AGH Journal of Mining and Geoengineering • Vol. 36 • No. 2 • 2012

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UTILIZATION OF SURFACE- AND GROUNDWATER FOR POST-MINING OPEN PITS RECLAMATION IN LIGNITE MINING

1. Introduction

The development of water basins in the pits of opencast mines is related to a series of different problems which appear in association with natural and anthropogenic conditions. The necessity for the water utilization of the mine's pit is a consequence of mining the mineral resources located beneath groundwater level. Drainage of the rock-mass in the extents of the mining excavation allows for creation of land conditions for mineral exploitation. However, after mining of the deposit is finished, the pits have to be adapted to functioning in water conditions. Water conditions are the target conditions of functioning for the opencast pits. This means that it is necessary to conduct earthworks, engineering works and hydrotechnical works before the flooding of the pit can begin, which happens in a relatively short period of time.

2. Stability of benches and slopes

The drainage of open pits allows for the maintaining of relatively steep inclinations of benches and slopes. Introduction of water in the rock-mass creates hydrostatic and hydrodynamic head forces. The force of the hydrostatic pressure causes a worsening of mechanical parameters (cohesion and angle of internal friction) which decreases the angle of natural repose and increases porous pressure. The waterflow towards the pit causes the force of hydrodynamic lift to become apparent. The flow pressure creates a lifting force which results in the suffosion of ground material. The lift forces create significant changes in slope stability conditions. Water outflow from a bench may lead to re-profiling of the suffosion-type

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landslides. These processes occur in particularly loose, porous rocks. In typical conditions occurring during exploitation of deposits using open-pit method, problems with slope stability manifest most often in lignite mines.

Figure 1 presents the results of stability calculations for a slope in an open-pit lignite mine for various groundwater levels. The results of these calculations show that when the water level rises, the stability conditions significantly worsen. The calculations were performed for an exemplary slope on the assumption of hydrodynamic equilibrium maintained by drainage of slopes of the flooded pit.

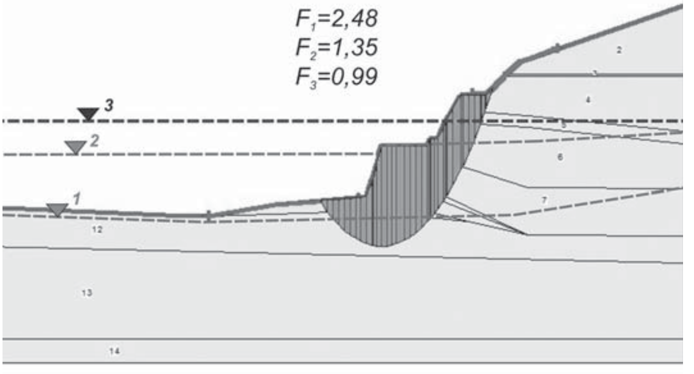

Fig. 1. Slope stability indicator for various water levels in the final pit lake calculated by Janbu method[3]

The calculations conducted show that during the flooding of the pit, it is necessary to maintain the hydrodynamic balance within the slopes of the reservoir. Furthermore, in the final stage of mining works it is necessary to re-profile the slope in order to improve the stability conditions.

Because of the negative balance of earth masses, the reconstruction of the slope profile is limited to a correction of the final slopes inclination using available overburden material. It is therefore necessary to conduct water reclamation of pits in such a way that the range of the essential earthworks is minimised and simultaneously the safety requirements in the direct vicinity of the pit are maintained.

In order to maintain stability conditions, one must ensure the hydrodynamic equilibrium of groundwaters in the proximity of the pit lake. Excessive pressure of surface water in relation to groundwater pressure allows for the consolidation of rock material constituting the benches and slopes of the open pit. As improvement in hydrodynamic balance conditions is possible through three methods:

1) through maintenance of drainage with a barrier of dewatering wells located outside the borders of the pit and simultaneous drop of the pumped waters to the open pit,
2) by the drop of waters coming from outside the cone of depression in quantities allowing for the maintaining of excessive water pressure in the pit in relation to the groundwater level,

3) by using both aforementioned methods simultaneously. The essence of such method of flooding has been depicted in figure 2.

