**UNIVERSITY OF PETROSANI**

**DOCTORAL SCHOOL**

# DOCTORAL THESIS ABSTRACT

## THE STUDY OF THE POSSIBILITIES OF RECOVERING THE FUEL MASS FROM THE COAL REFUSE DEPOSITED IN THE JIU VALLEY USING MODERN PREDICTABILITY METHODS

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The economic development of human society as well as population growth have led to the intensification of the degree of use of renewable and non-renewable natural resources. Anthropogenic activities related to the exploitation and valorization of these resources, in addition to progress, have also generated appreciable amounts of residues, polluting emissions and other variables responsible for the degradation of the quality of the environment. Man conquered the entire planet, and the increasing rate of demographic growth led to the appearance of large urban agglomerations, what we call megalopolises nowadays.

Romania's status as a member of the European Union also meant the harmonization of national legislation with the European one, thus transposing a series of directives and laws related to the environment. One of the areas in Romania where the environment suffered from anthropic activities is the Jiu Valley (Petrosani Depression), an area where the main activity was and continues to be coal mining. The purpose of mining in this area was to obtain the highest possible coal production regardless the costs.

In parallel with the development of the coal mining industry, which represented the main economic activity, enterprises of other industries were established in the Jiului Valley, completing the landscape of economic life and boosting the urbanization process. Pollution, an unknown concept before industrial development, has been recorded since the 1950s.

The return to the economic circuit of lands degraded by mining activity, tailings dumps and settling ponds is based on a complex of works that primarily refers to reclamation of the affected surfaces from a mining point of view. Through the restoration works, the previous economic potential of the area must be reached. Land restoration must become an integral part of the mining activity and not a post-mining treatment with additional costs. The recovery of the areas abandoned by the mining activity is an increasingly important necessity requested by the mining companies, local administration, and the legislation, but above all by the inhabitants of the respective areas.

The tailing dumps of the coal preparation plants in Jiu Valley can constitute reusable secondary resources, at least from the point of view of the possibilities of recovering the fuel mass. There is also interest from the point of view of their energy potential, in the tailings dumps and the three settling ponds used for decanting the sludge from the former Coroiești processing plant. Samples were collected from the dumps and ponds and analyzes were carried out to determine the physical-mechanical characteristics of the deposited tailings.

In order to be able to decide on the opportunity of investments in the valorization of the energy potential of these coal wastes, samples were also taken from the tailings dump from the Lupeni Preparation (branch II) and densimetric analyzes were carried out. This

location was chosen because in the western area of the basin, the coal has superior characteristics in terms of quality and calorific potential.

The purpose of this study, which constitutes the essence of the doctoral thesis, is the development of an integrated system of analyses and processing of their results, for the determination of the quantitative and qualitative characteristics, and the processability of a material with a combustible fraction content (coal), as well as finding the most appropriate technologies for its processing with optimal efficiency.

In Chapter 1 GENERAL PRESENTATION OF THE JIUVALLEY COAL BASIN, the landforms of the area are first presented, highlighting the fact that hill formations occupy the largest area of approximately 70%. Next, a series of issues related to climate and hydrography are addressed. Special attention is paid to the geology of the Petroşani Depression, highlighting the geological periods of formation of the sedimentary deposits here. Thus, the cover deposits of Neozoic origin can be divided into five lithostratigraphic strata. The geological works of prospecting, exploration and exploitation of coal highlighted the existence of a number of 20-22 coal seams, all being located in the productive horizon 2. At the end of this chapter, a series of aspects related to the flora and fauna of the Jiu Valley are presented.

The second chapter of the thesis is entitled SOURCES OF ENVIRONMENTAL POLLUTION AND THE ASSESSMENT OF THE IMPACT OF THE ANTHROPIC ACTIVITIES IN THE JIU VALLEY. At the beginning of the chapter it is shown that the assessment of the soil quality in the Jiu Valley can only be done following the quantification of the land surfaces that are occupied by different deposits such as those containing household waste, abandoned quarries, mining premises and constructions, tailings dumps as well as the settling ponds. The analyzed deposits and lands can be categorized according to their composition, their stability (stable, relatively stable and unstable) as well as the their status (in use or conservation).

