Chemical Composition of the Extremely Alkaline Water within "Górka" Pit Lake (Chrzanow Region, South Poland)

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Abstract

Industrial pit lake "Górka" was formed in inactive Jurassic limestone quarry after cessation of the open-pit dewatering. Main problem for water environment quality in this area is connected with 500.000 m^3 volume, extremely alkaline leachate gathered in flooded quarry. Average pH of the leachate from Górka pit lake is between 11,5 and 13,4 with high concentration of sodium (2-6 g/L) and some microelements (Al, As, Cr, Mo, P and V). The water gathered within pit lake has a rare hydrochemical type Na-CO_3 or Na-CO_3-OH, with predominance of the sodium, bicarbonate and hydroxyl ions. The chemical composition of the extremely alkaline leachate was formed as a result of the groundwater contact with the industrial red-mud wastes containing about 5-10% of sodium carbonate.

Key words: extremely alkaline environments, extremely alkaline leachate, red-mud wastes, Górka pit lake, Chrzanow region

Introduction

The pit lakes are the important element of the water environment in the post-mining landscape. Artificial water reservoirs quite often gather the polluted water, with chemistry controlled by processes of the groundwater interaction with mining waste and/or dewatered ground containing secondary weathering minerals. The vast number of the scientific articles dealing with the problem of the pit lakes water chemistry is connected with reservoirs impacted by AMD or ARD (brown coal, coal and metalliferous sulfide ores).

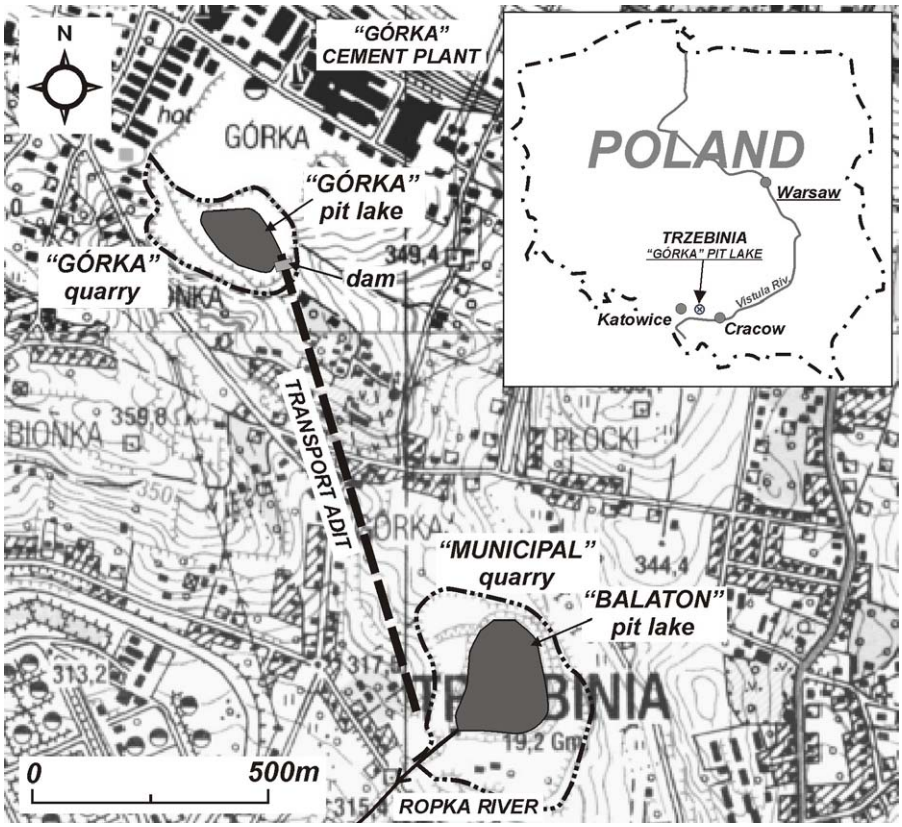
Górka pit lake is a probably the one of the most alkaline water bodies in the Earth, with pH highest than typical soda lakes. Unique feature of the water from Górka pit lake is also the highest concentration of the organic matter and anoxic condition within whole water body.

