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ANALYSIS OF ENVIRONMENTAL AND ECONOMICAL
EFFECTS OF TREATMENT OF SULFUR AFTER-
-EXPLOITATION EXCAVATION IN THE REGION
OF TARNOBRZEG

SKUTKI ŚRODOWISKOWE I EKONOMICZNE
ZAGOSPODAROWANIA WYROBISKA
POEKSPLOATACYJNEGO SIARKI W TARNOBRZEGU

Abstract

As a result of recession and decrease in both demands and prices of sulfur on world markets in the early 1990s, the exploitation of sulfur from strip mines "Machów" and "Grzybów" was terminated. Areas left after sulfur exploitation were damaged to a large extent, and excavation openings and technical exploitation infrastructure of "Jeziórko" and "Grzybów" mines were hazardous for the natural environment [7]. Problems concerning with neutralization of excavation as well as advantages resulting from treatment of the area were presented in the article.

Keywords: excavation, strip mine, environmental effects, economical effects

Streszczenie

W wyniku recesji gospodarczej i negatywnych zjawisk (spadek popytu i cen siarki) występujących od początku lat 90. na światowych rynkach siarki, całkowicie zakończono wydobywanie w odkrywkowej Kopalni Siarki „Machów” i „Grzybów” w Tarnobrzegu. Tereny poeksploatacyjne charakteryzowały się dużą degradacją, a wyrobiska odkrywkowej Kopalni Siarki „Machów” i „Piaseczno” stanowiły zagrożenie ekologiczne dla środowiska [7]. W artykule zostały przedstawione problemy związane z neutralizacją wyrobiska oraz korzyści wynikające z zagospodarowania terenu poeksploatacyjnego.

Słowa kluczowe: wyrobisko, kopalnia odkrywkowa, skutki środowiskowe, skutki ekonomiczne

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1. Introduction

The sulfur mine “Machów”, located near the town of Tarnobrzeg, started its operation in 1964 after discovering a rich deposit of sulfur. In 1969 the open cast ore exploitation started. During the years 1964-1992 about 280 million of cubic meters of callos and about 55.8 million of sulfur ore was excavated, from which about 11 million tons of sulfur was produced. Some of the callos was backfilled (interior dumping grounds) but the major part of callos mass was stored on external dumping grounds.

A severe decrease in the world market prices of sulfur in mid 1991 together with reduction of its consumption by domestic industry caused termination of sulfur mining in Poland. In 1993 exploitation and production of sulfur was stopped for good.

The problem of neutralization of colossal open cast excavation with the surface of about 600 hectares and the depth up to 110 meters, however, as well as elimination of its negative influence on natural environment remained to be solved. Liquidation activities in the company were started in 1994, with orientation on water type of open cast excavation’s reclamation [3].

2. Effects of operating of sulfur extraction and production

Sulfur ore extraction and sulfur production in “Machów” mine were a severe environmental nuisance, causing various negative changes in the natural environment. On the basis of the analysis these effects can be categorized into the following groups:

- a) soil:
 - elimination of large areas from agricultural and forest operational use (external dumping ground eliminated the area of 800 ha from use),
 - total devastation of topsoil in the area of opencast, dumping grounds and industrial waste deposits,
 - degradation of over 400 hectares of soil caused by flotation waste sedimentation in the basins “Ocice” and “Cygany”, clarifier of deposit waters,
 - decrease of soil productivity on major areas in the neighborhood of excavation area, caused by emission of sulfur and its compounds,
- b) water:
 - changes of the hydrographic system in the area as well as rebuilding of surface waters system,
 - water relationship disturbance consist in depression of ground waters level being the result of intense pumping of water by mine dewatering system,
 - discharge of strongly mineralized waters into the Vistula river, after removal of hydrogen sulfide,
- c) topographic profile:
 - formation of depression crater 8 km in diameter in a tertiary water-bearing stage around “Machów” and “Piaseczno” open cast excavations,
 - disturbance of existing geological structure,
 - disturbance of existing geomorphologic structure as a result of creation of artificial forms of landscape (external dumping ground, deposits of flotational waste),
 - change of microclimate as a result of transformation of topographic profile, devastation of flora, as well as chemical effect.