The tailings dumps resulting from underground and surface mining operations are in use in a percentage of 44.56% (92.69 ha) and in conservation in a percentage of 55.44% (115.15 ha). From the point of view of stability, they are stable in percentage of 45% (92.93 ha) and relatively stable in percentage of 55% (114.91 ha). The tailings dumps resulting from the coal preparation plants are in use in a percentage of 99.85% (66.60 ha) and in conservation in percentage of 0.15% (0.10 ha). They are stable in a percentage of 3.7% (2.50 ha) and relatively stable and unstable in a percentage of 96.3% (64.20 ha). The high percentage of tailings dumps that show instability or relative stability characteristics, makes these formations exert influences on nearby lands with an area of 51 ha.

The settling ponds for sludge and thermal power plant ashes, represent another source of soil pollution in the Jiu Valley. By depositing the tailings under water, these ponds can be considered artificial deltas. This aspect makes the distinction between settling ponds and tailings dumps.

Chapter 3 is entitled CURRENT STATUS OF THE TAILINGS DUMPS AND SETTLING PONDS RESULTED FROM COAL EXTRACTION AND PROCESSING ACTIVITIES IN THE JIU VALLEY. In its first part the status and general characteristics of the tailings dumps in Jiu Valley are presented. Thus, currently there are 49 tailings dumps, 17 of which are functional and 32 are under conservation. They accumulate a total waste volume of approximately 41.6 million $m^3$, occupying around 274.54 ha of land. About 51 ha of land is added to this area, representing the directly influenced area. The content of these dumps in Jiu Valley is coal refuse, which is an unusable material resulting from the underground coal exploitation and processing activity, transported and stored in the dumps with the help of the funiculars.

The preliminary analysis of the studies carried out over time, leads to the conclusion that only the tailings dumps from the three former coal processing plants are of interest for further valorization. In this regard, samples of material dumped on the funicular branches of the preparation plants were collected, mainly where the probability of the presence of the valuable combustible mass is the highest. At the same time, considerations related to accessibility were taken into account for a possible valorization of the dump. The samples were collected from the dump on branch IV of the Petrila funicular, the dump on branch II of the Coroieşti funicular and the dump on branch II of the Lupeni funicular. For these three dumps, the geometric characteristics are presented, which refer to the length and width of the lower and upper part of the dump, as well as the average height. In the Thesis, the main physical-mechanical characteristics of the samples collected from the dumps are highlighted: the granulometry and the main physical properties, as well as the contents of macro-elements present in the samples from the three dumps under study.

Next in this chapter, the main physical-mechanical characteristics of tailings stored in settling ponds are presented. In this context, the two ponds from the Coroiesti Coal Preparation Plant - a plant that processed the coal from the Vulcan, Paroşeni, Aninoasa and Livezeni mines - are taken into account. Here, following the flotation process of the raw waste, thickened sludge results, which settles and is stored at the bottom of the ponds.

The results of ash contents and calorific power for the drillings carried out at different points of the ponds, highlighted that the upper layers (up to a depth of 3 m) are valuable and can be exploited for the high coal mass they contain. Based from the opportunity to capitalize

on the sludge stored in settling pond I, sections A and B, the exploitation and recovery of coal sludge began in 2012. In the thesis the technological flow applied for the recovery of coal slurry was presented. This recovery technology consists in removing the clay (ultrafine fraction) from the stored material, through two steps (screening and hydrocycling), after the mandatory attrition operation (removal by friction of the superficial clay stuck to the coal particles). The raw material was extracted from the pond using a dredging rig attached to a floating pontoon. The quality of the sludge delivered to the thermal power plants had calorific values higher than 3,200 kcal/kg, and the humidity of the sludge loaded was in the range of 12-14%. In the final part of this chapter, the problem of the slope stability of an embankment section of the Coroieşti settling pond using was addressed using numerical methods. Studying the stability of slopes is essential for the predictability of settlements, deformations and landslides due to different mechanical loads, being important for safety reasons. Regarding the pore pressure in the soil, the model adopted to analyze the stability of the embankment section is based on Darcy's law. The Mohr-Coulomb criterion is used for the elastoplastic analysis of the simulated model. The method used is the Shear Strength Reduction Method, where the material parameters (Mohr-Coulomb) are functions dependent on the shear resistance reduction factor. Decreasing the value of the material parameters in proportion to the reduction factor, causes a reduction in the shear strength of the soil, thus producing slope collapse for a given combination of loads. Two scenarios were considered: the first refers to the embankment section of the pond in its initial state, while the second refers to the current situation when sludge was deposited on the bottom of the pond with the passage of time. The COMSOL Multiphysics software package was used to solve the two models, which has a powerful geomechanics module. Since according to Darcy's law, the hydraulic conductivity has a random character, its definition was made by means of a probability function with normal distribution, having two parameters and a standard deviation of 0.001. The steps of the simulation are standard for a study using COMSOL Multiphysics: defining the simulation parameters, defining the variables, building the model geometry, establishing the loaded, fixed and mobile surfaces of the geometry as well as imposing the characteristics of the finite elements mesh.

