ARCHIVES OF ENVIRONMENTAL PROTECTION
ARCHIWUM OCHRONY ŚRODOWISKA
vol. 33 no. 3 pp. 53 - 65 2007

PL ISSN 0324-8461

PROTECTION OF WATER FROM INFILTRATION OF ALKALINE WASTE FROM THE GÓRKA QUARRY

ZYGMUNT KOWALSKI[1], RYSZARD STRZELECKI[2], PRZEMYSŁAW WOLSKI[3], JOANNA KULCZYCKA[4], PIOTR RUDNICKI[5], AGNIESZKA SOBCZAK[6]

[1] Institute of Environmental Engineering of the Polish Academy of Sciences
ul. M. Skłodowskiej-Curie 34, 41-819 Zabrze, Poland
[2] Polish Geological Institute, ul. Rakowiecka 4, 00-975 Warszawa, Poland
[3] Warsaw Agricultural University, Department of Landscape Architecture
ul. Nowoursynowska 166, 02-787 Warszawa, Poland
[4] Mineral and Energy Economy Research Institute of the Polish Academy of Sciences
ul. Wybickiego 7, 31-261 Kraków, Poland
[5] Wrocław University of Technology, Faculty of Environmental Engineering
ul. Wyspiańskiego 27, 50-370 Wrocław, Poland
[6] Cracow University of Technology, Institute of Chemistry and Inorganic Technology
ul. Warszawska 24, 31-155 Kraków, Poland

Keywords: alkaline waste, infiltration, quarry, land reclamation.

OCHRONA WÓD PRZED INFILTRACJĄ ZE SKŁADOWISKA ODPADÓW ALKALICZNYCH „GÓRKA"

Na terenie byłego kamieniołomu „Górka" znajduje się składowisko o powierzchni 6,7 ha oraz staw o powierzchni około 3 ha. Wyrobisko„Górka" wypełniony jest odpadami stałymi z produkcji tlenku glinu, w ilości około 600 0000 m^3, które zgromadzono na zwałowisku zlokalizowanym w północnej części wyrobiska i alkalicznymi odciekami (430 000 m^3), które tworzą akwen wypełniający południową część wyrobiska oraz nasycają zwał odpadów stałych. Na dnie akwenu zalega ponadto około 57 000 m^3 szlamów alkalicznych. Do zbiornika dopływa około 130 m^3/dobę zanieczyszczonych wód. W większości są to infiltraty ze wspomnianego składowiska odpadów. Podstawowym problemem ścieków zawartych w stawie „Górka" jest ich wysoka alkaliczność (pH 12–14). Niepokojące jest też przesiąkanie ścieków przez dno zbiornika i ich infiltracja do podziemnych zbiorników wód jurajskich i triasowych. Ilość tych infiltratów jest szacowana na 40 m^3/dobę. W pracy przedstawiono kompleksową propozycję rozwiązania problemu składowiska odpadów wyrobiska „Górka" podstawę, której stanowi wypompowanie 50 000 m^3 ścieków ze zbiornika i oczyszczenie ich metodą odwróconej osmozy, która została sprawdzona w skali ćwierć technicznej. Oczyszczone do jakości wód V klasy ścieki zrzucane będą do rzeczki Ropa. Koncentrat solankowy natomiast będzie zestalony i zdeponowany na składowisku zewnętrznym. Drugi etap przewiduje usunięcie i przetworzenie w formę produktu betonopodobnego szlamów nagromadzonych na dnie osadnika; produkt ten będzie na miejscu wykorzystany przy rekultywacji terenu, do uszczelnienia powierzchni składowiska odpadów wysokoglinowych. Następny etap to odsłonięcie źródeł w północnej części dawnego wyrobiska kamieniołomu celem odtworzenia pierwotnego reżimu odpływu od źródeł do sztolni. Wydobywane odpady zostaną przemieszczone na pozostałą część składowiska odpadów wysokoglinowych, którego powierzchnia zostanie uszczelniona i następnie zrekultywowana. Ostatni etap to makroniwelacja terenu (w układzie amfiteatralnym), z odtworzeniem warstwy ziemi urodzajnej i urządzeniem oczka wodnego oraz finalna rekultywację terenu.

Summary

In the defunct Górka heading there is both a waste disposal site with an area of 6.7 ha containing approximately 600 000 m^3 of waste generated in the course of aluminum oxide production and a pond with an area of 3 ha and depth of up to 15 m containing about 400 000 m^3 of effluent (leachate water). The reservoir is filled with infiltrates flowing in from the above-mentioned disposal site at a rate ~ 130 m^3/day. The subsidence of the pond bottom and infiltration of solutions into the Triassic and Jurassic water resources, estimated at ~ 40 m^3/day, is a cause of serious concern. The basic problem of the effluents in the Górka pond is their high alkalinity (pH 12–14) and variable pollutant content, the level of which increases with the pond's depth. The proposed solution involves pumping out and treating about 500 000 m^3 of effluents retained in the Górka reservoir. The effluents would be treated in a reverse osmosis plant using a process which has so far been verified on a quarter-commercial scale. The treatment process by-product would be discharged into the Ropa stream. The brine solution (containing ~ 25% NaCl), would be solidified. The next stage after pumping would be the utilization of approximately 50 000 m^3 of bottom slurry. Highly alkaline slurries would be utilized in the production of self-solidifying mixtures. These mixtures would be used to seal the bottom of the Górka reservoir and part of the edges of the defunct quarry, according to requirements. The next stage would involve outcropping the feed-water sources located in the northern section of the old heading to reconstruct the original flow system from the sources to the Ropa River. The excavated solid waste would be relocated into the remainder of the disposal site containing solid aluminium waste. The surface of the site would be sealed and then reclaimed. The final stage involves macrolevelling of the site into an amphitheatre system, outcropping the fertile soil layer, constructing a lake and streams, and finally land reclamation of the whole site.