Górka pit lake is located within build-up area of the Trzebina Town, in the Silesian-Cracow region of the south Poland (Fig. 1). Artificial water reservoir was formed in a consequence of errors and negligence during the process of the Jurassic limestone quarry abandoning. The main error in the process of the quarry reclamation was connected with belittle of the groundwater inflow. The groundwater recharge to open-pit was relatively low, only about 60 L/min. (83 m^3/d). During quarry operation the mine water inflowing to the open-pit sump was directed to the surface drainage ditch and next to the transport and drain adit. It's interesting that adit was created in the 16^{th} century for dewatering of the Zn-Pb ore deposits and about 1930 was adopted for transportation of the raw material from "municipal" quarry to the cement plant located in the neighborhood of the "Górka" quarry (Czop et al., 2002).

The next important negligence making the possibility for formation of the highly polluted artificial reservoir was the industrial waste disposal in the northern part of the quarry. The deposited wastes were origin from the processes of the aluminum oxide production from the non-bauxite raw material, and contain from 5% to 10% of the sodium carbonate (soda). In the last period of the waste disposal some quantity of the sludge was also deposited in the "Górka" quarry. During last stage of the waste disposal, just before the quarry abandoning, the main zone of the groundwater inflow to the open-pit was backfilled by red-mud wastes. As a result of the water-waste interaction the extremely alkaline and also highly polluted leachate was generated. Initially the leachate was directed to the waste-water treatment plant, but difficulties and disturbances in treatment processes excluded this opportunity. Then the alkaline leachate flowed to the 1 km-long drainage adit and created the serious hazard for aquatic life in the Ropka river. The main problem was connected with possible health hazard to the people in the area of the "Balaton" pit lake (flooded deepest part of the "municipal" quarry) – the popular recreational water reservoir.

Protection of the "Balaton water reservoir was the reason for non-consider and harmful decision of the concrete dam building near entrance of the transport adit to the "Górka" quarry. As a consequence of the closing of the inflow way of the polluted water the open-pit was filled by approximately 500 000 m^3 of the extremely alkaline leachate (Fig. 2).

Figure 1 *Location of the "Górka" pit lake and also other important objects*



The existence of the extremely alkaline water reservoir in the central part of the Trzebinia Town urbanized area also create environmental hazard for water environment, especially for groundwater within Jurassic and Triassic aquifers. The "Górka" pit lake is a important menace to recreational functioning of the "Balaton" pit lake. Extremely alkaline water body is located about 30 m above the adit entrance to the "municipal" quarry and in the worst-case scenario after dam failure the all volume of the caustic leachate will be inflow to the mentioned above open-pit until complete drying of the "Górka" pit lake. The concrete dam actually is the key element for the protection of the environment against significant disaster. Dam was built in 1991 with conception of the temporary stoppage of the mine water flow to the transport adit, so after 17 years period of the concrete material contact with the caustic leachate the serious leakage is observed on the dam's face. Actually the polluted water from "Górka" pit lake is pumping off, purifying and directing to the Ropka river.