During the operation of “Machów” sulfur mine severe changes in 1600–1800 ha of landscape took place [4]. On some areas total devastation of soil and flora with disturbance of geological structure occurred, while creating of accompanying structures (such as dumping grounds, drainage ditches, sedimentary ponds, clarifiers, industrial waste deposits) deformed the relief permanently, and also caused the change in its economic utilization. The neutralization of negative influence of the open cast excavation on natural environment in the area is therefore a very complex venture, requiring co-ordination of many various activities, as well as large financial investment. But, beyond all doubt, possible damage made in the natural environment (for example contamination of the area with hydrogen sulfide) would be much more serious if no liquidation activities were taken.

3. Neutralization of open cast and stages of its management

In place of massive excavation, building a reservoir of recreational nature, of the surface of about 500 ha and depth of about 40 m, is planned. Transformation of the open cast into a reservoir is quite a common solution of management for such types of excavations both at home and abroad.

In order to carry out the adopted trend of management of the open cast, at the beginning the area was cleaned, but first of all the bed of the excavation was sealed by placing a 25 meter layer of insulating material – clay. The layer is necessary to eliminate the direct contact of deposit waters with high content of hydrogen sulfide (about 300 mg/dm³) with ground waters of the future reservoir.

3.1. Preparatory work

In 2001 preparatory work started, and after four consecutive years, filling of the reservoir began. The project is planned to be completed by the end of 2008. The schedule of work includes:

- a) formation of the open cast embankment in order to provide slope stability after filling it with water,
- b) deposit of flotation waste (3.5 million m³) on the bed of the open cast,
- c) building of an insulating layer on the bottom of the future reservoir,
- d) building of hydro-structures enabling the water supply from the Vistula river to the excavation. Parts of the structure are: a supplying ditch, an inlet structure with locks, an open ditch transporting the water to the bottom of the open cast.

3.2. Filling of the excavation with water

The last stage of liquidation work is filling the open cast with water. Target parameters of the reservoir are presented in Table 1.

At the present stage of liquidation work, the following activities remain to be completed [2, 57]:

- finishing the embankment,
- finishing the north scarp in order to prevent landslide (for now completed in 98.5%),
- reclamation work on the areas adjacent to the excavation,

- conservatory work on the reclaimed areas,
- reclamation of the areas after building the technological system of water pumping and cleaning,
- filling the reservoir to the final level (146 m above sea level),
- pumping of deposit water until a full protection of “Piaseczno” excavation is completed.

Table 1

Main parameters of the “Machów” reservoir (Kirejczyk, 2004)

Parameter	Volume
Total capacity	111.2 ml m ³
Maximum ordinate of cumulating	146.0 m over sea level
Minimum ordinate of cumulating	145.0 m over sea level
Surface of water	500 hectares
Length of the reservoir	about 3,000 m
Width of the reservoir	about 2,500 m
Length of the land line	about 10 000 m
Maximum depth	42 m
Average depth	22.0 m

