Economic Analysis of the Application of the Technological System for Removing Suspended Solids from Mine Drainage Waters

Jolanta Gumińska 1, Franciszek Plewa 2, Aneta Grodzicka 2, Adam Gumiński 3, Magdalena Rozmus 4,* and Dariusz Michalak 4

1 Faculty of Energy and Environmental Engineering, Silesian University of Technology, Akademicka 2, 44-100 Gliwice, Poland; jolanta.guminska@polsl.pl
2 Faculty of Mining, Safety Engineering and Industrial Automation, Silesian University of Technology, Akademicka 2, 44-100 Gliwice, Poland; franciszek.plewa@polsl.pl (F.P.); aneta.grodzicka@polsl.pl (A.G.)
3 Faculty of Organization and Management, Silesian University of Technology, Akademicka 2, 44-100 Gliwice, Poland; adam.guminski@polsl.pl
4 KOMAG Institute of Mining Technology, Pszczyńska 37, 44-101 Gliwice, Poland; dmichalak@komag.eu
* Correspondence: mrozmus@komag.eu; Tel.: +48-32-2374-621

Abstract: This paper presents the results of the technological and economic analysis of mine water treatment systems before their discharge into the environment. The following analysis enabled us to determine the profitability of the investment, taking into account the TSS (total suspended solids) concentration in mine water. The simulation results showed that it is economically profitable to apply a water treatment system if natural sedimentation carried out in underground mine water passages, or in sedimentation tanks located on the ground, is ineffective for TSS removal. Economic and financial parameters allow us to conclude that all analyzed variants of the application of a pre-treatment system are characterized by high economic effectiveness. This mainly results from the high profitability of an analyzed investment, comparatively low capital expenditure, and present low market percentage rates. The most profitable variant (TSS concentration is 1000 mg/dm$^3$) brings significant economic indicators, i.e., high NPV–Net Present Value (100 319 270.28 PLN), a high NPVR–Net Present Value Ratio (8.96 PLN/PLN), and a short discount payback period (1 year 236.6 days). A high internal rate of return (157.8%) for this variant reduces the risk of losing profitability in a situation of growing capital costs in the monetary market.

Keywords: economy; mineral resources; management

1. Introduction

The exploitation of hard coal and the resumption of the abandoned coal mines are connected with the compulsory drainage of underground aquifers and the disposal of mine water into the environment, causing a serious hazard to the ecosystem. Mine waters are characterized by high salinity, suspended solids, and sometimes, the presence of heavy metals and radioactive isotopes. Coal mines systems monitoring the quantity and quality of drainage water are limited to monitoring the concentrations of chloride and sulphate ions and total suspended solids (TSS). The monitoring processes of mine water discharged into the environment are crucial to ensuring the good ecological status of surface waters. Actions to achieve this goal are aimed at the reduction of the amount of discharged mine water to the main water body and reduce the concentrations of priority substances, which are especially dangerous for the environment. The impact of mine water discharged to water reservoirs is assessed based on acceptable limit values for the selected pollutants. It should, however, be considered that the physical-chemical analysis provides information only regarding the threshold content of contamination. It is extremely difficult to predict the impact derived from their migration to the environment. As mine water contains...
different contaminations, an environmental risk assessment undertaken for mine waters, is desirable. Only by considering the reactions of the living organisms that inhabit the endangered ecosystem, is it possible to assess the consequences caused by the discharge of mine water into surface reservoirs. Aiming to minimize the environmental hazard, appropriate technologies of mine water treatment should be applied [1–17].

In most hard coal mines, the removal of total suspended solids from underground water pumped onto the mine surface is carried out in sedimentation ponds. These ponds are usually designed for a 2-day hydraulic retention time (HRT). This time is sufficient to remove suspensions from mine water before it is discharged to the receiver body. According to the current regulatory requirement (regulation of the Minister of the Environment on 18th November 2014 regarding the conditions that must be met during the discharge of waste into water or ground), the total suspended solids (TSS) concentration in water discharged to the environment should not exceed 35 mg/dm³. If this value was exceeded, the mines would be charged by increased environmental fees.