INTRODUCTION

The Górka quarry was formed as a result of 60 years of extraction of limestone and marl for the cement industry. The geological structure of the area in question includes Carboniferous, Triassic, Jurassic, Tertiary and Quaternary formations. Limestone and marl extraction in the heading has led to the floor of these layers being reached. Below them there are clayey formations with sandstone inserts which are yet to be exploited. Near Górka quarry, Triassic deposits of zinc and lead were extracted.

In the defunct Górka heading there is both a waste disposal site with an area of roughly 6.7 ha containing approximately 1 000 000 Mg of waste from cement and aluminium oxide production and a pond with an area of 3 ha containing about 400 000 m^3 of wastewater (Fig. 1).

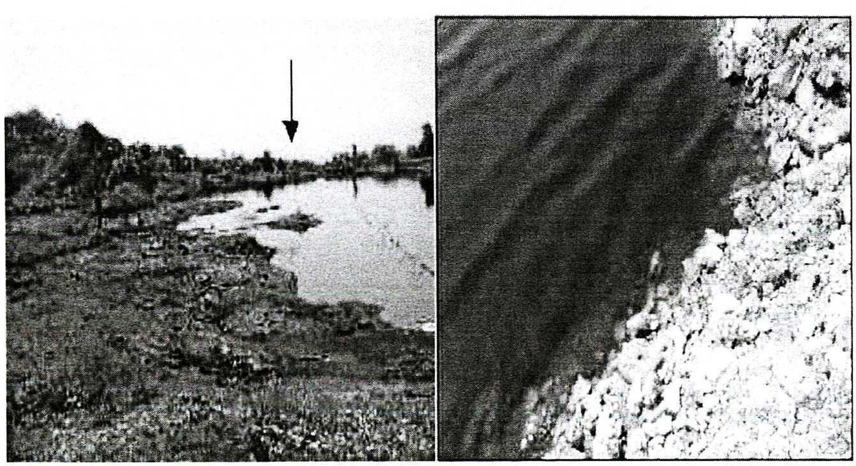

Fig. 1. The Górka reservoir in Trzebinia according to [1]

The waste reservoir in Górka quarry contains [1, 9] (Fig. 2):

- around 600 000 m^3 of solid waste from aluminium oxide production stored in a dump site in the northern part of heading;
- alkaline infiltrate, which has formed a water region that occupies the southern part of the heading and a saturated heap of solid waste, currently 400 000 m^3;
- approximately 130 m^3/day of wastewater flows into the reservoir, which mostly consists of infiltrates from the waste stockyard. It is possible that inflow of infiltrates with high levels of contamination from the stockyard could have continued for 30 years or more from the moment of its closure. A source of great concern is the progressive settlement of the pond bottom and infiltration of wastewater into the Triassic and Jurassic water reservoir at an estimated rate of 40 m^3/day;
- approximately 57 000 m^3 of alkaline sediment on the bottom of the reservoir. The basic problem presented by the wastewater-filled Górka pond is the high alkalinity of the waters (pH 12–14) due to the presence of hydroxyl ions, and the considerable variations in their composition depending on the depth of the reservoir. The wastewater profile indicates that its composition is variable and the content of impurities increases considerably as the pond depth increases [9].

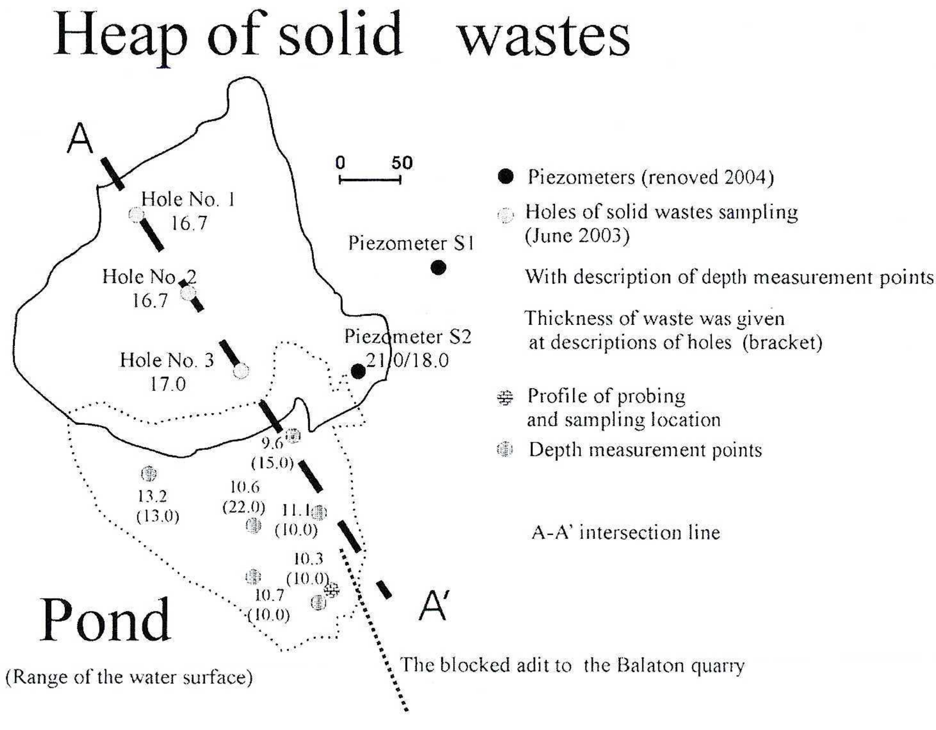

Fig. 2. Map of the stockyard in the Górka quarry (the solid line marks the range of the solid waste dump, the punctuated line marks the range of the free water surface of the reservoir) according to [6]

There is a systematic emission of impurities from the quarry:

- surface outflow from the reservoir has resulted in pollution of the surface water course in the river basin of the Chechło River,
- there is also infiltration of wastewater from the reservoir into underground water, including the No. 452 main underground water reservoir (Chrzanów) [2].