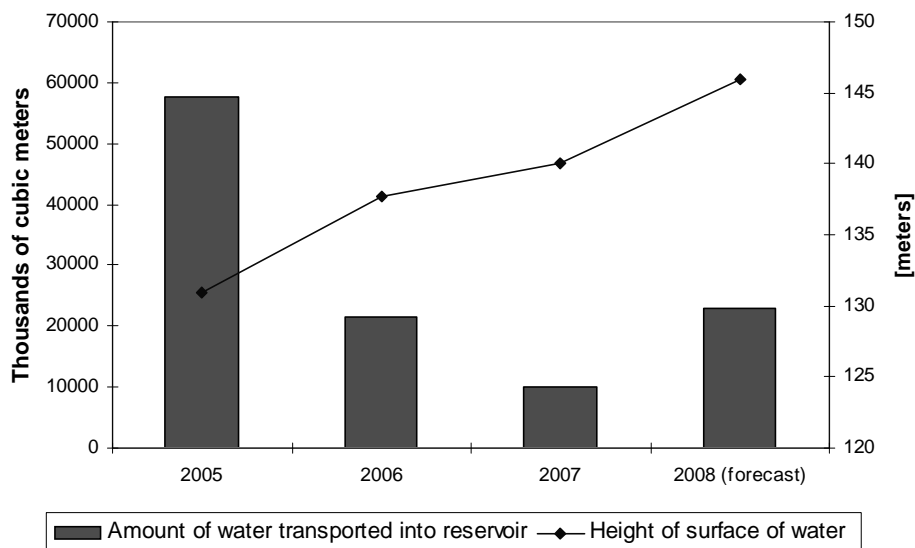


Fig. 1. Amount of water pumped into the open cast excavation in particular years 2005–2008

Rys. 1. Ilość wody dostarczonej do zbiornika w poszczególnych latach 2005–2008

4. Environmental effects of some reclamation activities

In this section the main reclamation activities have been presented together with positive environmental effects.

a) Reclamation of eastern scarp (30 ha)

Environmental effect: the area of 12 ha of wooded and protected slope will be reclaimed. Natural succession of trees and shrubbery is included on the remaining land of 18 ha. The works will be completed by 2008.

b) Shaping of peninsula in south-western part of reservoir (12.51 ha)

Environmental effect: an interesting element of the landscape in the shoreline of reservoir will be created. The land reclamation will be completed by 2008.

c) Reclamation of forwarding ramp (9.92 ha)

The ramp was useful for transportation of the mining machines from the open cast excavation. The aim of the reclamation is to build a system of drainage ditches. Environmental effect: a biologically active surface close to the excavation will be reclaimed. The works will be completed by 2008.

d) Reclamation of section of northern scarp (6.6 ha)

The aim of the reclamation is to create a place for recreation and to stabilize and protect the slope against sliding effects.

Environmental effect: The wooded slope will ensure safe access to the reservoir. The land reclamation will be completed by 2009.

e) Dewatering of north-eastern scarp (5.56 ha)

Environmental effect: the area of 5.56 has of biologically active surface close to the excavation was restored. The land reclamation was completed in 2007.

f) Reclamation of post-floatation waste tank "Ocice" (56,8 ha)

The aim of the reclamation is to control the relief, and to fertilize the soil by placing an organic layer, and also to plant trees and shrubbery. Environmental effect: An architecturally attractive place will be created, close to the reservoir "Machów". The reclamation will be done by November 2013.

g) Reclamation of the clarifier "Klarownik 2", with the adjoining area (39 ha)

Environmental effect: a very toxic structure will be eliminated (28.5 ha), which emitted hydrogen sulfide that next caused acidification and salinification of surface water and soil. In this place a biologically active area will be created as a place for recreation not far from the reservoir. The reclamation will be done by 2013.

h) Reclamation of "Piaskownia" area (24 ha)

In the years 1985-1993 on the area of "Piaskownia" there was an experimental mine, which exploited sulfur ore; it caused settlement of the soil, pollution, acidification and salinification of topsoil. Environmental effect: very attractive areas situated close to the reservoir will be restored. The area will be fertilized and sowed by special mixture of grasses; what is more, there will be many attractive trees and shrubbery planted. The activities will be done by 2013.

Maintenance works on reclaimed areas. Lands where reclamation was completed require yearly conservation. These works cover: mowing the grass and weeding, desludging of ditches, shoulders of roads, and strengthening of surfaces. The total area where works are run exceeds 310 ha. On the reclaimed lands there have settled down deer, hare, pheasant, wild boar. There are also fields, where farmers collect crops.

