Hydrogeological problems connected with closure of mines in the Upper Silesian Coal Basin

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Abstract: Consequences of the cessation of mine pumping up and flooding the mines with inflowing waters has been described. The problem of existing hydraulic connections between adjacent coal mines in the Upper Silesian Coal Basin and the water hazard for the mines adjacent to the flooded ones has been presented. Discussed also has been the methodology of prediction the course in time of the process of flooding the group of interconnected mines. The changes of water quality in flooded coal mines have been characterized.

1 ANALYSIS OF THE CONSEQUENCES OF MINE DRAINAGE CESSATION

The hydrogeological problems connected with mine closure concerns chiefly the correct prediction of changes of water conditions in the rock masses and on the ground surface. The cessation of pumping water out of the mine causes their flooding with water from the natural inflow. The water table in mine workings stabilizes depending on the geological structure and mining situation in the closed mine and the adjacent ones.

The closure of same particular mines may cause changes of hydrogeological conditions on important areas and especially the uncontrolled water flows from flooded mine to the adjacent ones may occur, causing water hazard for them. Therefore an analysis of consequences of cessation the mine drainage is carried out before starting the closure of a mine. Such analysis should take into consideration the water hazard for adjacent mines, as well as influence of mine flooding on the natural environment and water management in the region.

In the framework of water hazard evaluation the following should be determined:

- the predicted datum of water table in workings basing in the analysis of connections with adjacent mines,
- the course in time of flooding,
- possibilities of water hazard for adjacent mines.

In the range of evaluation the influence of flooded mine on the natural environment should be determined:

- predicted mineralization and chemical composition of mine waters,
- predicted influence of the flooded mine on existing water intakes,
- predicted influence of mine flooding on phreatic waters and surface water conditions.

– ways of shafts closing in the aspect of hydrogeological conditions.

In the region of flooded mine and in the adjacent mine the current monitoring of water conditions in rock masses and in mine workings is carried on to be able undertaking the proper safety measures and to verify the elaborated prognoses.

2 HYDRAULIC CONNECTIONS BETWEEN MINESAND THE MAXIMUM WATER RISE

For the correct prognosis of the course of water rising in a mine the substantial is the difference between the separate mines and the joint ones.

The separate mines are the ones that have an independent pumping system and aren't connected with any adjacent mine. The joint mines are the ones, that compose of some interconnected parts independently drained by separate pumping systems, and the ones having connections with other mines.

Switching off the pumps in a separate mine causes flooding the workings with waters from natural inflow. The water table in mine workings rises gradually till it reaches the level of hydrodynamic equilibrium with water-bearing horizons in the surrounding rock masses. If the static water table stabilizes near the ground surface, the possibility of land inundation should be taken into consideration. Such a case needs a separate analysis.

The switching off the pumps in a joint mine causes flooding the workings up to the lowest connection with an adjacent mine, after which water flows by gravity from the flooded mine to the adjacent one. The adjacent mines not always are prepared to receive the additional water inflow from the closed mine and in such case there is necessary to continue pumping water in the closed mine to assure safety for the adjacent ones.

The flooding of mine workings may be disturbed if there are closed water stoppings in the mine. During the flooding of mine workings the water pressure at one side of the stopping may exceed its strength, causing its damage and unexpected violent flow of water. Therefore, before closure of the mine the free water flow across all kinds of stoppings should be ensured.

For evaluation of water hazard of mines adjacent to flooded one and elaboration of the prognosis of flooding process of a joint mine, the reconnaissance of all connections with adjacent mines and determining the lowest ones is necessary. Thereby the possible uncontrolled paths of water migration in the rock masses fractured by mine works should be taken into consideration. The zones of thinning or weakening of border pillars caused by mine works, exploitation fracturing or tectonic deformations may be substantial.

There is always possible some error of mapping the mine workings due chiefly to independent orienting of the both adjacent mines. Sporadically it may happen, that some existing working would not be plotted on the mining map.

The strength of border pillars may be evaluated, basing on the accepted methods of dimensioning the water safety pillars in mines. The additional factors

that may influence the strength of tightness of pillars should be thereby taken into consideration.