Swelling of wastewater in the quarry causes a serious hazard due to uncontrolled outflow of large amounts of alkaline wastewater from the Górka quarry in the direction of the town of Trzebinia.

The technological conception [6] proposes a multi-faceted solution for Górka quarry. The basic elements of the conception are:

- progressive draining of the heading of the old quarry – this will eliminate the hazard associated with emergencies and uncontrolled outflow of infiltrates;
- pumping out and cleaning of wastewater via the inverted osmosis method. After purification the wastewater (grade V quality water) will flow into surface waters, or into the sewage system, and residual "concentrate" of impurities (brine, slurry) will be consolidated and removed to a secure stockyard;
- elimination and processing (into a form similar to a concrete product) of slurry accumulated on the bottom of the settling pond, an amount of approx. 57 000 m^3 – this slurry will be used at land reclamation sites to seal off the stockyard surface consisting of high aluminium waste;
- outcropping of water sources in the northern part of the old quarry heading – the waste will be relocated to the remainder of the stockyard for aluminium waste and the surface will be sealed and regenerated. This will allow the regeneration of the original outflow regime from the sources thus solving the problem of wastewater infiltration from the quarry;
- macrolevelling of the area (in an amphitetric system) to restore the layer of cultivable land and repair the water mesh; final reclamation of the area and local monitoring of underground waters.

One basic problem that needs to be solved before implementing the reclamation program for the heading is the constant inflow of infiltrates and reflux of alkaline waste originating from the quarry. The technological conception for solving the problem of infiltration from the Górka quarry is presented in this paper.

PROFILE OF THE GÓRKA QUARRY HEADING

Górka quarry is located in a former quarry heading used for Upper Jurassic marl limestone extraction [3]. The immediate vicinity of the heading consists of Upper Jurassic formations and also, along a 100 m stretch on the southern side, Triassic dolomite, from which zinc and lead ores was extracted. In the bottom there are weak permeable formations from the lowest layers of the Upper Jurassic, with thickness in the order of 15–25 m.

In this area Triassic and Jurassic water-bearing stages occur. Hydrogeological conditions are complicated due to both the geological structure and interaction of zinc and lead ore mining and coal mining.

Mining operations in the Górka quarry led to dehydration of the area surrounding the heading, which caused the decline of previously existing springs and draining of wetness [3]. Before beginning waste disposal in the bottom of the heading, the quarry was equipped with a source with capacity of approximately 86 m^3/day. Water from the source was directed into a hollow in the bottom and the excess was channeled through an adit into the Balaton municipal quarry and on through the Ropka underflow into the Chechło River. Currently, outflow from the adit is directed to the Ropka, bypassing the Balaton reservoir.

Migration of underground water in the area in question generally proceeds in a southerly direction (Fig. 2). Triassic carbonated formations in the Trzebinia – Chrzanów area ensure that the inventory reservoir of underground water is of good quality. These advantages were the reason for the underground water area GZWP 452 Chrzanów being separated off in the main reservoir (Fig. 3).

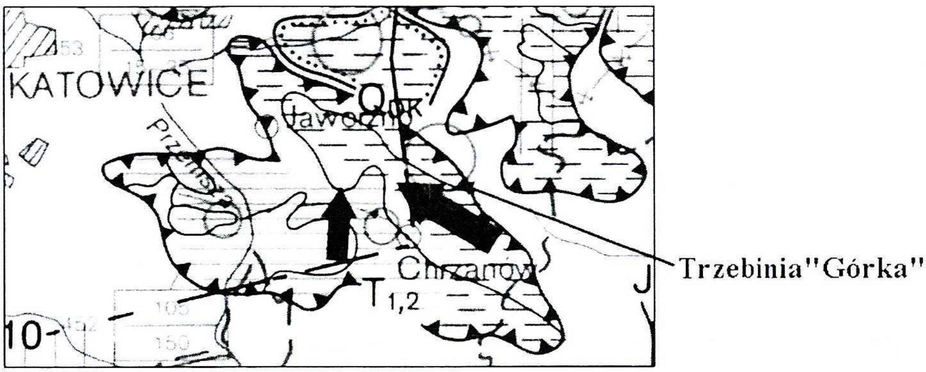

Fig. 3. Location of the quarry on the Map of the Main Reservoir Area of Underground Water (GZWP) according to [2]

The heading of the old Górka quarry is currently filled with wastewater to a level of approx. 355 m a.s.l. The excess water is carried through an adit to a municipal quarry and channeled into the Ropka water race [1, 6], which begins in the Balaton flood. The first 150 m of the water race is considered pure. However, from the place where water flows in from the Górka, the water quality is substantially decreased. The water race flows across heavily industrialized areas and also accepts water from rain drains. Its riverbed passes by a sewage treatment plant and enters the Ropa water race, which then flows into the Chechło River, the left-bank inflow of the Vistula River. The waters of the Chechło River are of grade II purity with regard to their physicochemical parameters and of grade III purity with regard to their biological parameters [1]. In the lowest downstream section the river also accepts mine water from Trzebionka Mine, the alluvions of which have high content of Pb, Zn and Cd. The river flows through the Chechło artificial water reservoir, which is situated below Chrzanów and is used for recreation purposes [1, 3]. The areas around Trzebinia are classified as being subject to a strong environmental influence from the mining industry. Many years of mine dewatering have caused drawdown of the underground water level which in turn affects surface waters. Many of the smallest underflows and water meshes have been drained, while the flow of water in the largest rivers has fallen off significantly [1, 3].