According to many researchers, the use of sedimentation tanks to remove total suspended solids requires best management practices (BMP) of the design and operation guidelines to achieve designed TSS removal. The BMP guidelines provide information for instances where settling aids are required and estimates the TSS concentration in water after the sedimentation process [18–23].

The removal of mineral suspension from the groundwater is not a problem, as long as it is possible to precipitate the suspension in sedimentation ponds with a hydraulic retention time that guarantees the required suspension concentration. However, over time, the capacity of the settling pond decreases due to its gradual decrease of available volume. In such a situation, obtaining the required residual TSS is more and more difficult, and the excessive TSS concentration is very significant, which often forces organizations to either clean the settling ponds or to build new ones if the location and economic conditions favor such a solution.

In some mines, due to the lack of surface water sedimentation ponds, the process of TSS separation is carried out in underground passages, which act as surface water sedimentation tanks. However, due to a significant increase in the amount of mine water, the water retention time in mine passages may turn out to be too short and will not obtain the required residual TSS concentration. Moreover, the process of separation is difficult to carry out due to the fact that mine waters also contain undefined substances, the source of which may be other sewage, which significantly impedes the sedimentation process of suspension solids.

The existing location conditions often encourage, both due to the estimated size of the installation and the possibility of controlling the treatment process, the construction of a ground water treatment system on the surface of the coal mine area. In this article, based on the assumed hard coal mine exploitation data, the cost of operation and construction of TSS removal treatment installation in relation to the cost of mine water discharge directly into the environment were analyzed. This analysis does not concern other types of contamination.

2. Material and Methods

Two systems of mine water disposal were analyzed. The coal mine where the research was conducted is located in Upper Silesia. The first system was based on flocculation and sedimentation processes before the water was discharged into the river. The treatment installation was constructed as a result of the technological research (on a pilot scale) carried out in one of the hard coal mines. The second system was direct water disposal into the river without pretreatment processes. The comparative analysis of both systems enabled us to determine the effectiveness of technological pretreatment and to estimate the scale of water environment contamination resulting from the direct mine water disposal. To assess the profitability of the introduction of mine water treatment in flocculation-sedimentation processes for TSS removal before disposal to the river, discount methods were used. The
profitability of the investment was analyzed in terms of reducing the costs that would be incurred in the case of direct water discharge to the receiving body.

2.1. The Technological Treatment System of Coal Mine Water

The aim of the research in a semi-technical installation was to determine the dose flocculant and the hydraulic parameters of the treatment system operation to obtain the required, permissible concentration of the suspension in treated water at the normative concentration of 35 mg/dm$^3$. Due to the high variability of TSS concentration in water supplied to the treatment installation, the tests were repeated several times to determine the relationship between TSS concentration and the reagent dose, and hence the required scope of the process control. The flocculation time and the hydraulic load of the settling tank were also determined to obtain the expected TSS concentration in the treated water, regardless of the level of contamination.

At the first stage, the laboratory study was carried out. At that stage, 6 commercial coagulants and 4 polyelectrolytes (flocculants), including 3 cationic ones, were tested. The effectiveness of coagulation with the simultaneous dosing of the selected coagulant and polyelectrolyte was also analyzed. A total of 15 reagent configurations were tested. Coagulation was performed by the jar tests method with the use of a six-beaker flocculator. In the first step, the optimal dose of each of the tested reagents was established. The process involved rapid mixing in various reagents doses (1 min, 200 rpm), then slow mixing-flocculation (15 min, 50 rpm), and 30-min sedimentation. After the sedimentation process, the quality of treated water was analyzed in each sample, e.g., based on turbidity measurement, which can be taken as an indicator of the number of suspended solids. Based on the results of these tests, the optimal dose of the reagent was selected. For the sample in which the optimal dose was applied, the sedimentation tests were carried out in the Imhoff sedimentation cone. According to the methodology of this test, measurements were made after 2-h of sedimentation. Taking into account the cost of the reagents, sedimentation properties, as well as the amount and structure of the sediment, the best results were obtained for the cationic polyelectrolyte, and this reagent was tested in a semi-technical treatment installation. At the second stage, the pilot testing was carried out in the combined chamber, which enabled us to carry out coagulation, flocculation, and sedimentation processes in one device.