In the northern part of the Upper Silesian Coal Basin, within the reach of Chief Saddle and Bytom Trough, 38 coal mines are interconnected, creating the very large group of jointed mines. Therefore, in spite of total or partial closure of some mines, cessation of their drainage is not possible. It is illustrated on the Figure 1, where the block scheme of connections between mines in this part of the Basin is presented.

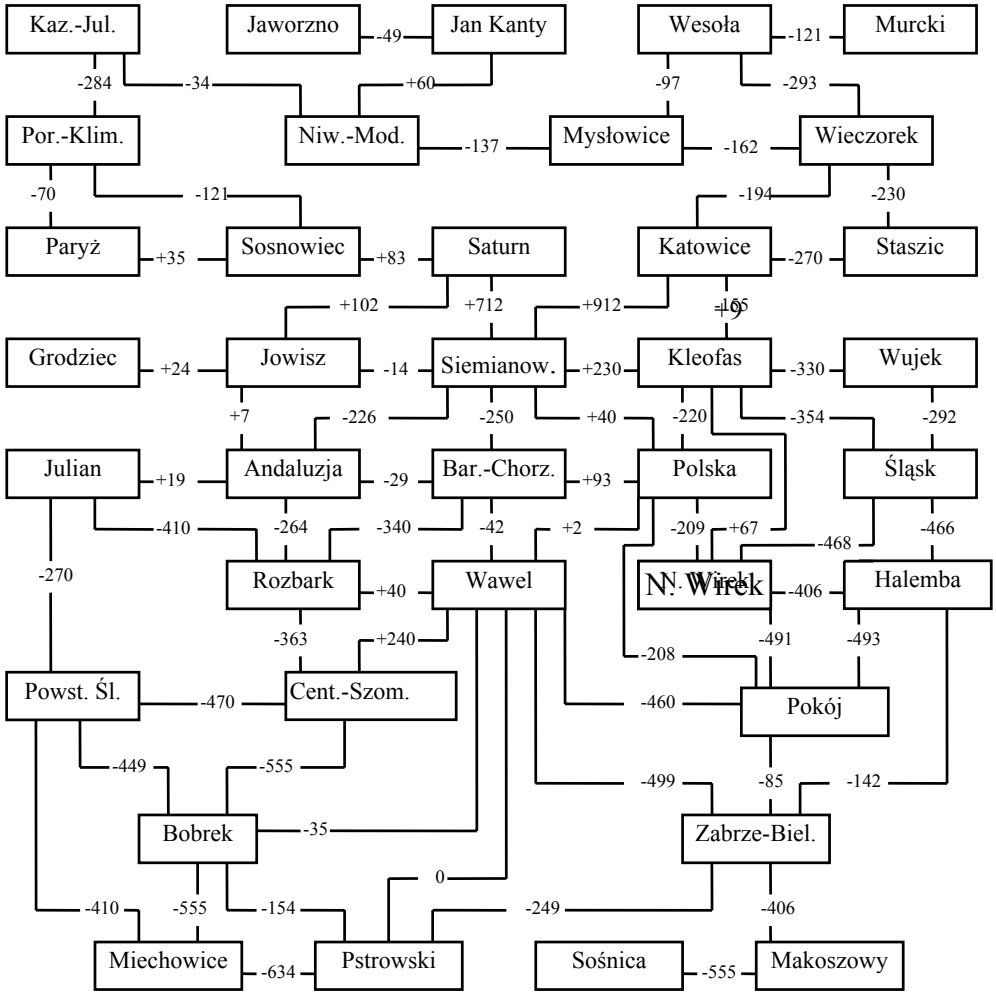

Figure 1 Connections between coal mines situated in he northern part of Upper Silesian Coal Basin (Poland)

Up to date the following closed or under closure mines are drained considering the water hazard for adjacent mines: "Barbara-Chorzów", „Siemianowice", "Saturn", "Paryż", „Sosnowiec", „Grodziec", „Jowisz", "Porąbka-Klimontów", „Andaluzja", „Powstańców Śląskich", „Bobrek", „Szombierki", "Pstrowski" and „Gliwice". Only small parts of the lowest situated

workings in these mines have been flooded and the higher situated levels are drained. This drainage will continue till the adjacent active mines will be closed. In several coal mines being under closure, some small parts of deposit have been separated, and thereon some smaller collieries have been created to exploit the resting coal reserves. These collieries continue the mining drainage. Closing of the mentioned mines doesn't cause any substantial limitation of the quantity of mine water disposed into rivers.

