horizontal industry. After 1990, the state had to support this industry through providing funds from the budget.

Beginning with 1997, Romania's Government started a program of accelerated job decrease in the mining industry. Its objective was to allow re-organizing and restructuring. Shortly after (the period 1997 – 1998), the number dropped by almost 60%. The process found the governments unprepared to face the associated social issues that powerfully manifested within the mono-industrial and mining by tradition areas and the serious problems connected with environment pollution.

The doctoral thesis entitled **"Theoretical and experimental researches concerning the equipment for treating and monitoring polluted waters evacuated from closed and greened mining waste deposits"** is structured in seven chapters.

Chapter I presents the legislation in the domain of mining waste deposits and the inventory of the mining perimeters in Romania where such deposits are located. Although in 2017 a national inventory of the mining waste deposits was carried out, it is necessary to continue the inventory and inspection activities with the stage involving the checking of the data and the getting of supplemental information. It is highly required the implementation of the European good practices and demands in the field of storing and treating mining waste, the revising of the national inventory through drawing out a data base useful to all the authorities that address legislative, inspection, control, regulation or land planning proposals.

In the case of the objectives that are visually considered highly instable, it is necessary that specialized institutes elaborate expertise / researches.

The analysis of the two case studies presented by the Report concerning the inventory and the visual inspection in 2017 at Valea Șesei pond and the mining waste deposit at Berbești shows only the measures targeting the fixing of the shortcomings and not definitive solutions for preventing similar situations.

As far as the new Project of the Mine Law is concerned, a series of non-correlations with essential normative acts have been identified, as follows:

- Decision 856 /13.08.2008, entitled "Management of waste in extractive industry", regulates the administering of waste resulting from prospection, exploitation, underground extraction or quarry exploitation, of greening and storing mineral resources, further called extractive waste.

Article 2, paragraph (2) only refers to "Indirect waste" that result from activities which are adjacent to extraction and which are regulated by Law 211/2011 and HG 856/2002, updated, namely iron, wood, paper, cardboard, petrol waste, oil waste.

- The need for observing similar Directives that refer to waste in the extractive industry and that have not been taken over by Romanian legislation, such as:

  - Decision 2009/359/CE, dated April 30th, 2009, for completing inert waste, in accordance with the application of article 22, paragraph (1), letter (f) of

Directive 2006/21/CE of the European Parliament and Council concerning the management of waste in the extractive industries;

- Decision 2009/360/CE, dated April 30th, 2009, for completing the technical requirements for characterising waste settled by Directive 2006/21/CE of the European Parliament and Council concerning the management of waste in the extractive industries;
- Decision 2009/337/CE, dated April 20th, 2009, concerning the defining of the criteria of classification of the equipment for waste management in accordance with Annex II of Directive 2006/21/CE of the European Parliament and Council concerning the management of waste in the extractive industries.

The main share of the amounts allocated for carrying out works of ecologic reconstruction is detained by financing the ecologic reconstruction works of the mining objectives with associated risks. A special attention should be given to the dangerous evolution of the physical and mechanical phenomena of underground crashing, to surfaces' subsidence or massive landfalls.

As a result of the increased underfinancing of the projects of closure and greening, of the process of reconstruction of the areas affected by mining industries, there are also important risks in the case of the mining areas where mining waste deposits, others than those ranging within the category of dangerous ones, are stored. All these determine delays that regard the carrying out of greening works. Another difficult situation is determined by the uncertain patrimonial condition of the lands on which closure and greening works are carried out; the carrying out of works for modernizing the units for treating mine waters belonging to the Ministry of Economy is influenced by the patrimonial condition of the lands on which such works are located and the delay of this process compromises the greening works already carried out (Ligava Mine, Ciudanovița Mine, Leurda Mine, Țebea Mine, Mătăsari Drăgotești Mines, etc).

Romania owns at present a system for waste management mostly based on storing. A series of difficulties are encountered nowadays as Romania has the largest waste storing rate in the EU (72%), which is much higher than the EU average of 25.6%.

In accordance, the Set of measures concerning the Circular Economy of the European Economy is correlated with Directive 2006/21/CE and includes yearly targets for greening mining waste.

Mining waste display a special condition depending on the category represented (dangerous or non-dangerous). The types of cleaning mining waste pass through are different (mechanical, physical, biological, thermic or chemical processes or a combination of processes applied to mineral resources). Due to the amount of such types of waste and their impact on the environment, they are considered to have a high potential of being promoted in the context of circular economy. This aspect is displayed in Chapter VI, where the possibility of retrieving useful substances from the mining waste deposit at Branch 1 – Lupeni is also considered.