The treatment technology system to be applied on a technical scale was established on the basis of the achieved results of the laboratory tests and a semi-technical scale study. The semi-technical treatment system was tested in a selected hard coal mine in 2018, and on the basis of the research results, the technological, and hydraulic parameters of the unit treatment processes necessary to design a full-scale treatment system were determined. The research has shown that TSS sedimentation without any reagent dosing is ineffective. Spontaneous sedimentation was observed after only 24 h. The aim of the treatment processes carried out in the selected coal mine was to obtain post-coagulation flocs susceptible to sedimentation in a time significantly shorter than the time required for effective removal during spontaneous sedimentation carried out in water passage. The predicted system HRT is estimated to be less than one hour. Taking into account the cost of various tested reagents (coagulants and flocculants), sedimentation properties, as well as the amount and structure of the sludge, the best results were obtained with the use of a flocculant-cationic polyelectrolyte. The use of this reagent would be advantageous in the case of possible coal particles recovery, as this flocculant has no negative impact on the composition of the sludge and its energetic properties, which would have to be considered while using aluminum salts. Based on the study results, the following assumptions for the design of the flocculation–sedimentation treatment system were made:

- TSS concentration in pumped water: 250–1500 mg/dm$^3$ (depending on the water retention time in the underground passage);
- Nominal capacity of pumps feeding the treatment system: (480 m$^3$/h);
• 2-pumping periods in a day, for 5 h each, which corresponds to 4800 m$^3$/d of the total daily amount of pumped water.

Based on the above assumptions, the optimal mine water purification installation of nominal capacity equal to the pumps’ capacity (480 m$^3$/h) was adopted. On a technical scale, during pumping, water will be directly supplied to the treatment system. The installation of a combined flocculation and sedimentation chamber is presented in Figure 1.

![Figure 1. The installation of a combined flocculation and sedimentation chamber; (1—flocculation chamber; 2—settling tank; 3—system of lamella plates; 4—clarified water installation outflow).](image)

Polyelectrolyte is to be dosed into the flocculation chamber. The flocculation chamber is equipped with a medium-speed mixer. From the flocculation chamber, water flows by gravity to the settling tank. The settling tank is equipped with a system of lamella plates that enhance sedimentation and a slow-speed mixer installed to improve the efficiency of sediment thickening. Installation of a slow-speed mixer in the settling tank is not required for the correct operation of the installation. The clarified water is discharged through the installation outflow trough to the outflow pipeline transporting the purified mine water to the receiver. Sludge from the bottom of the sedimentation tank is fed to the 50 m$^3$ sludge retention tank by means of transfer sedimentation pumps, from which, after 12-h thickening, it will be transferred to filter presses. On the basis of our own research conducted in 2017–2018, the calculated amount of sludge, measured in kg of dry matter of sludge (d.m.s.), for the assumed average TSS concentration of 1000 g/m$^3$, is exactly 4.8 t d.m.s. per day. It is necessary to use a flocculant for proper sludge dewatering. The conducted tests showed that it is possible to use the same flocculant for sludge dewatering as the flocculant used in the main treatment train. The dewatered sludge from the filter press will be discharged onto a car trailer, from where it will be directed for disposal. It is assumed that the amount of hydrated sludge should be approx. 8–14 m$^3$/d.

The basic devices and basic consumers of electricity of the proposed installation include:
• The combined flocculation and sedimentation chamber with lamella plates;
• The installation for storage, dissolving and dosing of polyelectrolyte;
• Sludge pumps from the sedimentation tank to the buffer tank;
• The sludge buffer tank;
• Sludge pumps from the buffer tank to the filter presses;
• Filter presses with complete equipment.

2.2. The System of Mine Water Discharged Directly into the Environment (with Pretreatment)

Three variants of water discharge into the river, preceded by pretreatment, were subjected to economic analysis:
• Variant 1—the water disposal to the river for TSS concentration exceeded the normative value by 1000 mg/dm$^3$;
• Variant 2—the water disposal to the river for TSS concentration exceeded the normative value by 500 mg/dm$^3$;
• Variant 3—the water disposal to the river for TSS concentration the normative value exceeded by 200 mg/dm$^3$.