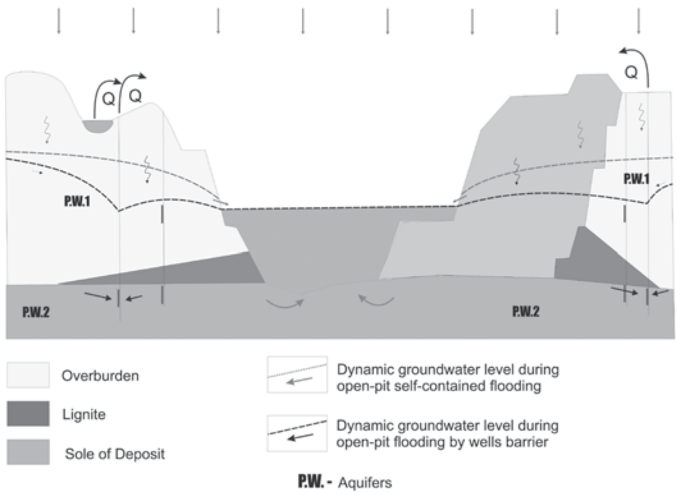

Fig. 2. Flooding of open pit with the use of surface and groundwaters [2]

After flooding is finished, new conditions of the balance equilibrium of the newly created pit lake formulate. As a result of the evaporation of water from the open water level, the deficit of water is replenished by underground reacherge, however this direction of water flow is not favourable from the point of view of maintaining stability. During the design of slope inclination one must take into account the projected water level in the pit and the extents of the pit lake's catchment.

3. Water quality in the final basin

Dewatering of the rock-mass causes a decrease of groundwater pressure in the extents of depression cone. As a result, atmospheric oxygen is delivered to the water-bearing environment. The change of conditions causes oxidizing chemical decay of the overburden rocks. Sulphide minerals are the most susceptible to chemical decay. The oxidation of dispersed pyrite is these a threat to the mine water quality. The oxidation (decay) process of iron sulphides can be noted as follows:

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + 2H_2SO_4 \quad (1)$$

$$H_2SO_4 \rightarrow H + HSO_4 \rightarrow 2H + SO_4 \quad (2)$$

Both atmospheric air and oxygen-rich infiltration a water can be the source of oxygen. As a result of oxydation, pyrite decays into easily dissoluble sulphide minerals and water solution of sulphuric acid. The decay of this acid enriches the groundwater in sulphates. This subsequently results in a releasing of hydrogen cations and decreases the water's pH reaction. The acid reaction of groundwater causes further dissolution of the rock material creating the ground's frame. The neutralization of acids take place at the expense of the enrichment of groundwater in dissolved components. A hydrochemical type of water is the subject of the mineralogical composition of rocks creating the water-bearing medium and solubility of particular minerals.

The above-mentioned hydrogeochemical phenomena unfavourably affects the pit flooding process. The dynamics and scope of these unfavourable changes depends on the mineralogical composition of the rocks in the extents of the depression cone. In the case of open-pit lignite mining in Poland, the existence of dispersed pyrite is related to formations from Neogen period.

Turning off the drainage system causes renewed water inflow into the water-bearing environment and the transport of contaminants to the final reservoir. Their cumulation in the pit threatens degradation of the newly formed lake. One may prevent this by flooding the final pit with waters coming from outside the cone of depression. A drop in uncontaminated water allows for the remediation of contaminants, but also for reducing the yield of groundwater stream flowing into the open pit. This outcome is possible by causing excessive pressure of water in the basin in relation to the pressure of groundwater.

Hydrochemical types of waters flowing into an exemplary flooded open pit have been shown in figure 3.

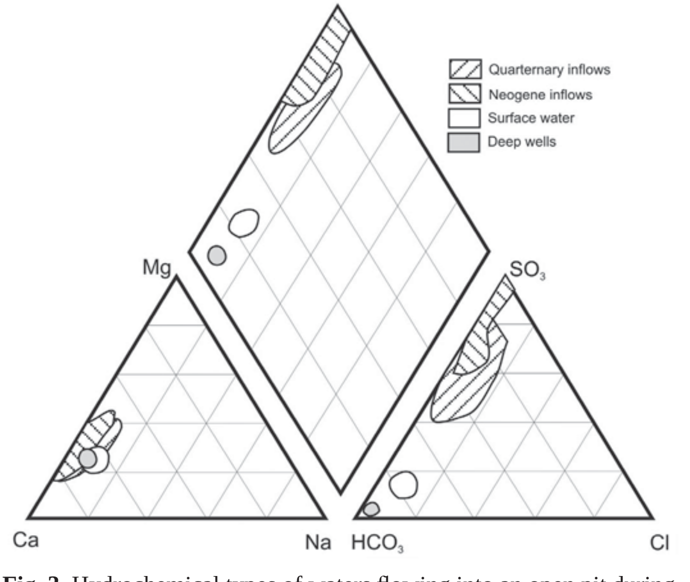

Fig. 3. Hydrochemical types of waters flowing into an open pit during its flooding (source: own study)

The completion of the final pit formation usually concludes the period of post-mining terrain reclamation. At this moment the active influence on the basin, which was carried out as a part of the mining activity, ceases. The main forces now deciding on further transformations in the pit lake and in its surroundings are natural forces existing in nature.