Chapter II gives details on the "Present international stage of the management and monitoring of the closed and greened mining waste deposits." The chapter analyses the stipulations, standards, best practices, techniques used with a view to green acid mining drainage, the techniques used for greening polluted soils as a result of mining activities, techniques of mine closure and remediation of the post-mining areas in the states of the European Union. A comparison with the Romanian legislation is carried out, where, in accordance with legal stipulations, the procedure of getting environment authorisations for activity closing is not tailored for mining activities. There is a common procedure for the closure of all types of activities; yet, the local authority for environment protection does not

own the decisional tools able to settle the required measures and recommendations as part of authorisation procedure.

In Romania, the process of risk evaluation should be carried out by an authorised individual or company and is required by the competent environment authority, in accordance with HG no. 184/1997 of the Ministry of Environment and Waters Administration for the approval of the procedure evaluating the impact of this operation upon the environment. There is no specific procedure regarding the risk evaluation for the mining evacuation units (basins/ponds and mining waste deposits).

Risk evaluation is required by the environment authority whenever a high degree of pollution is discovered at a certain location, which is above the intervention margins stipulated by Romanian regulations, as follows:

Risk evaluation is carried out in two cases (regulation procedures), namely:

- Within the procedure for the issuing of the authorisation.

In the case a general activity is carried out or in the case of a storage activity, the procedure for the issuing of the authorisation observes the stipulations of Order no. 876 / 2004 of the Ministry of the Environment and Waters Administration.

- Within the procedure settling environment obligations.

The competent environment authority issues an Environment Notification, which stipulates environment obligations, in accordance with the study for the risk evaluation and other previous agreements, if applicable, between the operator and the competent authority.

At present, there is no law for this type of procedure; the Law for the Environment Protection in Romania requires a special document for the cases of activity closure, assets sale, fusion, division, bankruptcy, etc.

The incidents connected with the processing sterile are more often in the case of upstream constructions than in the case of downstream constructions. Bulletin no. 121 of UNEP/ICOLD also concluded that the successful planning and administering of the equipment for processing sterile could benefit from:

- The involvement of interested individuals
- Thorough investigations and risk evaluation
- Thorough documentation
- Administration of processing sterile integrated within mine planning, exploitation and closure.

Chapter III displays the mathematical and physical modelling of the phenomena that concern the dispersion of the pollutants resulting from the mining waste deposits through air and water.

The approach of pollution issues requires the elaboration of a series of models of water quality including three important components: temporary decrease, spatial decrease and degree of detailing of the ecological component. It is recommended to define the objectives in accordance with the scheme displayed in this chapter. The transportation and dispersion of pollutants in fluid environments is based on the law of molecular diffusion (Fick's Law) and on the equations of fluids movement (Navier – Stokes equations, continuity equation).

The study of surface waters pollution is based on the geometric representation of the system, owing to null models, one-dimensional models or multidimensional ones, while considering the hydraulic features of the polluted river beds as well as the manner pollutant injection occurs. The development stages in the transportation of pollutants are the following ones: movement of non-stratified fluids, movement at the margin of stability and movement in an advanced mixed stage.

Chapter IV. Researches concerning the methods for the investigation and evaluation of the pollution of the geological environment in the case of the closed and greened mining waste deposits

Generally, a geological investigation includes all the types of specific investigations matching the fields included in the study of the earth: geological, hydrogeological, paleontological, geophysical, geochemical, pedological, etc.

Each of investigation method displays its own possibilities, targets and objectives, its own advantages and specific limitations.

The success of geological methods as a whole for the investigation and evaluation of the pollution of geological environment is determined by the choosing of the optimal strategy for applying various methods in accordance with the target and the conditions encountered.

The use of two or three methods is required with a view to cover all the domains of interest, to carry out an integrated analysis of the data and to reduce the degree of interpretation ambiguity. Meanwhile, the whole system of the geological environment soil – underground waters – geological formations should be investigated both as a whole and component by component.

These are the reasons that grounded the settling of the compulsory minimal set of methods for investigating and evaluating contamination:

- Pedological methods, for finding out the structure and quality of the soil;
- Geological methods, for finding out geological structure;
- Hydrogeological methods, for getting to know the aquifers and their quality;
- Geochemical methods, for finding out the distribution of chemical elements in the geological environment, for identifying and settling the concentrations and distributing pollutants;
- Geophysical methods, for the knowing and spatial distribution of the geological structure of contaminated areas.

The investigation of the pollution of geological environments may be carried out simultaneously with all the methods included within the compulsory minimal set.

Meanwhile, the investigations may be done separately for each method, followed by the synthesis and correlation of the data in the geological report. Considering the possible presence and evolution of the physical phenomena underground, it is recommended that separate investigations should be carried out every two years.