For the above variants, the costs incurred by the mine in the case of direct discharge of an excessive TSS concentration are an increased fee for exceeding the conditions of the water-legal permit in the scope of suspension concentration-4.87 PLN/kg (Regulation of the Council of Ministers of 27 December 2017 on the setting of increased fees for exceeding the conditions for discharging sewage into water or into the ground).

3. Estimated Economic Input Data for the Profitability Analysis of the Application of Pretreatment System before Water Discharge to the Receiver Body

The estimated CAPEX (Capital Expenditure) of the investment of the treatment installation is 11,200,000 PLN. The CAPEX cost is based on the valuations and offers collected during the implementation of the investment with a similar technological and technical scope and system efficiency. The detailed list of investment costs is presented in Table 1.

Table 1. The investment cost of the treatment installation.

| Id. | The Element of the Capture Expenditure | Cost, PLN |
|-----|---------------------------------------|----------|
| 1   | Executive project                      | 450,000  |
| 2   | Building                               | 5,200,000|
| 3   | Installation of flocculation and sedimentation | 730,000  |
| 4   | Sludge transport pumps from settling tank to sludge tank (2 units) | 105,000  |
| 5   | Sludge retention tank V = 50 m$^3$    | 105,000  |
| 6   | Pumps for feeding presses from the sludge tank (2 units) | 120,000  |
| 7   | Installation of sedimentation unit with piping | 210,000  |
| 8   | Installation for digesting and dosing flocculant | 127,000  |
| 9   | Filter press with auxiliary installations | 650,000  |
| 10  | Installation of the filter press       | 90,000   |
| 11  | Receiving pipeline to the receiver     | 150,000  |
| 12  | Electrical power supply for the treatment plant | 800,000  |
| 13  | Making the connections                 | 375,000  |
| 14  | Internal electrical installation       | 120,000  |
| 15  | Control cabinets                       | 240,000  |
| 16  | Control and instrumentation equipment  | 168,000  |
| 17  | Delivery and assembly of measuring equipment | 225,000  |
| 18  | Software, commissioning, operator training, quality documentation, manuals | 135,000  |
| 19  | Post-completion documentation, trial start-up, land development and leveling, obtaining an occupancy permit, final acceptance of the installation with a positive result | 1,200,000 |
|    | Total                                 | 11,200,000|

However, the presented investment expenditure should be treated as a budget price. Determining the exact costs of the investment is possible only on the basis of a multi-sector
detailed design. Unit operating costs of the technological system were specified for the maximum capacity of the installation, taking into account the cost of electricity, necessary reagents, and staff. The cost of the annual operation of a flocculation and sedimentation system is predicted to be 200,000 PLN. The most important operating costs involve:

- Flocculant for coagulation;
- Electricity;
- Flocculant for sludge dewatering;
- Storage cost in case of failure possibilities of sludge management.

In the case of the discharge of mine waters into the environment, preceded by pre-treatment, the cost taking into consideration over normative TSS concentration would be as follows:

- Variant 1—Table 2 present cash flows calculated for the 20-year-period of the investment (TSS concentration exceeded by 1 kg/m$^3$ in relation to the normative value).
- In the case of direct water disposal to the river, the calculated annual costs for TSS discharge are 1 kg/m$^3$·4800 m$^3$/d·365 days/year·4.87 PLN/kg = 8,532,240 PLN.
- Variant 2—Table 3 present cash flows calculated for the 20-year-period of the investment (TSS concentration exceeded by 0.5 kg/m$^3$ in relation to the normative value).
- In the case of the direct water disposal to the river, the calculated annual costs for TSS discharge are 0.5 kg/m$^3$·4800 m$^3$/d·365 days/year·4.87 PLN/kg = 4,266,120 PLN.
- Variant 3—Table 4 present cash flows calculated for the 20-year-period of the investment (TSS concentration exceeded by 0.2 kg/m$^3$ in relation to the normative value).
- In the case of the direct water disposal to the river, the calculated annual costs for TSS discharge are 0.2 kg/m$^3$·4800 m$^3$/d·365 days/year·4.87 PLN/kg = 1,706,448 PLN.