A lot of mines are separated between them with narrow border pillars, whose strength against breaking under unilateral water pressure isn't known. However if the workings on both sides of the pillar are filled with sand stowing, one can suppose, that the pillar won't break when the closed mine will be flooded, but only some low rate seepage across pillar is possible. This opinion is however controversial, as the regions of border pillars are usually inaccessible and therefore their state is not known. Also the toughness of stowing on both sides of the pillar isn't known.

Owing to the net of connections between the mines in northern part of the Upper Silesian Coal Basin, they may be drained in the future by central pumping stations. The pumping stations would be located in mines having the lowest situated connections, through which water will flow from adjacent mines to the pumps. As an example of such solution may serve the pumping station „Chorzów" that drains workings of the closed „Barbara-Chorzów" Mine and partly also of „Siemianowice" Mine.

To minimize costs of closed mines drainage, the replacement of stationary pumps with deep-well pumps is predicted. The pumps would be hanged on delivery pipelines in suitably prepared shafts. Such solution doesn't need maintaining of the crew down in the mine and therewith eliminates the need of pump room ventilation, maintaining of a second shaft and so on. The solution is expensive as to the investment costs, but the operating costs are much lower, then by stationary pump stations.

The drainage of closed mines causes, that in the near future the quantity of mine water disposed into rivers won't decrease, however some change of proportions between quantities of water and salt disposed into Vistula and Odra river catchment areas may appear.

The maintaining of partial drainage of closed mines will make impossible restoration of the primary hydrostatic level in rock masses, therefore no phenomena of land inundation will appear.

3 FORECAST OF THE MINE FLOODING PROCESS

Evaluation of flooding time of the particular mine levels needs the determination of water capacity of workings and drained rock masses as well as knowledge of the rate of predicted water inflows to mine workings.

The water capacity is calculated as the product of volume of exploited seam and of the water capacity factor (Rogoż, 1978). The rocks in the range of mine drainage influence is drained, however the estimation of its water capacity is in general difficult. It is made, basing on the reconnaissance of hydrogeological conditions of the region under analysis. In rock masses composed of sandstones, the water capacity of rocks may be much higher than the one of workings.

To determine the forecast of flooding process and its dynamics during the mine closure, besides the mine workings analysis, characteristics of mine water inflows is necessary. It should contain information concerning the disposition of water inflows in mine workings, location of concentrated inflows and their rates, as well as determination of total inflows to particular levels or parts of the mine.

Due to usually complicated system of mine workings and complicated hydrogeological conditions of the drained rock masses, construction of the reliable numeric model, that would allow to predict accurate the inflows changes in course of mine flooding, would be extremely work-consuming and often impossible to do. For the practical evaluation of these changes, introduction of some simplifications is necessary. Usually the simplified calculation scheme of inflows is adopted, basing on the following assumes:

- in the course of mine flooding, the water table in mine workings rises,
- in every phase of flooding, the water inflows to the workings situated above the water table stay unchanged, while the inflows to flooded workings decrease proportionally to the water depression,
- all waters inflowing to the mine, originate from the confined aquifers, whose piezometric levels stable on the same datum.

The flooding time of mine workings is the quotient of their water capacity and water inflow rate. Due to the complicated geometry of mine workings and irregular disposition of mine workings in the vertical section, as well as the differentiated inflows, the calculation of flooding time is as a rule burdened with important error. To decrease this error the water capacity of the workings and time of their flooding is calculated in some depth intervals, for which the average inflow rates are determined. The calculation procedure is like this:

1) determination of the levels limiting analytical intervals,
2) calculation of the water capacities of workings in the intervals,
3) calculation of the mean water inflows to particular intervals,
4) calculation of the flooding times in accepted intervals.

Calculations of flooding time of a group of mines are usually troublesome and time-consuming, because they are as a rule effectuated in several variants, in dependence on the choose of mine flooded as the first. To make the calculation easier, the computer program LIKOP has been elaborated in the Central Mining Institute. The program enables construction of mining - hydraulic models of groups mines interconnected at various depths. Such models enables numeric simulation of the time course of flooding of a group of mines, starting with an optional mine.