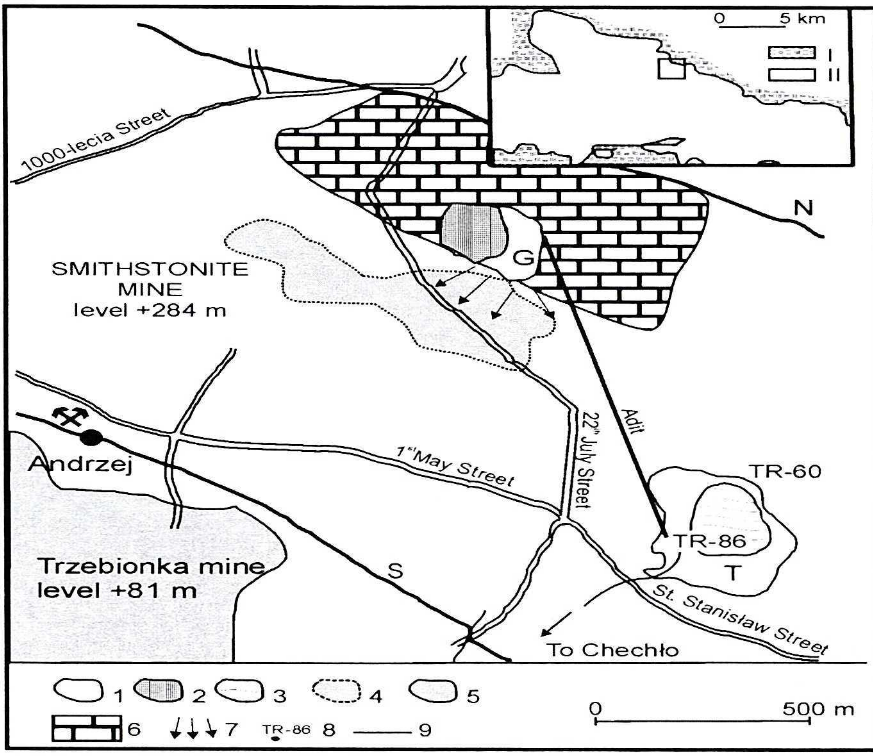

Fig. 4. Hydrogeological draft of the Górka stockyard area of waste in Trzebinia according to [3]; 1 – quarries: G – Górka, T – municipal quarry in Trzebinia; 2 – stockyard of industrial waste; 3 – the Balaton clean water reservoir; 4 – old abandoned orey cavings; 5 – cavings of Trzebionka zinc and lead ore quarry; 6 – Jurassic formations in the rift valley in the Trzebinia – Będzin zone; 7 – potential directions of pollution penetration on the boundary of the reservoir, including sections with undisturbed Triassic soil; 8 – water sampling location; 9 – the fault delineating the Trzebinia – Będzin zone: N – the northern separating Mesozoic formations from Palaeozoic formations; S – the southern zone separating the fault-horst structure from the Chrzanów syncline; the geological draft of GZWP Chrzanów (without upper formations from the Middle Triassic): I – outcrops of Paleozoic formations, II – range of lower and Middle Triassic formations

The hydrological balance of the area of the Górka quarry heading is based on three main components: supply, outflow and infiltration (Tab. 1). The percentage of individual components in this balance has changed over the years with changes in the approach to resolving inflowing water problems.

Infiltrate from the stockyard forms as a result of elution of soluble substances from solid waste by water precipitation and due to underground waters with lateral inflow to a heap from the Jurassic water-bearing stage. Elution by rainfall water is possible due to the heap being left without a hermetic cover on its surface. Contact with underground waters is the result of lack of isolation of the heap from the water-bearing basis. Backfilling of sources on the floor of the quarry by waste has created almost perfect conditions for leaching.

Before 1991, in natural conditions, infiltrated water flowed in through the adit to the Balaton quarry, and from there with superficial water races into Chechło. Closure of the adit by a barrier caused waters to accumulate. Up to 1996, swelling was kept at a level defined by ordinate + 345 m. This was made possible by pumping out approx. 124 m^3/day of wastewater, which flowed via the municipal sewage system into the sewage-treatment plant in Chrzanów. Difficulties maintaining the quality of cleaned wastewater after the outlet from the sewage-treatment plant led to pumping being discontinued as well as corrosion of sewerage wires by wastewater. Also, hard carbonated deposits precipitating during flow quickly decreased the pipe diameters.

Table 1. Balance of the water reservoir in Górka quarry in 2002 according to [4]

Supply	[m^3/day]	[dm^3/s]	Remarks
1. Inflow quantity	165.2	1.91	
– direct	78.8	0.91	Results of fall on the surface of quarry (7.1 ha including free surface of water and also surface of dumping ground of solid waste), rainfall 810 mm/year (mean 1930–1980) minus evaporation
– lateral	86.4	1.00	Inflow of underground water from Jurassic water-bearing floor, on the basis of average results of measurement before swelling (i.e. 60 dm^3/min
2. Overflow	93.6	1.08	Mean defined on the basis of measurement in period from March 2001 to August 2002, range of fluctuations 0–350 dm^3/min
3. Infiltration	71.6	0.83	Into underground water in Jurassic and Triassic floor, depends on water level in pond: in the nineties years, when pumping about 124 m^3/day maintained constant level defined by ordinate about + 345 m, its height could evaluate on about 40 m^3/day

The pumping operation was stopped in 1996. The level therefore rose over the next four years, which brought about the present situation. Currently, wastewater filling the southern part of the quarry and the level of swelling are determined by the position of gravitational overflow. Wastewater excess flows out through a gravitational overflow via a bore-hole to the adit and then through an open water race into the Chechło River. Rainfall levels and the quantity of water infiltrated into the underground water-bearing floor determine the quantity of outflow (Tab. 1) [3].

