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THE RECLAMATION OF POST-MINING AREAS OF LUBUSKI REGION (POLAND) ON EXAMPLE OF SIENIAWA LIGNITE MINE

1. Introduction

Mining is one of the branches of industrial activities which on one hand brings significant economic benefits and on the other — inevitably leads to a conflict with the natural environment. The influence on the environment manifests itself as a reduction natural resources, degradation (and sometimes devastation) of the terrains acquired for mining, disturbance of the hydrogeological relations and emissions into the atmosphere. The laws which are in force in Poland enforce the duty to conduct reclamation in order to bring back the utility values of the affected areas [8]. At present, modern reclamation also has more important goals than just bringing the utility value. Its purpose is to create complex and complete ecosystems in the post-mining areas. In this case the open-pit mining (and lignite mining in particular) and modern reclamation may create new possibilities of shaping the landscape, including water, forest and agricultural ecosystems [11].

An example of a proper approach to reclamation of post-mining terrains and conducting the so-called sustainable deposit management may be found in one of the longest functioning lignite mines in Poland — Lignite Mine Sieniawa. The mine can be praised because of the effective and properly conducted reclamation works carried out there.

2. Deposit conditionings and characteristics of Lignite Mine Sieniawa

When considering geomorphology, the „Sieniawa" lignite deposit is located in the area called Wysoczyzna Lubuska and if taking geology into account — on the border of Niecka Szczecinska and Monoklina Przedsudecka.

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The deposit in question is a stratigraphic deposit created in Tertiary era (Miocene) which has been glacially disturbed during the Quarternary. These deformations manifest themselves in over 30 folds (colloquially called saddles) with the general direction of the axis NW-SE and South-Western vergence. The folds spread for over 10 km. The depth of the lignite seam in Sieniawa deposit is various because of the geological structure. It ranges from a few meters in the saddle areas to over 150 meters in syncline areas while the thickness of the lignite layer varies between 0.5 and 15 meters. The strong folding of the Tertiary and Quarternary sediments, numerous erosive cuts and the creation of deep erosive washouts filled with sand and gravel sediments have caused a break in the continuity of the isolative layers and allowed for hydraulic migration between particular water levels, creating two water-bearing zones – one under the seam and the other over the seam.

The water level of the top zone is unconfined or slightly confined, with a general condition of water flow following the inclination of the terrain while the bottom water level (under the lignite seam) is confined [12].

The shallow depth of the lignite deposit is one of the reasons why lignite mining in the area started as early as the second half of 19th century in small private German underground mines. This continued until 1945. After World War II, in 1950 a State Enterprise „Sieniawa" was established. It conducted the underground exploitation of lignite until 1979 when the open-pit method was introduced. Both methods were used simultaneously. New economic conditions after 1990, time of restructuring and limited demand for lignite caused the mine to go into liquidation in 1997 and subsequently — closed in the first half of 2002 [4–6].

In the second half of 2002 basing calculations on the assets of liquidated mine, a new private mining enterprise called Lignite Mine "Sieniawa" Ltd. was established. Until this day it mines lignite using the open-pit method. The haulage of the overburden to the internal dump is conducted using the ECS (excavator-conveyor-spreader) system with shovel excavators. Such excavators are also used for exploitation of lignite which is subsequently a subject of fractionation in sorting plant and transported to the clients with trucks (to local clients) or wagons (to the strategic clients) [4–6]. In relation to other Polish mines, Lignite Mine "Sieniawa" is relatively atypical in many fields. This is a result of [4]:

— Different geological structure of the deposit
— In the past (until 1997) traditional lignite mining method (underground) was successfully used
— The market for the mine is different (local individual and municipal clients, small industrial enterprises)
— It is relatively "small" when considering the area of the mine, production and the number of employees.

3. Mining and the transformation of the natural environment

At first the exploitation of lignite in the Sieniawa Mine was conducted using the underground method. Open-pit exploitation did not start until 1979. At the moment the now-private mine is operated exclusively as an open-pit plant.

The terrains acquired for both underground and open-pit exploitation were typical end moraine areas, characterized by a high variety of landscape forms. The majority of the mining area was covered by brown and rusty soils on which beech and mixed (beech-pine--birch) forests grew [4, 9]. The remaining terrains were used as agrarian fields. Additionally, the area was characterized by a lack of any developed and regulated hydrographic network with the only exception being that of temporary (forming during heavy rain periods) sinkholes filled with water occurring in the area of saddles III and VI.

The underground mining activity in Sieniawa Lignite Mine was conducted in various periods of time in five saddles (III, IV, VI, VII and VIII) while the open-pit method was used to mine lignite in the Eastern part of saddle VI and western part of the Eastern wing of saddle VII. At present the exploitation is continued in saddle IX.