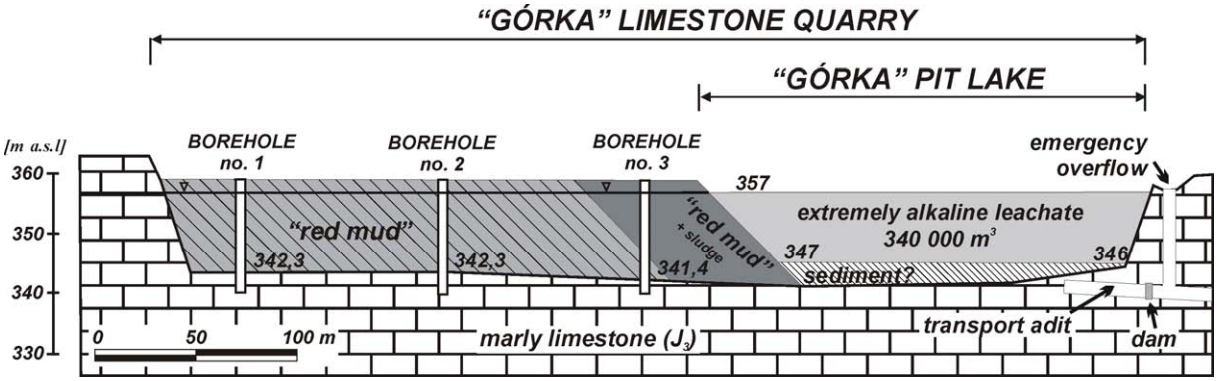
Limnology of the "Górka" pit lake

Artificial water reservoir existing within the part of the abandoned "Górka" quarry has a irregular shape, similar to the equilateral triangle with sides length range from 200 m to 250 m. The water body area attain the value of 3,1 ha.

Depth of the described pit lake was reconstructed on the base of the archival topographic and mining maps and also aerial photographs. The average value of the reservoir reached the value of 15 m. In the central part of the flooded quarry the bottom was expected on the depth about 17-18 m. The measurements of the pit lake depth reviled the significantly less reservoir depth especially in the central and northern part. The difference between reconstructed and measured depth in this zones range from 2 m to even 7 m. Reason for this phenomenon is actually unknown, but possible it's due to slope failure, precipitation of the minerals and occurrence of the mine infrastructure elements or non-

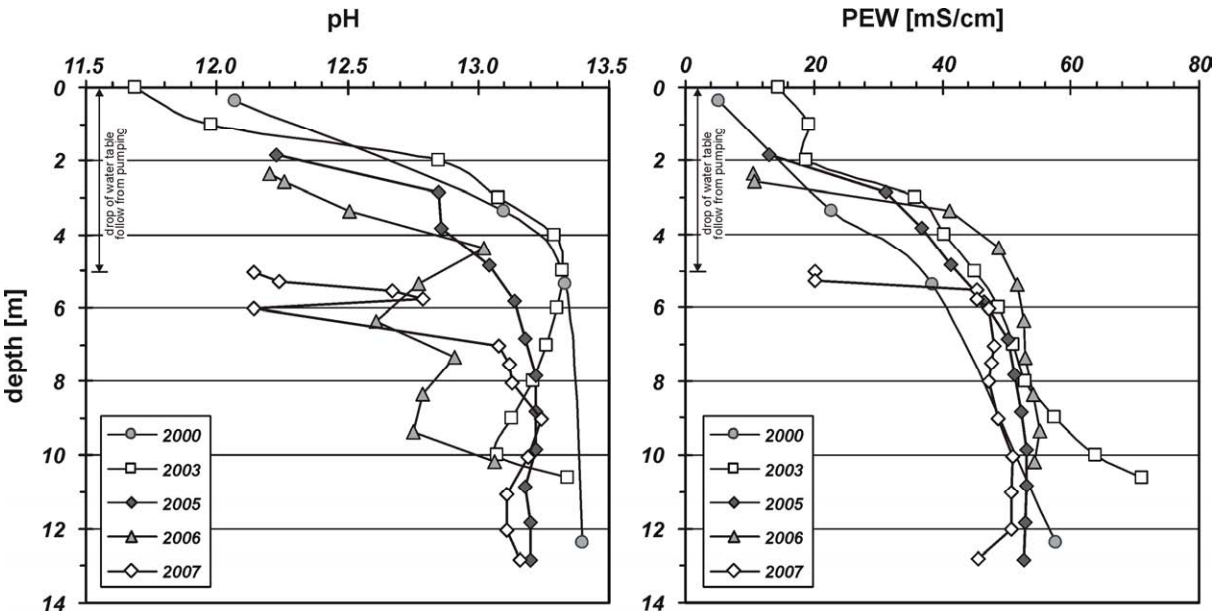
registered disposal of the waste material. Average depth of the "Górka" pit lake obtained from direct measurements is 11 m (Czop et al., 2005).
The relative "Górka" pit lake depth reached the value of about 5,5% or 7,5%, which is depend on the used average reservoir depth - 11 m (from direct measurements) or 15 m (from reconstruction). This value in comparison with the typical values for the pit lakes (10-40%) is relatively low. Relative depth of the "Górka" pit lake is close rather to the maximum values reporting for natural lakes (2-5%) (Castro, Moore, 2000).
The "Górka" pit lake contain about 340 000 m^3 of the extremely alkaline leachate, which was formed as a result of the groundwater interaction with industrial wastes (mainly "red mud") deposited in the north-eastern part of abandoned quarry. In addition about 160 000 m^3 of the caustic solution is gathered within porosity space of the "red mud" wastes (Czop et al., 2004).