The formation of the reservoir has caused an increase in the level of underground water in the areas of the Jurassic water-bearing floor in the vicinity of the quarry and the solid waste heap.

The amount of infiltrates which have accumulated in the stockyard has been estimated at approx. 434 000 m^3 [2]. They include infiltrates in the reservoir and saturated heaps of solid waste. However, this estimate does not take into account the amount of underground waters polluted by infiltration waters within the areas of Jurassic water-bearing floor in the vicinity of Górka quarry. Water-saturated deposits at the bottom of the reservoir have not been included too.

Analyses of wastewater in the Górka pond are given in Table 2, while a profile of infiltrate-saturated solid waste is presented in Table 3. Table 2 also includes boundary values for grade V (poor quality to illustrate the condition of surface waters according to [8]. Analysis of wastewater composition indicates that it features:

- extremely high pH, approximated to a maximum value;
- high salinity, confirmed by high conductivity (4–24 times higher than the grade V standard), a high level of dissolved substances (6–30 times higher), high concentration of sodium, SO_4^{2-} (2–7 times higher) and F^- (twice as much);

- high concentrations of some elements, especially heavy metals: B (twice as much), Al (32–260 times more), Cr (2–5 times more), Fe (in the bottom layer 6–27 times more);
- high concentrations of TOC (3–23 times higher) resulting in an intense color (12–120 times more intense than grade V standard), high COD chemical oxygen demand (3–32 times more) and also a considerable deficit of dissolved oxygen (from 2 to 75% of the acceptable standard).

Table 2. Chemical analysis of wastewater in the Górka reservoir according to [9]

Parameter	Unit	Depth					Boundary values for V class
		0 m	3 m	5 m	10 m	bottom ~ 11 m	
Temperature	°C	24.0	7.2	7.0	10.2	11.8	> 28
Color	mg Pt/dm^3	600		5200	5700	5800	> 50
pH	–	11.69	13.8	13.32	13.07	13.34	> 9.0
Conductivity	mS/cm	14.398	35.780	45.070	63.790	71.130	> 3.00
Redox potential	mV	224	-121	-122	-121	-145	
Total dissolved solids	mg/dm^3	7628	14804	18986	27128	38966	> 1200
Dissolved mineral solids	mg/dm^3	4518	9017	10264	13164	19532	
Total hardness	mval/dm^3	0.21	0.24	0.26	11.26	63.07	
Suspended solids	mg/dm^3	< 10	< 10	< 10	538	n.o.	> 100
Chemical oxygen demand	mg O_2/dm^3		765	1010	1379	1311	
Dissolved oxygen	mg O_2/dm^3	2.83	O tl.	0.08	0.08	0.07	< 4
TOC	mg C/dm^3	63	265	347	463	460	> 20
Mineral alkalinity	mval/dm^3	51	118	170	240	240	
Total alkalinity	mval/dm^3	97	174	222	295	304	< 10
SO_4^{2-}	mg/dm^3	802	1658	1695	1839	1962	> 300
CO_3^{2-}	mg/dm^3	2760	3360	3120	3300	3840	
OH^-	mg/dm^3	95	1178	2242	3515	3344	
SiO_2	mg/dm^3	92	173	203	282	265	
P total	mg/dm^3	0.06	0.23	0.40	0.40	0.37	> 1.0
N-NO_3^-	mg/dm^3	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	> 50
N-NO_2^-	mg/dm^3	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	> 1.0
N-NH_4^+	mg/dm^3	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	> 4
N total	mg/dm^3	< 0.5	10.5	14.0	20.3	21.0	> 20
F	mg/dm^3	2.2		2.9	3.8	3.7	> 1.7
S^{2-}	mg/dm^3	0.25	0.26	0.38	0.32	0.29	
B	mg/dm^3	2.73	5.54			8.40	> 4.0
Ba	mg/dm^3	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	> 1.0
Fe	mg/dm^3	0.25	0.33	0.51	13.97	53.04	> 2.0
Mn	mg/dm^3	< 0.003	< 0.003	< 0.002	< 0.004	< 0.006	> 1.0
Sr	mg/dm^3	< 0.01	0.02	0.02	0.01	0.01	
Zn	mg/dm^3	0.010	0.021	0.027	0.051	0.061	> 2
Ti	mg/dm^3	0.01	0.01	0.01	0.02	0.03	
Al	mg/dm^3	25.2	54.8	68.9	115.7	206.7	> 0.8
Cr	mg/dm^3	0.145	0.347	0.372	0.435	0.407	> 0.10
Mo	mg/dm^3	0.29	0.92	1.30	1.78	1.67	