Chapter 4 of the Thesis is entitled THE STUDY OF THE POSSIBILITIES OF RECOVERING THE FUEL MASS FROM THE COAL REFUSE AFTER PROCESSING. The study of the possibilities of recovering the combustible fraction from the tailings after preparation, involves establishing the characteristics of the material stored in the IV Petrila, II Coroiesti and II Lupeni branches of the tailings dumps of the respective preparation plants. These branches were chosen due to the fact that they are accessible for sample collecting and

also representative of the material stored over time. Performing the analyzes allows establishing the storage branch that has the highest content of combustible mass as well as the amount of coal that can be recovered following a processing flow that leads to a recoverable product with a calorific value of 3,600 kcal/kg. The chapter presents a laboratory processing scheme of material samples belonging to the 40 mm class. The scheme has two circuits, one of them additionally has the crushing operation, in addition to the homogenization and reduction operations. The application of this scheme leads to obtaining samples for granulometric analysis and weighted samples for densimetric analysis.

The granulometry variation diagrams for the +40 mm class after crushing and for the -40 class after classification were plotted for the three dumps. Thus, the reprocessing of the tailings must be carried out following a preliminary classification that eliminates the class larger than 80 mm. This class has a very low content of combustible material, being made up of mineralogical components that are more resistant than coal to granulometric degradation. As a work variant, the reverse clogging method for the recovery of granules that still contain coal mass can be considered.

For the tailings from the Lupeni dump, even the +80 mm class has a relatively high proportion of combustible material. Its utilization requires reverse clogging and crushing in order to introduce the material into the circuit of under 40 mm classes. At the same time, starting from the results of the granulometric and the ash content analyses, the share of the 0-40 fractions and + 40 mm fractions, their ash content, the calorific value by class, and the average for the branches of the dumps with the highest energy potential were calculated.

The raw coal subjected to preparation is in the form of coal and shale association in the most diverse proportions, starting from clean coal to almost clean tailings. These associations directly influence density and default ash content. Since the preparation methods applied are gravimetric ones, based on the difference in density between coal and tailings, the distribution of the various coal fractions according to density (ash content) and therefore of the preparation possibilities, is done using densimetric curves known as Henry–Reinhard (H–R) charts, also called washability curves.

The values of the densimetric analysis of the samples represented the calculation basis for the manual drawing of the Henry–Reinhardt (H-R) charts. These are used to establish the theoretical preparation indices. For the three tailings dumps analyzed, the non-recoverable waste fraction that should be removed through a new preparation process, the weight of the recoverable densimetric fractions and the theoretically possible results (extraction by weight and the corresponding average ash content) are presented in the case of waste separation at a

density of 2.2 kg/dm3. Based on the results of these densimetric analyses, the curves for the three dumps were calculated and plotted.

Next in this chapter, a case study was presented, regarding the possibilities of recovery of the combustible fraction from the tailings of Lupeni Halda II dump. For each section of the dump, four points were chosen to collect samples, which were further prepared by homogenization and quartering. A technological scheme is presented which allows to obtain from the dump an energetic coal with 41.6% ash content and a calorific value of 3,600 kcal/kg. In the last part of this chapter, a series of proposals for the ecological reconstruction of the areas affected by tailings dumps are presented.