The terrains where underground exploitation existed were previously deforested and excluded for forestry activity for around 15 to 20 years, depending on the duration of mining works, resources available in the deposit and character of the rock layers surrounding the seam. Taking the thickness of the seam, used a mining method (caving without backfilling the mined space) and the depth of the exploitation and the negative impact on the environment manifested itself as numerous craters with diameter of up to several meters, ditches and steps of up to a few meters deep and several meters long. As the result of these deformations the soil structure was damaged, especially in the areas of landslides, slopes and steps. The fertile top layer of soil was removed and the lower layers of sand and sand clays were exposed. Because of the existence of silt and clay isolating layers above and below the lignite seam, the exploitation has not influenced the complex water conditions. In some of the sinkholes located over the silt basis, small water ponds (fit very well into the existing landscape character) were formed [4–6, 9].

Underground mining activity caused an anthropogenic transformation of areas reaching 101,71 ha in which almost 3245 m of forest roads were destroyed or damaged (Table 1). This caused indirect but significant problems to transport in the area of ca. 500 ha located between the saddles and in the forestry in the areas surrounding the mine [4, 7, 8].

TABLE 1

Maksymalne wartości przemieszczeń pionowych (10^{-3} m) i odkształceń (10^{-6}) stalowej powłoki uzyskane z pomiarów i obliczeń podczas zagęszczania gruntu

Type of damage	Saddle number					Total
	III	IV	VI	VII	VIII	
Paved roads destroyed [m]	480.0	—	1 050.0	155.0	650.0	2 335.0
Unpaved roads destroyed [m]	100.0	—	350.0	460.0	—	910.0
Modified areas [ha]	31.0	8.0	22.9	27.8	12.0	101.7

The environmental effect of the open-pit mining activity can be described as occurrence of significant transformations of post-mining elements, namely pits and dumps. These

mining objects are characterized by areas reaching up to a few hectares and depth (height) of up to several meters [4].

Basing on numerous soil analyses these post-industrial wastelands were classified as category BO-2 and BO-3 (respectively: hard and very hard biological restoration) because of the changes in the landscape and adverse water conditions. When considering the usefulness of the grounds for reclamation (Skawina classification) the majority of land was classified as class C — defective grounds unsuitable for agricultural reclamation. But after at least partial improvements, it is possible to conduct some forest reclamation. Only small part of the mining areas fit into class D — defective, sterile grounds, requiring basic fertilization or isolation. A small number of areas were classified as class E — very adverse grounds, requiring neutralization or isolation. The reason for this occurrence is the low pH and elevated level of sulphur [1, 2, 4].

4. Description and assessment of the reclamation works

Taking into account that the majority of post-mining grounds were classified as class C and the fact that the areas acquired for mining activity were previously afforested it was decided that forest reclamation will be the main method of reclamation. Additionally, this choice was supported by the fact that in the 1970's the Lignite Mine in Sieniawa passed over 20 ha of reclaimed lands (saddle III) to the State Forests enterprise. During this time so-called expectant renewal of forests was used. The main activities of this method included removing trees older than 35 years from the mining area and replacing them with young plants. The new forest more easily adapted itself to the surface deformations and new environmental conditions [10]. Taking into account that on some of the saddles no reclamation works were conducted during the mining process and after completion of works, it seemed reasonable to divide the reclamation process into two parts. The first one comprised of preparing the reclaimed areas for planting and the other included works and activities related to planting and nurturing the young trees. Table 2 shows the amounts and character of conducted preparatory and actual reclamation works in Lignite Mine Sieniawa between 1997 and 2002.

The decision to choose forest reclamation as the leading method in the post-mining terrains of the Sieniawa Lignite Mine was preceded by numerous consultations with the representatives of local authorities, State Forests and the managers of the mine. The important postulate made by the local authorities speaking for the forest reclamation was the character of lands acquired for mining activity and neighbouring the mining area. However, no specified demands were given concerning the method of afforestation. Such requirements were however given by the representatives of State Forests with a special emphasis on the proper preparation of the basis through the bringing of relevant amount of fertile soil layer and the introduction of productive species. The attitude presented is typical for State Forests which in most cases become the gamekeeper of the reclaimed post-mining terrains [9].