Figure 2 *Schematic cross-section of the "Górka" limestone quarry*



Hydrochemisty of water from „Górka" pit lake
As was depicted above the Górka pit lake is a probably the one of the most alkaline water bodies in the Earth, with pH highest than typical soda lakes. Roadcap et al. (2005, 2006) stated that pH of the extremely alkaline groundwater from Lake Calumet region of Chicago range from 11,2 to 12,8. The highest reported in scientific literature pH is origin from steel slag infilling of wetland.
The pH values measured in the profile of the "Górka" pit lake typically range from about 11,7 to 13,4. The lower pH values are observed for shallow water layer, which is the effect of the precipitation recharge. In the deeper part of the pit lake profile pH of the water range from 12,5 to 13,4 (Fig. 3).

Figure 3 *pH and electrical conductivity in the profile of the "Górka" pit lake*



Water electrical conductivity in the "Górka" reservoir is relatively very high. The stratification of the water column within pit lake is occurring, the shallow water layer is characterized by EC range from 5 mS/cm to about 20 mS/cm. The deeper water layer typically has a EC exceeding the value of 40 mS/cm. The maximum value of EC, about 70 mS/cm was measured in year 2003, in the zone close to the quarry bottom. As a result of the water pumping from "Górka" pit lake the thickness of the shallow water layer, with lower values of depicted above parameters, significantly decreased.
Similar pattern of concentration changes in the "Górka" pit lake profile is observed for all chemical constituents. The deepest part of the reservoir is occupying by water containing about 2-3 times greater loads of particular pollutants than in a shallow, surface layer.
The water gathered within "Górka" pit lake has a rare hydrochemical type Na-CO_3 or Na-CO_3-OH, with predominance of the sodium, bicarbonate and hydroxyl ions. Concentrations of the sodium range from 2 g/L to 10 g/L. Water samples contain also the relatively high concentrations of the aluminium (11-430 mg/L), vanadium (1,2-5,4 mg/L), arsenic (0,6-5,2 mg/L), chromium (0,2-4,9 mg/L), molybdenum (0,3-2,6 mg/L) and gallium (0,3-1,7 mg/L) (Czop et al., 2002, 2004, 2005).
Unique feature of the leachate from Górka pit lake is also the highest concentration of the organic matter. The measured concentration of the dissolved organic carbon in water column of the Górka pit lake range from 100 to 800 mg/L. In a consequence of the high pH and also occurrence of the organic matter within the water body of the Górka reservoir the extremely anoxic condition was observed. The redox potential measured in the lake profile range from +100 mV in the thin upper zone (0,5 m thickness) to –400 mV in the deepest part of the lake.

Conclusions

"Górka" pit lake contain the water with extremely high pH range from about 11,7 to 13,4. Chemical composition of water within "Górka" pit lake is formed as a result of soluble constituent leaching from industrial waste (red-mud type) disposed in seventies in north – west part of the quarry. Migration of the leachate plume impact on groundwater and also surface water quality.
Serious environmental hazard of the "Górka" pit lake, especially the menace to recreational functioning of the "Balaton" reservoir were the reasons for beginning of the extremely alkaline reservoir remediation. Remediation started with effect from summer 2005. Actually the caustic leachate is pumping off, purifying and directing to the Ropka river
Pumping of the water from "Górka" pit lake is connected with increasing homogenization of the water column within reservoir. Water suction is occurring from the reservoir surface, than the shallow layer with lesser polluted water is removing. Pumping of the water also resulted in the intensification of the Jurassic groundwater inflow to the flooded quarry. This process is responsible for decreasing of practically all analyzed constituent concentrations in the reservoir water profile. Exception to the rule is applying to the sodium because the concentration of this constituent increasing significantly in the consequence of water pumping from "Górka" reservoir.
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