V	mg/dm^3	1.85	3.39	4.04	4.28	4.24	
Cu	mg/dm^3	0.021	0.016	0.015	0.011	0.014	> 0.100
As	mg/dm^3	0.90	2.60	3.63	4.81	4.72	> 0.100
Tl	mg/dm^3	0.04	< 0.01	< 0.01	< 0.01	< 0.01	
Ni	mg/dm^3	0.121	0.163	0.179	0.169	0.167	
Cd	mg/dm^3	0.011	0.020	0.027	0.031	0.026	> 0.005
Sb	mg/dm^3	< 0.01	< 0.01	0.22	< 0.01	< 0.01	
Be	mg/dm^3	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	
Sn	mg/dm^3	< 0.01	0.07	0.03	< 0.01	0.04	
Cr^{+6}	mg/dm^3	< 0.01	< 0.01	< 0.01	< 0.03	< 0.01	> 0.04
Co	mg/dm^3	< 0.001	0.002	0.002	0.001	0.002	
Pb	mg/dm^3	0.006	0.006	0.005	0.006	0.008	> 0.05
Se	mg/dm^3	0.002	0.003	0.003	0.005	0.005	> 0.04
Ag	mg/dm^3	< 0.01	0.02	0.05	0.02	0.05	
Ga	mg/dm^3	0.36	0.72	1.03	1.46	1.38	

Parameters for those exceeding V class limit marked in grey

Table 3. Chemical analysis of the infiltration-saturated solid waste heap according to [6] (Wastewater sampled from different depth of three holes drilled in the heap)

Measurement	Unit	Hole No. 1, depth:			Hole No. 2, depth:			Hole No. 3, depth:		
		2.1 m	7.4 m	16.0 m	2.3 m	8.0 m	16.0 m	2.0 m	8.0 m	16.0 m
pH	–	12.52	12.68	12.83	12.68	12.79	13.02	12.42	12.75	12.65
Conductivity	mS/cm	11.497	17.529	27.910	16.136	21.730	48.480	10.364	31.970	25.150
Dissolved substances	mg/dm^3	3296	5408	12810	4194	6078	18868	4876	13318	10778
Dissolved mineral substances	mg/dm^3	2336	3383	4471	2662	3970	7106	2988	9064	7187
Total hardness	mval/dm^3	5.41	1.67	1.09	0.28	0.23	0.04	8.64	8.57	3.20
Mineral alkalinity	mval/dm^3	40	60	85	55	72	104	40	85	75
Total alkalinity	mval/dm^3	58	85	105	72	100	155	70	128	108
Ca	mg/dm^3	108.2	33.3	21.8	5.6	4.6	0.8	146.8	146.3	55.2
Mg	mg/dm^3	2.24	0.46	0.35	0.08	0.02	0.01	15.84	15.27	5.34
Na	mg/dm^3	1264	1917	2559	1504	2176	3916	1116	3625	3042
K	mg/dm^3	19.4	33.3	49.9	33.8	44.9	93.7	29.0	127.0	103.0
Cl^-	mg/dm^3	38	30	120	70	42	110	80	250	210
SO_4^{2-}	mg/dm^3	239	329	712	144	337	1184	218	2448	1790
HCO_3^-	mg/dm^3	0	0	0	0	0	0	0	0	0
CO_3^{2-}	mg/dm^3	1080	1500	1200	1020	1680	3060	1800	2580	1980
OH^-	mg/dm^3	418	665	1235	722	836	1007	190	798	798
SiO_2	mg/dm^3	92	142	170	76	128	196	108	268	234
P total	mg/dm^3	0.56	0.51	0.78	0.38	0.19	0.24	1.25	0.18	0.76
B	mg/dm^3	1.43	2.15	3.44	1.37	2.49	5.26	1.31	11.05	8.85
Ba	mg/dm^3	0.06	0.01	0.01	< 0.01	< 0.01	< 0.01	0.28	0.22	0.08
Fe	mg/dm^3	52.13	14.01	9.30	2.98	1.64	0.05	67.73	70.32	12.01
Li	mg/dm^3	0.07	0.04	0.05	0.06	0.31	0.78	0.23	0.17	0.10
Mn	mg/dm^3	0.265	0.066	0.044	0.018	0.008	< 0.001	0.808	0.346	0.129

Sr	mg/dm³	0.17	0.05	0.04	0.02	0.02	< 0.01	0.31	0.34	0.28
Zn	mg/dm³	0.122	0.021	0.011	0.005	0.012	0.019	0.774	0.474	0.235
Ti	mg/dm³	2.81	1.02	0.68	0.17	0.16	0.01	3.76	3.88	0.11
Al	mg/dm³	70.9	33.9	28.3	45.5	44.9	28.1	153.6	114.0	45.6
Cr	mg/dm³	0.177	0.114	0.503	0.142	0.276	1.28	0.136	0.073	0.027
Mo	mg/dm³	0.07	0.07	0.40	< 0.01	0.08	0.78	0.07	0.83	0.58
V	mg/dm³	1.23	1.92	2.07	1.11	1.40	2.34	3.90	8.76	5.51
Cu	mg/dm³	0.104	0.088	0.049	0.044	0.033	0.047	0.571	0.099	0.023
As	mg/dm³	0.20	0.53	0.93	0.28	0.45	1.46	0.41	3.30	1.00
Tl	mg/dm³	< 0.01	0.02	0.04	< 0.01	0.02	< 0.01	< 0.01	< 0.01	< 0.01
Ni	mg/dm³	0.102	0.147	0.148	0.092	0.108	0.133	0.343	0.492	0.317
W	mg/dm³	< 0.01	< 0.01	0.03	2.98	< 0.01	0.08	< 0.01	< 0.01	0.13
Cd	mg/dm³	<0.001	0.009	0.014	0.005	0.007	0.018	0.005	0.034	0.011
Sb	mg/dm³	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.17	0.12
Be	mg/dm³	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Sn	mg/dm³	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02	< 0.01	< 0.01
Co	mg/dm³	<0.001	< 0.001	<0.001	< 0.001	<0.001	0.002	0.003	0.002	0.004
Pb	mg/dm³	0.046	0.009	0.007	0.002	0.003	<0.001	0.293	0.649	0.099
Ag	mg/dm³	0.02	< 0.01	< 0.01	< 0.01	< 0.01	0.19	< 0.01	< 0.01	< 0.01
Ga	mg/dm³	0.19	0.30	0.31	0.24	0.36	0.55	0.18	0.59	0.36

Compared to the results of research from 2000 the present condition [9] shows an increase of mineralization throughout the reservoir profile. A growing tendency was recorded for all the above-mentioned designations, with the exception of chromium and dissolved oxygen content.