In general, between 1957 and 1998 Swiebodzin, Sieniawa and Lagow Forest Inspectorates passed over 136 ha of forest lands for exploitation to Lignite Mine Sieniawa while

Table 2. List of preparatory and reclamation works in post-mining areas in Sieniawa Lignite Mine in the years 1997–2002 [1, 2, 4]

Character of works	Reclamation of terrains with underground exploitation						Reclamation of terrains with open-pit				Grand Total
	Saddle number						VI	VIII		Total	
	III	IV	VI	VII	VIII	Total		Pit West I	Pit West II		
Preparatory works											
1. Deforestation, agrotechnical melioration [ha]	10.66	8.00	3.10	19.50	11.35	52.61	—	1.80		1.80	**54.41**
2. Earthworks:											
– Transport of earth masses [m^3]	3000	1000	1000	3000	2500	10 500	30 000	75 000		105 800	**116 300**
– Moving the earth masses within the saddle area [m^3]	43 000	34 000	19 000	112 000	67 500	275 500	80 000	68 500		148 500	**424 000**
3. Levelling of the grounds [ha]	7.26	7.25	3.10	19.31	11.15	48.07	7.60	—	—	7.60	**55.67**
4. Organic fertilization with lignite:											
– area [ha]	7.26	7.25	3.10	19.31	11.15	48.07	6.50	6.85	3.31	16.66	**64.73**
– lignite used [Mg]	871	870	372	2317	1338	5768	1170	1233	596	2999	**8767**
– lime used [Mg]	—	—	—	—	—	—	130	137	66	333	**333**
5. Construction of roads:											
– paved [m]	480	—	200	155	—	835	620	—	—	620	**1455**
– unpaved [m]	100	—	—	460	645	1205	570	—	750	1320	**2525**
– temporary [m]	400	300	—	1800	1500	4000	—	—	—	—	**4000**
6. Construction and reconstruction of the terrain drainage system:											
– Ponds [ha]	—	—	—	—	—	—	0.5	—	2×0.5	3×0.5	**3×0.5**
– Construction of a flat watercourse [m]	—	—	—	—	—	—	240	—	—	240	**240**
– Renovation of draining ditches [m]	—	—	—	—	—	—	—	750	—	750	**750**
Afforestation and nurturing works											
1. Protection from offsets [ha]	7.26	7.25	3.10	19.31	11.15	48.07	6.50	14.76		21.26	**69.33**
2. New plantings:											
– Area [ha]	7.26	7.25	3.10	19.31	11.15	48.07	6.50	14.76		21.26	**69.33**
– Number of plants [pcs.]	72 600	72 500	31 000	193 100	115 000	48 000	65 000	147 600		212 600	**692 600**
3. Plantings in the existing forests:											
– Area [ha]	3.40	0.75	—	—	—	4.15	—	4.91		4.91	**9.06**
– Number of plants [pcs.]	27 200	6000	—	—	—	33 200	—	5000		5000	**38 200**

between 1992 and 2022 the mine passed almost 127 ha of reclaimed grounds to Swiebodzin Forest Inspectorate including 120 ha of areas ready for planting. The remaining part consisted of roads, ponds and dividing lines in the forests.

From the perspective of 9 to 19 years since reclamation work finished in particular saddles, one may state that the forest reclamation was carried out without any significant complications and the results are satisfying. The mix of tree species was properly chosen. Beech, oak, pine, larch, pruce and fir were the basic production species, birch, linden, hemlock-spruce, maple and sycamore as additional species and finally rowan, lilac, hawthorn and wild rose as the biocenotic species. The reclaimed lands are no different to the surrounding areas (Fig. 1, 2). Simultaneously they became a habitat for the local animals which led to an increase in their population. The proper shaping of the former sinkholes and pits allowed to remove the water accordingly to the original surface water flow [4]. Some of the sinkholes and depressions were left on purpose and became a source for new water ponds which fit superbly into the physiographical character of the area and now fulfill retention functions (Fig. 3).

Fig. 1. . Forest reclamation in Saddle VII (underground exploitation)
a) in October 1998; b) in October 2002; c) in October 2010. Photo: KWB Sieniawa

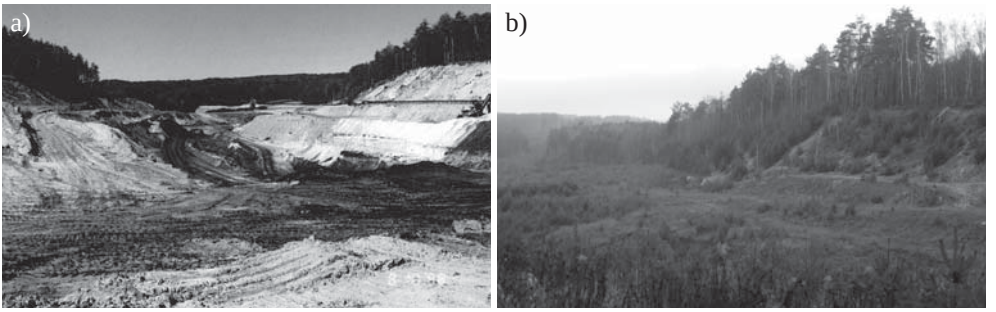

Fig. 2. . Successful reclamation in Saddle VI (open-pit exploitation)
a) exploitation (in October 1998); b) reclamation (October 2010). Photo: KWB Sieniawa

The flooded sinkholes are supplied with water mainly from the atmospheric precipitation and are characterized with relatively low mineralization, medium hardness and alkaline reaction. The ion composition is dominated by calcium, sulphates and carbonates. This composition allows us to classify the water as sulphate-carbonate-calcium (SO_4 — HCO_3 — Ca) accordingly to Szczukariew-Priklonski classification. It is worth noting that while the sulphate concentration is high (over 110 mg/dm^3), a small coexistence of iron exist (less than

1 mg/dm^3). The chosen psychical and chemical parameters typical for the waters filling the sinkholes are shown in table 3.