**Table 2.** Cash flows in Variant 1 (TSS concentration = 1000 mg/dm$^3$).

| Id. | Specification | 2020 | 2029 | 2039 |
|-----|---------------|------|------|------|
| 1.  | Capital expenditure | 11,200,000.00 | ... | 0.00 | 0.00 |
| 2.  | Total costs | -7,772,240.00 | ... | -7,772,240.00 | ... |
| 2.1 | Exploitation costs of coagulation and sedimentation system | 200,000.00 | ... | 200,000.00 | ... |
| 2.2 | The cost reduction (lower fee of suspension concentration) | -8,532,240.00 | ... | -8,532,240.00 | ... |
| 2.3 | Amortization | 560,000.00 | ... | 560,000.00 | ... |
| 3.  | Operational cash flow | 0.00 | ... | 0.00 | ... |
| 3.1 | Revenues from water sales | 0.00 | ... | 0.00 | ... |
| 3.2 | Other revenues | 0.00 | ... | 0.00 | ... |
| 4.  | Gross profit (3. − 2.) | 7,772,240.00 | ... | 7,772,240.00 | ... |
| 5.  | Tax (CIT) | 1,476,725.60 | ... | 1,476,725.60 | ... |
| 6.  | Net profit | 6,295,514.40 | ... | 6,295,514.40 | ... |
| 7.  | Total net cash flow (6. + 2.5. − 1) | -4,344,485.60 | ... | -4,344,485.60 | ... |
| 8.  | Discounted NCF | -4,344,485.60 | ... | 5,591,668.80 | ... |
| 9.  | Cumulative discounted NCF | -4,344,485.60 | ... | 50,845,278.52 | ... |

|       | 2029 | 2039 |
|-------|------|------|
| 5.    | 1,476,725.60 | ... |
| 6.    | 6,295,514.40 | ... |
| 7.    | -4,344,485.60 | ... |
| 8.    | -4,344,485.60 | ... |
| 9.    | -4,344,485.60 | ... | 50,845,278.52 | ... | 100,319,270.28 |
Table 3. Cash flows in Variant 2 (TSS concentration = 500 mg/dm$^3$).

| Id. | Specification                                      | 2020        | ... | 2029        | ... | 2039        |
|-----|---------------------------------------------------|-------------|-----|-------------|-----|-------------|
| 1.  | Capital expenditure                               | 11,200,000.00 | ... | 0.00        | ... | 0.00        |
| 2.  | Total costs                                       | −3,506,120.00 | ... | −3,506,120.00 | ... | −3,506,120.00 |
| 2.1 | Exploitation costs of coagulation and sedimentation system | 200,000.00 | ... | 200,000.00 | ... | 200,000.00 |
| 2.2 | The cost reduction (lower fee of suspension concentration) | −4,266,120.00 | ... | −4,266,120.00 | ... | −4,266,120.00 |
| 2.3 | Amortization                                      | 560,000.00  | ... | 560,000.00  | ... | 560,000.00  |
| 3.  | Operational cash flow                             | 0.00        | ... | 0.00        | ... | 0.00        |
| 3.1 | Revenues from water sales                         | 0.00        | ... | 0.00        | ... | 0.00        |
| 3.2 | Other revenues                                    | 0.00        | ... | 0.00        | ... | 0.00        |
| 4.  | Gross profit (3. − 2.)                            | 3,506,120.00 | ... | 3,506,120.00 | ... | 3,506,120.00 |
| 5.  | Tax (CIT)                                         | 666,162.80  | ... | 666,162.80  | ... | 666,162.80  |
| 6.  | Net profit                                       | 2,839,957.20 | ... | 2,839,957.20 | ... | 2,839,957.20 |
| 7.  | Total net cash flow (6. + 2.5. − 1)               | −7,800,042.80 | ... | 3,399,957.20 | ... | 3,399,957.20 |
| 8.  | Discounted NCF                                    | −7,800,042.80 | ... | 2,211,276.53 | ... | 2,211,276.53 |
| 9.  | Cumulative discounted NCF                         | −7,800,042.80 | ... | 44,107,410.04 | ... | 44,107,410.04 |