The chemical parameters for the water-saturated solid waste heap have considerably lower values. In the event of a decrease in the level in the reservoir, flow of less mineralized water from the heap will be started up and after that inflow of underground water from the Jurassic water-bearing floor, which is characterized by the smallest degree of mineralization (for example water from piezometer Sl according to data from February 2004: pH 10.6, 803 mg/cm³ of dissolved solids, conductivity of 0.78 mS/cm, SO_4^{2-} – 245 mg/cm³, Al – 0.85 mg/cm³, COD – 60.5 mg O_2/cm³). This will result in a graded dilute of infiltrates during a decrease in the reservoir level.

CONCEPT FOR THE SOLUTION TO THE INFILTRATION WATER PROBLEM

The first variant of the solution to the problem of infiltrate from the quarry of high aluminium content consisted in intake of infiltrates from the stockyard with use of abyssal wells and possibly ditches, and now also includes channeling of the infiltrates to water races for dilution. This would be possible after examination of the underflow system of the Górka reservoir using geochemical methods. Such a solution was successfully implemented on the chromic heap in Alwernia, which has an area of 19 ha and has been used for the past seven years [5].

The second alternative, which is based on hydrogeological analysis, involved locating intakes of water sources and forming a rivulet to allow run-off of intake waters into the Ropa stream. This solution was formulated in a concept designed specifically to meet the requirements of the Górka heading reclamation [6].

The proposed concept [6] of the solution assumes complete liquidation of the existing water reservoir and activation of a run-off through the blocked drainage adit. It will allow the water flow regime to be restored to its previous condition. If this solution is implemented, approximately 165 m^3/day of water that should be managed will flow into the heading.

Archival geological data shows that the lateral supply of the heading occurs in the vicinity of the source zone situated in the northwest part of quarry. This zone is currently covered by waste. In order to take in water flowing from the Jurassic water-bearing floor it is necessary to remove the waste and uncover the sources. The waste should be removed down to the bed-rock and flowing waters should then be directed through an artificial profiled flume at the bottom of the quarry to a pond situated at the lowest point of the quarry. Due to the natural occurrence of clayey formations there will probably be no need for additional plugging around the flume and at the bottom of the reservoir. To uncover the source zone output, displacement of approximately 130 000 m^3 of waste will be necessary. The waste will be displaced into the remainder of the stockyard, which will allow for its proper formation and complete reclamation consisting of:

– covering of the remaining stockyard area of solid waste with a solidified slurry layer taken from the bottom of the pond, which will allow it to be completely sealed. The surface of the covered stockyard should be 40 000 m^2, which means (assuming coat thickness of 50 cm) use of about 20 000 m^3 of solidified slurry [6];
– sealing of the stockyard with a ground layer with a thickness of approximately 30–50 cm;
– management of this area according to the program.

The proposed location of the flume and water reservoir will also allow for management of rainfall flowing into quarry.

Excess of water from the reservoir will be channeled into a drain adit using an overfall to achieve it stable level in the projected reservoir in situation of continual supply of lateral inflow and also periodical surface-flow of rainfall.

On the whole, such factors as infiltration or evaporation could be omitted from the proposed solution.

It is necessary to analyze the quantity of inflowing lateral Jurassic waters as it highlights the progress of the liquation of the Siersza mine – from year 2002 to the last inundates. That process will probably cause a gradual increase in the efficiency of Jurassic sources which are in hydraulic contact with the Triassic and Carboniferous water-bearing floors. The existing prognosis defines the time necessary to reconstruct the natural water relations in this region, which are incorrect; at this point in time it is difficult to establish the rate of this process.

The paper [9] proposes creating a park in the heading. The central point of this park would be a valley of the post-marl heading that would be cleaned from sediments and drained from infiltrated water. From the eastern and southern side of the heading the natural slope of the heading would be retained. The northern part would be formed from waste removed from the Jurassic sources zone. Land masses from excavation would be used to build an embankment forming the western part of valley. Slopes in the southern-western part of the valley would be formed into wide (4 m) ground terraces 2 m in height forming an amphiteric system. Terraces would be formed on a substructure of ground masses consisting of solid waste excavated from above the Jurassic sources zone and the hollow flume of the water reservoir at the bottom of the quarry. A layer of draining system, an insulation layer and a 30 cm layer of rich soil would be placed on the substructure.

Terraces covered with turf would be freely planted with trees and bushes. Point wise, the layer of rich soil should have a thickness of approximately 1 m in areas of tree plantations. An ellipsoidal glade surrounded with a reservoir with water plants is planned for the axis slopes of the heading, forming an amphiteric at the bottom of the valley. A dyke situated on the axis of assumption would be the only entrance to the glade. The amphiteric interior would be a recreational area with the possibility of organizing occasional performances there. The glade would act as a large stage and the terraces formed on the slope of the heading would act as a place for spectators. Ramps leading along the traverse would enable movements among the terraces. Ramps would also be located at both shoulders of the "amphitheatre": on the sides and western slopes of the heading.

This kind of development would provide an opportunity to transform this post-industrial area into a vibrant natural and cultural focal point for the city. Revitalization of this area is all the more desirable as it is situated in the city centre.

The water from Jurassic sources would be taken in to flow into projected water reservoir to be laid out along the natural slope of the quarry. The reservoir with steady water flow, equipped with plants filters, would be connected with an adit draining off the excess water into the Balaton reservoir.