5. Economic and social aspects of reclamation of excavation

From the economic point of view it is unquestionable that reclamation of excavation was the only proper solution. Since 1992, when sulfur exploitation was stopped, waters strongly contaminated with hydrogen sulfide were continuously pumped up from under the heading. The cost of this activity involved expenses of about 30-40 million PLN monthly, and in the case of not pumping up the waters, the atmosphere contamination with hydrogen sulfide in the radius of 200 km would take place.

During the time between sulfur exploitation termination and beginning of reservoir construction, about 900 ml PLN was wasted only on neutralization of the contaminated waters. The money could have been saved, if only the reservoir construction had started immediately after sulfur exploitation was terminated. For comparison, total financial resources spent on liquidation of the excavation in consecutive years (1994-2007) are presented in Table 2. As can be seen, the money spent on liquidation and treatment during the years 1994-2007 amounts to about 800 ml PLN. Additionally, the amounts of lodged and granted subsidies in specific years were also presented in Table 2. In the year 2001 within the whole granted subsidy, the amount of 49.95 ml was granted by the National Fund of Environmental Protection. In Table 3, the costs of some specific types of liquidation activities are presented.

Table 2

Financial resources spent on liquidation and treatment in the years 1994–2007

Year	Granted subsidy (million of PLN)	Lodged subsidy (million of PLN)
1994	31.50	49.8
1995	37.50	64.9
1996	45.20	108.1
1997	61.50	162.3
1998	60.00	129.9
1999	63.15	161.1
2000	68.00	116.6
2001	116.15	160.4
2002	70.40	116.0
2003	60.50	109.6
2004	53.00	115.4
2005	41.38	172.5
2006	47.90	160.2
2007	47.90	165.9

Alongside the construction of the „Machów” reservoir many associated objects are expected to be built objects [1], which may help in development of tourism in the area. The following investments are planned:

- water sports base,
- recreation base on the area of 2.7 ha with 42 separate building sites, and area for sale (28 sites, 3 each). On the neighbouring area, in the south, a motel with 50 beds is planned,
- 1.7 ha camping area, equipped with sanitary facilities, self-service kitchen, seasonal grocery. The official camping site is expected to prevent illegal camping,

- 12 ha golf course. in place of clarifier number 2,
- sailing and navigation infrastructure. It is necessary to build a slope enabling launching boats. and a port. together with a car park. yacht club facilities. and water police station,
- bicycle cross on the area of 2.5 ha. on the place of former dewatering structure. The main aim of the object is to create artificial obstacles. and the object will be connected with the network of bicycle roads designed around the reservoir.

Table 3

Costs of some liquidation activities performed in the years 1994-2007

Type of activity	Cost (thousands of PLN)
Liquidation of excavation	129,000,000
Liquidation of superficial structure and disassembly of machinery and devices	2,100
Discontinue of mining exploitation and damages liquidation	1,630
Land reclamation	84,867
Anti-hazard activities	44,491
Hydrotechnic development. filling of reservoir with water from the Vistula river	17,056

6. Conclusions

It is obvious that liquidation of damage caused by long-term sulfur exploitation and restoration of the areas for the natural environment. will bring measurable effects both environmental and economic. Taking into consideration both the policy of the reclamation activities and the character of the region. the construction of the reservoir will enhance tourist attractiveness of the Tarnobrzeg area and help reduce unemployment rate. After suitable adaptation of watersides of reservoir for recreation (building of beaches. swimming areas. observation points. ports. bicycle roads etc.) as well as creating a suitable back-up facilities for tourists (hotels. camping sites. playgrounds). the area of "Machów" reservoir will be a very attractive tourist region. Other advantages of the area include:

- vicinity of the town of Tarnobrzeg and other municipalities in the region. such as Sandomierz and Stalowa Wola.
- low population rate in the area around the reservoir.
- first class water clarity in the reservoir.

For today many of the presented activities are at the planning stage. but investors are interested in the area surrounding the reservoir. and about a dozen businesses have already started operating.

The article is effect of statutory work number 11.11.100.276.

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