Table 4. Cash flows in Variant 3 (TSS concentration = 200 mg/dm$^3$).

| Id. | Specification                                      | 2020        | ... | 2029        | ... | 2039        |
|-----|---------------------------------------------------|-------------|-----|-------------|-----|-------------|
| 1.  | Capital expenditure                               | 11,200,000.00 | ... | 0.00        | ... | 0.00        |
| 2.  | Total costs                                       | −946,448.00 | ... | −946,448.00 | ... | −946,448.00 |
| 2.1 | Exploitation costs of coagulation and sedimentation system | 200,000.00 | ... | 200,000.00 | ... | 200,000.00 |
| 2.2 | The cost reduction (lower fee of suspension concentration) | −1,706,448.00 | ... | −1,706,448.00 | ... | −1,706,448.00 |
| 2.3 | Amortization                                      | 560,000.00  | ... | 560,000.00  | ... | 560,000.00  |
| 3.  | Operational cash flow                             | 0.00        | ... | 0.00        | ... | 0.00        |
| 3.1 | Revenues from water sales                         | 0.00        | ... | 0.00        | ... | 0.00        |
| 3.2 | Other revenues                                    | 0.00        | ... | 0.00        | ... | 0.00        |
| 4.  | Gross profit (3. − 2.)                            | 946,448.00  | ... | 946,448.00  | ... | 946,448.00  |
| 5.  | Tax (CIT)                                         | 179,825.12  | ... | 179,825.12  | ... | 179,825.12  |
| 6.  | Net profit                                       | 766,622.88  | ... | 766,622.88  | ... | 766,622.88  |
| 7.  | Total net cash flow (6. + 2.5. − 1)               | −9,873,377.12 | ... | 1,326,622.88 | ... | 1,326,622.88 |
| 8.  | Discounted NCF                                    | −9,873,377.12 | ... | 862,813.81  | ... | 862,813.81  |
| 9.  | Cumulative discounted NCF                         | −9,873,377.12 | ... | 10,380,293.89 | ... | 10,380,293.89 |

4. The Methodology of a Financial and Economic Analysis

In order to carry out the profitability analysis of the application of mine water treatment in flocculation–sedimentation processes before disposal into the river, discount methods were used. These methods take into account the changing value of money over time and are widely used in the analysis of economic profitability of investment projects [24–29]:

- The NPV (Net Present Value) method;
- The IRR (Internal Rate of Return) method;
- The discounted payback period method.

Key input data enabling the determination of indicators’ values in discount methods are net cash flow, known as the balance of incoming and outgoing cash, in each year of an investment phase and an operating phase in investments. Net cash flow is determined on the basis of a direct method or an indirect method, in accordance with the accounting regulations. In this article, the calculative model is based on an indirect method, i.e., net cash flow for each year of investment is a result of the net profit/loss and corrections (capital expenditure and the depreciation of fixed assets).

Data on the cost of the investment and operating costs of individual unit technological processes of the treatment systems have been obtained on the basis of the completed projects, which involved the unit treatment processes analyzed in the paper.
The profitability analysis of pretreatment installation before water discharge into the river was undertaken regarding specific technological, financial, and economic assumptions in relation to direct disposal of the contaminated water.

The economic and financial assumptions were as follow:

- The financial and economic analysis was based on three discount methods, i.e., NPV, IRR and discounted payback period;
- The calculative model, in all variants, takes into account the following economic parameters:
  - capital expenditure of a pretreatment installation;
  - additional costs associated with the maintenance of a pretreatment installation;
  - the costs of mine water discharge directly into the river without any treatment at three different TSS concentrations.
- The economic and financial analyzes were carried out for three presented earlier variants (Section 2.2) which also included unit operating costs of a technological system were specified for the maximum capacity of the installation, taking into account the cost of electricity, necessary reagents, and staff. The cost of the annual operation of a flocculation and sedimentation system is predicted to be 200,000 PLN;
- To determine the discount rate, an assumed risk premium was 2% and WIBOR1Y at 0.29% (15 July 2020).