The results are presented in following forms:

- table of water capacities in analytical intervals and cumulated times of their flooding with marked connections between mines (Table 1);
- table of flow rates through the connections between mines (Table 2);
- sketch of displacement of analytical levels and connections between mines (Figure 2);
- graph of the time course of flooding the mines (Figure 3).

The results of the flooding time calculation of some closed mines in the Upper Silesian Coal Basin are presented in the Tables 1 and 2 and on the Figures 2 and 3.

The graph on Figure 3 presents the flooding times of particular mines, starting with the mine no. 3. The continuous lines present the heights of water table in particular mines as a function of time. The vertical dotted lines show the water flow from one mine to the adjacent one, when the water table in the first mine achieves the connection level. When the water flow between mines starts, the water table in the first mine remains at the stable level, equal to the connection datum, till the water table in the adjacent mine rises up to this level. Afterwards the water table in both mines rises simultaneously.

4 CHANGES OF WATER QUALITY IN FLOODED MINES

Chief process causing the changes of chemical composition of the water flowing across the goaf or staying therein is dissolving of the products of pyrite oxidation.

The pyrite oxidation may proceed in an oxygenic or oxygen-free way. In the first case the oxidizing agent is oxygen from the air or dissolved in water, in the second one - the trivalent iron. Result of these processes is increasing of acid reaction of water.

In the process of pyrite oxidation by trivalent iron an important part play microbes Thiobacillus ferrooxidans. The participation of microbes in pyrite oxidation depends on the environmental conditions (Twardowska, 1981). There has been stated, that the maximum oxidation of Fe^{2+} into Fe^{3+} takes place in the temperature of 37^0C and the most intensive growth of microbes is observed in the temperature of 28^0C with pH = 3.0 - 4.2.