In Chapter 5, entitled COAL PROCESSING TECHNOLOGIES AND PREDICTABILITY METHODS OF THE TAILINGS DUMPS PROCESSING RESULTS FROM THE LUPENI, COROIESTI AND PETRILA COAL PREPARATION PLANTS, coal processing technologies are first presented. It was shown that in order to obtain coal to the quality required by consumers and to exploit it with increased economic efficiency, it must be subjected to a complex of mechanical operations known as preparation. It was emphasized that the study of the physical-chemical properties of the coals correlated with their structural parameters is of particular importance in establishing the most appropriate variant of their valorization and use. The physical-chemical properties of the coals depend on the genetic material and the carbonization conditions, thus on their chemical composition and structure.

Next, the quality conditions imposed on coal concentrates are analyzed. From the point of view of the preparation, the quality of the concentrate is important both in terms of its content in basic combustible substance, but also the content of other substances that can have a positive or negative effect in the combustion process. At the same time, a decisive role in the combustion and heat transfer process is played by the granulometry and the humidity of the coal. Regardless of the complexity of coal processing technologies, they present a series of general characteristics that must be well known before their adoption and application in practice. In this sense, the main characteristics of coal processing technologies are presented, as well as a processing flow with the corresponding preparation procedures. For the processing of small and fine grades of coal, the complexity of the technological preparation process is highlighted schematically.

Preparability was defined as the behavior in the process of preparing a certain type of useful mineral substance. This is established on scientific bases and changes over time depending on the geo-morphological characteristics of the deposit, the selectivity ensured by

the exploitation methods applied underground, the exploitation depth, the correlation of the opening and preparation works of the deposit with those of exploitation.

Variations in the quantity and quality of the washed coal depending on the ash content of the raw coal are determined with the help of graphical representations called abacuses. To trace them, it is assumed that in a certain period of time, the raw coal preparability remains constant. This allows H-R washing curves to be plotted for any ash content of the preparation plant feed. Keeping the values of ash content per density fractions constant, the weight extractions of material per density fractions are recalculated, applying a correction coefficient k. This coefficient can be subunitary or superunitary depending on the ash content to be considered for the calculation.

An increased accuracy of the abacuses requires the drawing of a large number of washability curves. This requires the use of numerical methods for calculating and plotting H-R curves and abacuses. The solution proposed in the thesis is represented by a package of programs written in C language. It allows the calculation and plotting of the H-R washing curves for any type of raw coal for which the results of the densimetric analysis are known, as well as the calculation and plotting of the variation abacuses of the theoretical recovery as a function of raw coal and washed products ashes.

Next, the program package intended for plotting H-R curves is described. The first program of the package manages the tailings dumps that are subject to analysis and allows adding new items to the file (waste dumps) as well as editing and deleting already existing items. The second program is the one that manages the files of values corresponding to weight extractions by density fractions and values corresponding to ash contents by density fractions corresponding to each dump. For the washing curves plotting program, the corresponding structural logic diagram is presented and described. The program allows drawing the H-R curves and calculates the points corresponding to the δ, y, c and b curves (abscissas and ordinates of the interpolation nodes) after which it displays the obtained results. The drawing of the four listed curves is done by interpolation with cubic spline functions.

Based on the washability curves, through a series of calculations, the abacuses are obtained, which are the basis of the methodology for establishing the organic yields, which is the main indicator for assessing the operation of any preparation plant.

The doctoral thesis includes the original part of the development of abacuses based on written computer programs that allow the processing of all stages of calculation and graphic representations up to the final phase of drawing the abacuses for any type of material subject to processing.

By developing this methodology, a modern approach is applied for the assessment of the preparation results, eliminating subjectivity and approximations in establishing the probable results.

The future directions of research aim at two aspects that are related to the topic and the results obtained in this doctoral thesis. First of all, the simulation of the slope stability of the embankments of the settling ponds from the former coal preparation plants in the Jiu Valley, creates the premise for continuing research in this direction by approaching the theory of fluids with non-Newtonian behavior and the thixotropic phenomenon applicable to the product resulting from decantation.

The second research direction refers to the study of the stability of the slopes of the landfills as a result of pre-fracturing phenomena due to water infiltration.