Economically, variant 1 should be assessed as the most profitable due to a high NPV (100,319,270.28 PLN), and additionally high NPVR value (8.96 PLN/PLN). The relatively low CAPEX results in a short discount payback period (1 year 236.6 days). A high internal rate of return (157.81%) for this variant reduces the risk of losing profitability in a situation of growing capital cost on the monetary market (Table 5).

Table 5. The values of economic effectiveness indicators in the analyzed variants.

| Id. | Economic Effectiveness Indicators | Variant 1 (TSS Concentration = 1000 mg/dm³) | Variant 2 (TSS Concentration = 500 mg/dm³) | Variant 3 (TSS Concentration = 200 mg/dm³) |
|-----|-----------------------------------|---------------------------------------------|---------------------------------------------|---------------------------------------------|
| 1.  | Net Present Value, NPV            | 100,319,270.28 PLN                          | 44,107,410.04 PLN                          | 10,380,293.89 PLN                          |
| 2.  | Internal Rate of Return, IRR      | 157.81%                                     | 43.54%                                     | 11.83%                                     |
| 3.  | Discounted Payback Period, DPP    | 1 year 236.6 days                           | 3 years 141.0 days                         | 9 years 93.0 days                          |
| 4.  | NPV Ratio, NPVR                   | 8.96 PLN/PLN                               | 3.94 PLN/PLN                              | 0.93 PLN/PLN                              |

Relatively low CAPEX in all variants enables us to achieve advantageous levels of economic indicators. Nevertheless, the economic effectiveness of all variants strongly depends on a discount rate what is shown in Figure 2.

In Figure 3, the sensitivity analysis of NPV on the level of TSS concentration was given. When the TSS concentration is below 107.7 mg/dm³ (the boundary value), it brings negative values to all economic indicators. The conclusion is that the analyzed investment is economically profitable when the TSS concentration is higher than the above-mentioned boundary value. Currently, this is highly probable when market percentage rates are very low. Considering the maximum possible TSS concentration (1500 mg/dm³), the highest NPV (due to present low percentage rates) would be 156,531,130.53 PLN.
5. Conclusions

1. Monitoring systems regarding the quality of mine water discharged into the environment is crucial to ensure the good ecological status of surface waters. It is important not to exceed the threshold concentration of substances classified as priority substances, which are especially dangerous for the water environment.

2. The application of pre-treatment systems based on coagulation and sedimentation enables a significant reduction of TSS concentration in mine waters discharged into the environment. The presented treatment installation was selected on the basis of laboratory tests and semi-technical scale pilot research. The research has shown that TSS sedimentation, without any reagents dosing, is ineffective. Spontaneous sedimentation was observed after just 24 h. The aim of the treatment process analyzed in the selected coal mine was to obtain post-coagulation flocs susceptible to sedimentation in a time significantly shorter than the time required for effective removal during spontaneous sedimentation carried out in water passage. Considering the cost of
various tested reagents (coagulants and flocculants), sedimentation properties, as well as the amount and structure of the sludge, the best results were obtained with the use of a flocculant-cationic polyelectrolyte.

3. Economic and financial parameters assumed in a computing model allow us to conclude that all analyzed variants of the application of a pre-treatment system are characterized by high economic effectiveness. The main reason for such high profitability of an analyzed investment is comparatively low capital expenditure and present low market percentage rates. The most profitable variant (TSS concentration is 1000 mg/dm$^3$) brings significant economic indicators, i.e., high NPV (100,319,270.28 PLN), a high NPVR (8.96 PLN/PLN) and a short discount payback period (1 year 236.6 days). A high internal rate of return (157.8%) for this variant reduces the risk of losing profitability in a situation of growing capital costs in the monetary market.

4. In the future, research on the use of organic reagents for TSS removal will be conducted, and the possibility to decrease the hydraulic retention time in the treatment installation will be determined. The quantity and thus the cost of managing the produced sludge will also be analyzed.

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