The compulsory minimal set of methods is carried out in accordance with the desired detailing degree, set for each investigation stage.

The compulsory minimal set of methods provides the complex and complete investigation of all pollution existing in the geological environment as well as the knowledge required with a view to found the decisions taken by the environment authorities.

Chapter V. Monitoring the evacuated polluted waters from mining waste perimeters and deposits in accordance with the model for the monitoring of vulnerable areas

Framework Directive for water introduces the notion of “body of water” as an *elementary unit* for the analysis of pressures and impact and for the evaluation of the risk of non-attaining environment objectives. It settles the manner of integrated approaching of monitoring, evaluation and monitoring strategies, designing a monitoring program as well as BAT stipulations for the management of mining waste and of residual sediments having resulted from mining activities.

Chapter VI. Experimental researches in the domain of the polluted waters evacuated from the mining waste deposit at the former Preparation of Lupeni – Branch 1 (Case study)

The mines of Lupeni, Lupeni Sud, Victoria, Carolina and Ileana were opened in 1840 as private assets. The location of the exploitations follows the direction of the outcrop of the productive formation in the Northern - Eastern area of the perimeter.

The deposits of mining waste at the former Preparation of Lupeni were formed through the layering of the stuff owing to funicular equipment in a bumpy area displaying high level differences. At present, there are three branches of mining sterile deposits, with angles of 15^0 between branches 1 and 2 and 40^0 between branches 2 and 3. The storage technology determined the formation of deposits in a single stage, whose geometrical parameters depend on the morphology of the ground's surface, on the elevations where the funicular is located and on the geotechnical characteristics of deposited rocks. During the unloading of the stuff from the transportation buckets, a certain granulometric selection occurs due to the movement of large granules at the basement of the deposit.

Sedimentary and magmatic formations are present within the analysed perimeter. The foundation of the mining waste deposit includes granodiorite and its clay-sandy sediment stuff. The character of the sediment stuff, its thickness and inclining may determine gliding phenomena. The mining waste deposits at branches R2 and R1 are located over sand stones and micro-conglomerate sand stones, including the afferent pelitic and pelitic-sandy sediment stuff.

Due to their lithological character, the slopes of the valleys around the mining waste deposits display a good stability as they are grounded on the stuff stored from Branch 1.

Hydrological, geological and geotechnical mapping resulted in detailed supplemental data at the level of the surface of the area besides the information previously known from the existing technical data afferent to each of the investigated component.

Geophysical measurements showed resistivity contrasts within the body of the mining waste deposit, which display constitutive differences of the mining sterile stuff stored in its natural state, affected by the phenomenon of self-ignition or exhibiting a high level of humidity in contrast with the basic rock.

Water accumulation and circulation on the bed of the old valleys and at the margin between various episodes of storing the stuff of the mining sterile deposit can also be seen. These accumulations and crossing paths within the mining waste deposit represent the source of the emergent at 784m and 774m.

Geophysical measurements offer, for the first time, a possibility of knowing the internal structure of the mining waste deposit of R1.

The gutter on the Eastern side of the mining waste deposit at branches R1 and R2, in the interfluvium of Boncii stream and Ferejele stream is an artificial "water course" created with a view to drain the waters of the lake located between the R1 and R2 mining waste deposits. This path is dug at the base of the stored stuff and through accelerated erosion it destabilizes the eastern side of the mining waste deposit at branch R1 and branch R2.

The surface of the hydrographical basin is crossed by secondary valleys and ravines within the body of the mining waste deposit (widths of 3-6 m and depths of 2-3 m), which become drainage paths for surface waters during the rainy periods.

Seasonal water flows have been mapped along the entire path in order to identify the sediments of iron oxides and calcite. Ferejele and Boncii streams contain in their minor beds, displaying variable widths from several meters to maximum 15 m, fragments that have their origin in the mining waste deposits they drain.

The flows are variable, surface drainage being accelerated by the abrupt slopes of the mountainsides. The stuff belonging to the mining waste deposit washed by the clayish fraction displays a good permeability and allows the rapid drainage of water in the upper part. Both the two main water flows (Ferejele and Boncii) and the two secondary ones have been tested with a view to identifying drained areas and pollution sources.

Chapter VII. Researches concerning the efficiency of the greening technology applied in the case of acid waters in the area of the former mining exploitation at Boita Haţeg (case study)

There are various methods for treating mine waters, depending on the volume of the effluent, the type and concentration of the existing pollutant substances.

The choosing of the cleaning variant relied upon the physical and chemical characteristics of waste waters (acidity, variable concentrations of heavy metals, presence of sulphates over the admitted margin), evacuation flows, technological implications and associated costs, amounts of waste resulted and requirements for environment protection.