4. Water management in the catchment area of the pit lake

Thermal changes are the main force driving the water circulation in lakes. In a moderate climate most lakes are subjected to a circulation twice a year, namely during autumn and spring circulation. Prolonged periods of stagnation occur in the summer and winter between these circulations. In ideal conditions the entire volume of water circulates in the period of one year. The larger the volume of water located in the bottom area of the reservoir, the slower the process of water exchange which takes place. If the reservoir is too deep, the hypolimnion may be subjected to circulation which is too slow, which causes its mineralisation and thus a lack of the possibility for its lifting towards the epilimnion zone. Such reservoirs therefore circulate only to a limited depth. One may then notice existence of a so-called chemocline zone (a zone of sudden change of water mineralization) and the vertical stratification of water. This phenomenon is often present in deep pit lakes [4].

Water circulation is also dependent on factors such as wind force or the morfology of the reservoir's bottom. It is therefore important to properly design the shape of the basin and to morphologically configure the surrounding terrain. Furthermore, proper design of forest reclamation of the lake's surroundings, including above the water benches and overburden dumps is also meaningful. The above-mentioned factors allow for using the force as a mechanism for improving lake water circulation. The idea of this mechanism has been presented in figure 4.

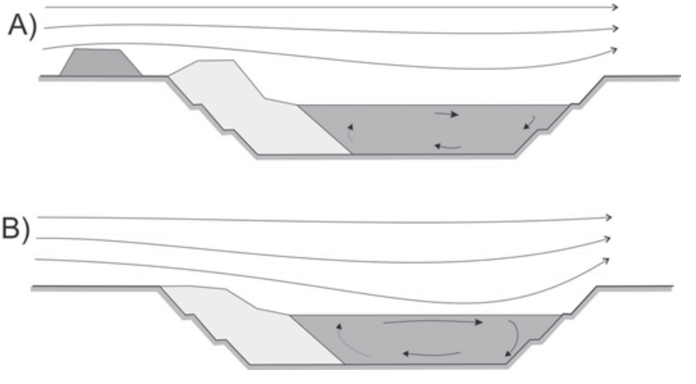

Fig. 4. Circulation of pit lake's water in various conditions of surrounding terrain configuration, A) uplifted overburden dump, B) surrounding of the reservoir without terrain obstacles [2]

The permanent water exchange may be ensured by the inclusion of the lake in to the hydrographic network. However, pit lakes are often without a run-off. Exchange of water with the surroundings often takes place through groundwater flow, atmospheric reacherge and evaporation from the lake's surface. Such reservoirs are susceptible to degradation.

Surface water inflow from the catchment's area to the lake causes the introduction of various contaminants. Nitrogen and phosphorus compounds present in the waters from the catchment which when transported to the lake are the main threat. These contaminants cause an increase of the trophicness and a decrease in water oxidation, which eventually leads eutrophication and to its marshing. The eutrophication process is especially dangerous to shallow reservoirs in which the deep zone, the so-called hypolimnion, has insufficient depth. Due to the considerable volume of the deep zone, pit lakes of the meromictic type may receive significant amounts of contaminants. Post-mining lakes are usually of a pseudoeutrophic type [1]. However the water circulation takes place only to a limited depth.

In relation to the cessation of mining activity, the water quality in the lake is influenced by hydromorphic and morphologic factors like: the area of the lake's catchment, the length of shore line which is the border of contact between the lake and the surroundings and the character of the catchment's utilization. Eventually, the susceptibility of the formed lake to degradation is dependent on the character of the catchment. This directly influences the possibilities and conditions of the reservoir's utilization.

5. Summary

The formation of open-pit mining excavations in which the exploitation is conducted beneath the original groundwater level forces water reclamation and utilization. The requirements for slope inclinations in land and water conditions are dissimilar. Calculations of stability performed for a chosen slope in an open-pit mine show that the slopes require the necessary corrections of the inclination angles of benches and slopes before the pit is flooded. Due to the negative balance of earth masses, the scope of works is unfortunately limited. However the drainage of slopes during water reclamation is a way for maintaining their stability.

Groundwater flow through the dewatered zone usually results in a worsening of the water quality. The cause of this process is due to the existence of easily dissoluble iron pyrites in the overburden rock formations. The utilization of water from the drainage of neighbouring mines can contribute to a remediation of contaminants and significantly decrease the groundwater stream yield. As a result the water quality in the pit lake improves.

Surface- and groundwater usage for open pit flooding is a necessary element of water reclamation. Such activities contribute to the improvement of safety conditions in the surrounding areas of the pit lake and raise the attractiveness of the formed reservoir. This results in the increased values of the reclaimed terrains which is beneficial to both the entrepreneur conducting the reclamation, local community and users of the basin and its surroundings.

Target conditions of the reservoir's functioning depend on the method of utilization of the lake's catchment and the proper use of nature's forces which form the environment in the extents of the pit lake. At the earliest stage of reclamation design, it is important to take into account all of the factors that increase the water exchange and its periodical circulation.

The important element in forming the environment is to settle the order of water and sewage management as well as the utilization of the pit lake's catchment area.

The publication was created as a result of statutory works no. 11.11.100.597

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