Table 3. Psychical and chemical parameters of ground waters filling the sinkholes caused by lignite exploitation in Sieniawa Lignite Mine ([4], modified)

Parameter	Value	
	2010	2011
A. General characteristics		
1. pH [-]	7.12	7.41
2. Mineralization [mg/dm^3]	289.90	301.40
3. Hardness [mg $CaCO_3$/dm^3]	192.70	193.14
4. Conductivity [mS/cm]	0.375	0.371
B. Ion balance		
1. Na^+ [mg/dm^3]	1.18	1.13
2. K^+ [mg/dm^3]	2.28	1.69
3. Ca^{+2} [mg/dm^3]	72.20	75.48
4. Mg^{+2} [mg/dm^3]	3.06	2.89
5. Fe^{+2} [mg/dm^3]	0.096	0.092
6. Cl^- [mg/dm^3]	3.70	3.56
7. $SO4^{-2}$ [mg/dm^3]	110.90	111.12
8. HCO_3^{-2} [mg/dm^3]	93.30	107.49

5. The current state of mining and reclamation works

At present the Lignite Mine Sieniawa conducts mining activity in saddle IX. The area used for open-pit mining (15,5 ha) was originally characterized for following use: agricultural fields (57% — 8,72 ha), forests (40% — 6,27 ha) and roads (3% — 0,5 ha). Since the end of 2002, the privately owned Sieniawa Lignite Mine Ltd. has established a reclamation process which has been conducted simultaneously with the mining works. In the first phase (2002–2005) the earth masses constituting for the overburden of saddle IX (ca. 385 000 m^3) were transported to the pit of saddle VIII (West II Pit). This allowed for smoothing of the slopes, increasing the pit bottom ordinate and shaping the surface water flow properly. The additional layer of humus created advantageous conditions for forestry. Due to this fact, the preparatory works were conducted and finished in just three years. The end of preparatory works in West II Pit made it possible to start storage of the overburden on the internal dump in the Eastern part of saddle IX together with simultaneous reclamation of its Western part. This area (almost 1 ha) was reclaimed and sold in 2009 (Fig. 4).

The mining activity constituting for internal dumping with simultaneous exploitation of the deposit are carried out to the present and are in full accordance to the reclamation works schedule. Quick filling of the pit and subsequent placing of humus layer of 0.7 meter significantly decrease the time of bringing the biological activity back. In the case of the Eastern part of saddle IX this took around 7 years for agricultural reclamation [4].

It is estimated that mining in the saddle IX will be conducted until the end of 2012 and the simultaneous internal dumping of overburden will make it possible to finish the

Fig. 4. Agricultural reclamation in the Eastern part of saddle IX in 2008
Photo: KWB Sieniawa

reclamation (preparatory) works in the end of 2014 (Table 4). The difference between the area acquired for exploitation and the reclaimed area is a result of the fact that 1,11 ha was used for the economic activities of the mine. The character of this area will not change because in 2012 mining in the eastern part of saddle VIII is planned to begin. The earth masses from overburden of saddle VIII will then be used to fill the pit in saddle IX.

Table 4. . Schedule of reclamation works for saddle IX
([4], modified)

The year of finish of reclamation works	Total area of reclaimed grounds [ha]
2009	0,87
2010	1,91
2011	0,47
2012	3,07
2013	4,17
2014	4,37
Razem	14,39

6. Summary

"Sieniawa" Lignite Mine is a perfect example of harmonious cooperation with the surrounding nature during over a 60-year period of the deposit exploitation. Because of the reclamation carried out in the post-mining areas as well as care for the environment, both in the neighbouring terrains and in the mining area, Lagow Landscape Park was established in 1985. At the moment mining is conducted on relatively low scale, without damage to

the natural environment. Currently conducted reclamation considerably reduces the negative impact of mining. In comparison with other Polish lignite mines, production in Sieniawa is significantly lower, but the reclamation works are as relevant as with the larger mines. Reclamation is conducted professionally and in line with guidelines (what has been confirmed with positive opinions of National Environmental Protection Fund and the Ministries of Economy, State Treasury and Environmental Protection. Foresters from all over the country that visit the mine and surrounding areas confirm these opinions.

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