In such a case, the greening of mine waters consists in lime neutralization which results in precipitates of Fe hydroxide and other metals as well as plaster ($CaSO_4$). Lime treatment determines pH increase from 6.0 to 8, allowing the elimination of the metals from the solution owing to the decrease of solubility of the metal ions. The required pH for a minimal solubility varies depending on the metal species; nonetheless, most neutralization devices operate at a pH between 9 and 12. Several neutralization agents can be used, such as: lime, as CaO or hydrated lime $Ca(OH)_2$, which is most frequently employed owing to its availability, reduced cost and increased efficiency.

In the case of the mining perimeter at Boiţa Haţeg, mine waters are evacuated along the channel of the gallery through a concrete loading basin, protected against the acids; the waters are then directed towards the reaction basins of the cleaning station. The cleaning station mainly consists in lime dissolution recipients equipped with a propeller mixer, reaction/neutralization vessels also equipped with mixers, where mine waters directly come into contact with the lime solution, a longitudinal decanter for depositing the precipitate and clearing the waters, a mud platform for dehydrating the sediment stored in the decanter.

The process applied determines the advanced precipitation of metals (Fe, Pb, Zn, Cu, Ni, Cd), with an efficiency of over 90% and the providing of remnant values in the soluble stage within the margins admitted by the national legislation (NTPA001/2005), as table 1 shows.

Calcium exhibits values over the admitted margin due to the intake given by pH regulating. In the case of sulphates, no significant decrease is registered due to the increased solubility of calcium sulphate.

Two stage precipitate with whitewash and air instillation would determine the improvement of the features of final effluents, yet, it is more expensive both in terms of investment and in terms of operational procedures.

A variant experienced with positive results, that is allowing the ranging of the treated effluent within the margins imposed at evacuation for all indices, including sulphates and calcium, is neutralization, oxidation and precipitation in a single stage at a pH of 11-12, with whitewash and calcium aluminate in the presence of insufflate air, followed by the re-correction of the pH at 8.5 and the separation of the stuff in suspension.

An efficient treatment implies generating neutral pH water and the decrease of its content of sulphates, iron and other metals to the margins allowed by environment legislation. When choosing cleaning fluxes, the technical, economic, environment performance aspects should be observed.

In order to be attractive, the process should involve decreased costs, should be easily installed and maintained and should result in limited amounts of solid sub-products.

Original contributions

The original contributions of this doctoral thesis, having resulted from the theoretical research and the implementation of a series of technological solutions, are the following ones:

- Ranging the objective of the thesis in the postulates of durable development and circular economy;
- Emphasizing the proposed measures able to contribute to the operationalization of the concept of durable development;
- Proposals for the elaboration of a detailed inventory of all the mining waste deposits on the territory of Romania;
- Identifying new potential dangers at the mining sites where the mining waste deposits are located;
- Analysing national legislation and the European Directives regarding mining waste deposits and concrete proposals to improve legislation;
- Presenting international experience regarding the management of mining waste deposits and identifying methods and solutions applicable to the mining waste deposits in Romania;
- Carrying out mathematical and physical modelling that concern the dispersion of pollutants resulting from the mining waste deposits through air and water;
- Adapting the methods for the investigation and evaluation of the pollution of the geological environment in the case of mining waste deposits;
- Elaborating a monitoring strategy for the mining waste deposits in accordance with the model for the monitoring of vulnerable areas;
- With a view to enlarge the research, two case studies have been elaborated. The mining site of Lupeni, namely the area of the waste deposits closed 20 years ago, was chosen, where, apparently, the stability and water pollution seem not to range within a risk area. For the first time, geophysical measurements offer knowledge of the inner structure of R1 mining waste deposit and points to the existence of pollution. These aspects may represent basic information for improving the site of Lupeni. The second case study was carried out at Boita Hateg treatment station, where proposals for the improvement of the functioning of the station for the greening of technological waters have been made;
- A data base containing photographs and maps of the analysed areas has been created. Stuff that may offer information concerning the construction of mining waste deposits at the former Preparation in Lupeni have been gathered;
- Statistic processing of the results of laboratory analyses, of drillings and their correct interpretation.

The analyses carried out resulted in the following recommendations both for the state institutions that administer the issues of the closed/abandoned mining sites and for the specialists in the mining field:

- Need for reviewing legislation in the domain of mining sterile deposits and for re-evaluating such deposits from the point of view of risks and possibility the retrieve useful minerals;

- Due to the large number of mining waste deposits and to the impact on the environment, they have an increased potential for being promoted in the context of circular economy.