The reservoir is a hollow in the bottom of the quarry and acts as a receiver of water coming from the eastern slope of the heading as well as from rainfall. This solution should improve the climatic condition. The depth of the reservoir is variable depending on the need to get proper slopes, with an average depth of about 2 m. The presence of water plants would encourage birds to inhabit the area and the formation of a secondary biotope.

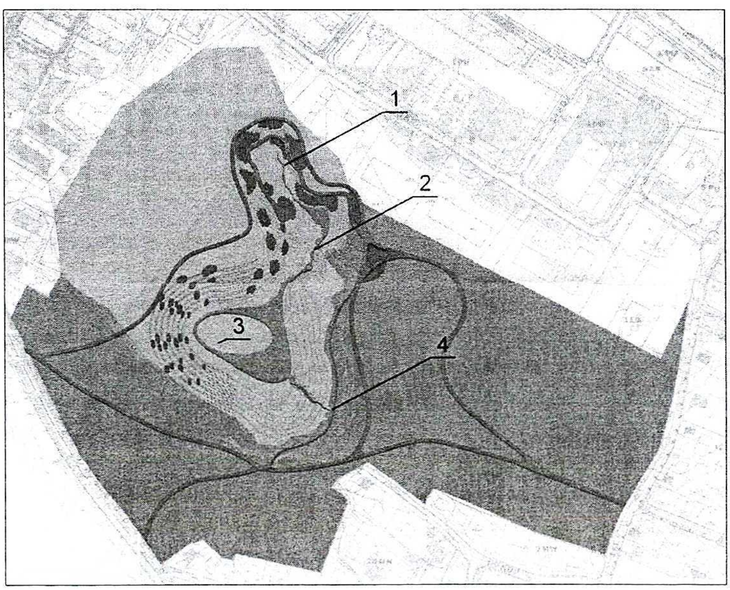

Fig. 5. Final form of the Górka heading; 1 – uncovered sources, 2 – artificial rivulet, 3 – pond, 4 – water outlet into the adit

CONCLUSIONS

The constant inflow of infiltration waters into the Górka reservoir from the waste stockyard is one of the basic problems which need to be solved before the reclamation program for the whole heading can be implemented. The proposed solution assumes that first liquidation of the existing wastewater reservoir should be carried out and water run--off through the actually blocked drain adit should start. The next stage involves disclosure of the uncovered Jurassic water source and construction of an artificial rivulet to drain waters to the existing Ropa flow.

The third stage involves reclamation of the entire post-marl Górka heading and its transformation into a landscape park. Such a project would eliminate the negative influence of surface and underground water on the environment. It would also eliminate the risk of serious accidents associated with reservoir overflow containing almost 500 000 m^3 of alkali waste. The implementation of this project is in accordance with the local development plan, and would also constitute a basis for further post-industrial waste land revitalization.

REFERENCES

[1] Albinus J., M. Szuwarzyński, L. Konosonoka, E. Krog, S. Christensen, C. Skov, K. Zacharz: *Industrial Waste Contaminated Lake Trzebinia, Poland*, Technical Note No. 1; Description of pollution, Projekt DANCEE w Polsce; Zbiornik wodny zanieczyszczony odpadami przemysłowymi w Górce 2002, http://www.nordichouse.pl/umtrzebinia/menu. php?id=notes.

[2] Bukowski J.: *Sprawozdanie z prac na obiekcie Wyrobisko „Górka" w Trzebini (wiercenia, analizy chemiczne, badania mineralogiczne)*, PUPH „PROGEO" Sp. z o.o., Katowice 2003.

[3] Czop M., J. Motyka, M. Szuwarzyński: *Zagrożenie jakości wód podziemnych w zbiorniku GZWP 452 (Chrzanów) odciekami ze składowiska odpadów „Górka" w Trzebini;* Gospodarka Surowcami Mineralnymi, **18**, 2 (2002).

[4] Kleczkowski A.S. (red.): *Mapa obszarów głównych zbiorników wód podziemnych (GZWP) w Polsce wymagających szczególnej ochrony*, CPBP 04.10, AGH, Instytut Hydrogeologii i Geologii Inżynierskiej, Kraków 1990.

[5] Kowalski Z., A. Kozak: *Protection of ground waters from migration of infiltrates from chromic waste storage and method of treating these infiltrates*, Water, Air, Soil Pollution, **128**, 115–137 (2001).

[6] Kowalski Z., J. Kulczycka, R. Strzelecki, P. Rudnicki: *Opracowanie optymalnego sposobu rekultywacji wyrobiska pomarglowego „Górka" wypełnionego odpadami*, Politechnika Krakowska i IGSME Kraków 2005 (niepublikowane).

[7] Projekt DANCEE, nr ref: 124/03 1-0265, *Zbiornik wodny w Trzebini (Polska) skażony odpadami przemysłowymi– Opis zanieczyszczeń*, Nota techniczna nr 1, Konspekt, wrzesień 2002.

[8] Rozporządzenie Ministra Środowiska z 11 lutego 2004 r. w sprawie klasyfikacji dla prezentowania stanu wód powierzchniowych i podziemnych, sposobu prowadzenia monitoringu oraz sposobu interpretacji wyników i prezentacji stanu tych wód (Dz. U. nr 32, poz. 284).

[9] Rudnicki P., A. Mioduszewski, Z. Kowalski, K. Fela: *Technological conception of the treatment of alkaline wastewater collected in the „Górka" reservoir situated in Trzebinia commune area*, Polish Journal of Chemical Technology, 2, 26–33 (2006).

Received: February 26, 2007; accepted: June 13, 2007.