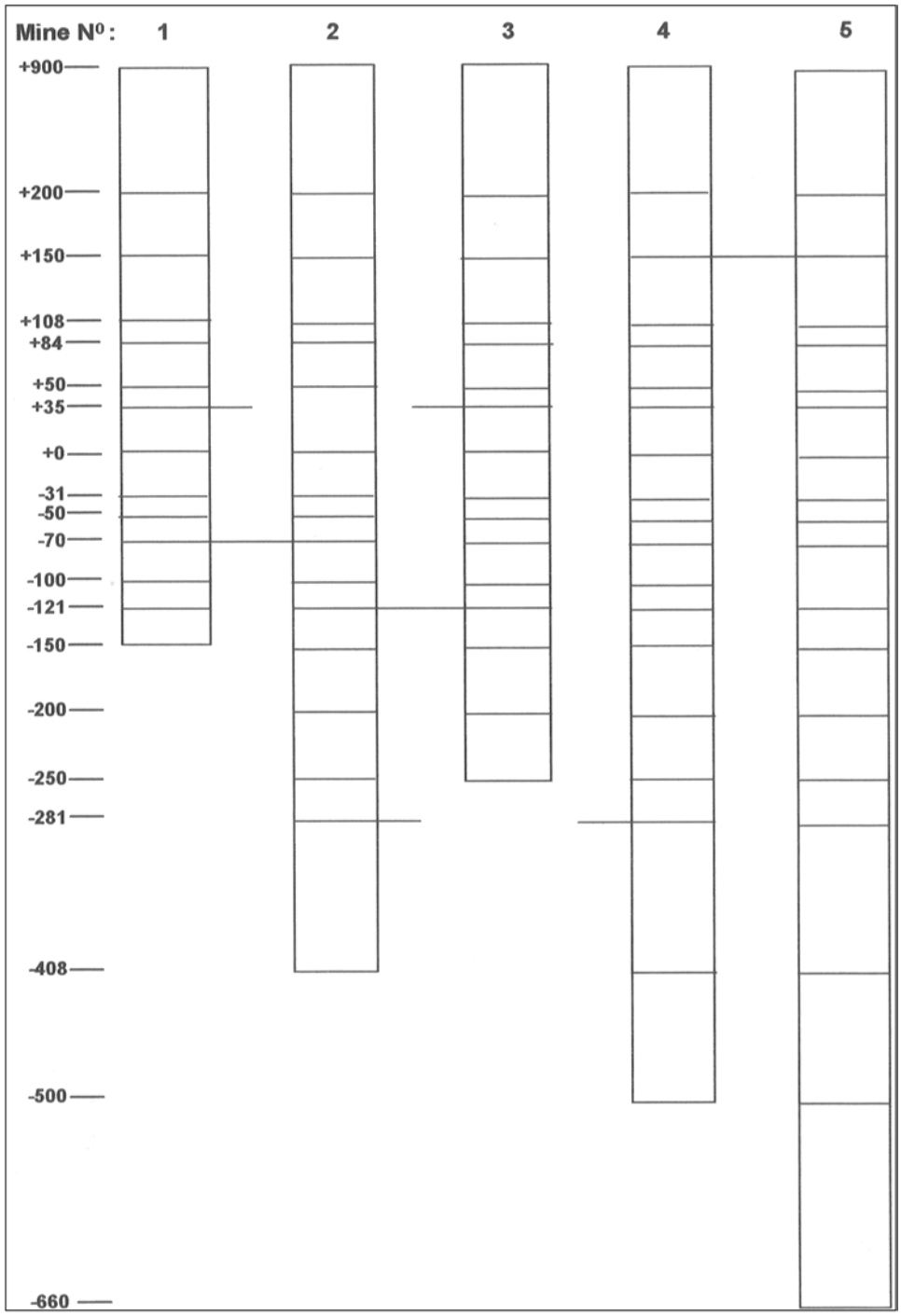

Figure 2 Scheme of connections between mines

Table 1 Capacities o mine workings and cumulated times o flooding the levels

Level	Mine 1		Mine 2		Mine 3		Mine 4	
+300.0	3290200	0	3512700	0	1988700	0	440500	0
+200.0	4162700	0	1900650	0	2073491	0	2001750	0
+150.0	8794100	4355	1900650	4355	2073491	4355	2001750	4355 -
+100.0	3929312	3781	697200	3781	663517	3781	722018	3781
+84.0	8349788	3578	1481550	3578	5860282	3578	1534288	3578
+50.0	2892800	3073	653625	3073	2585418	3073	676892	3073
+35.0	5701700	2884 -	1525125	2884	- 9130000	2884	1579414	2884
+0.0	1908964	2428	1603440	2428	3090056	2428	1534288	2428
-34.0	898336	2229	754560	2229	1454144	2229	539903	2229
-50.0	747000	2140	943200	2140	567960	2140	674879	2140
-70.0	974500	2070 -	- 1190400	2031	851940	2031	1012318	2031
-100.0	320334	2048	2181100	1894	1379900	1894	1080198	1894
-121.0	442366	2041	3434224	1687 -	- 613368	135	1491702	1687
-150.0	----------	2031	5921076	1473	1057532	89	2571900	1473
-200.0			6113155	1115	149500	11	2912440	1115
-250.0			4156945	738	----------	0	1980460	738
-284.0			1022500	185 -			- 4335900	481
-400.0			----------	135			2928500	304
-500.0							----------	185
-660.0								

Level	Mine 5	
+300.0	1041667	0
+200.0	520833	0
+150.0	- 530833	0
+100.0	156667	0
+84.0	354167	0
+50.0	156250	0
+35.0	364583	0
+0.0	354167	0
-34.0	166667	0
-50.0	208333	0
-70.0	312500	0
-100.0	218750	0
-121.0	302083	0
-150.0	520833	0
-200.0	520833	0
-250.0	354167	0
-284.0	1208333	0
-400.0	1041667	0
-500.0	1666667	0
-660.0	----------	0

Numbers of mines

1 - „Paryż”
2 - „Porąbka-Klimontów”
3 - „Sosnowiec”
4 - „Kazimierz-Juliusz”
5 - Theoretical mine with unlimited delivery of pumps

Table 2 Flows through connections between mines

No of connection	Level of connection	From mine No	To mine No	Flow rate m^3/day	Flow after time days	Initial inflow m^3/day	Total inflow m^3/day	Pumps delivery m^3/day
1	-121,0	3	2	13587	135	7090	20677	10000
2	-284,0	2	4	20770	185	3970	24740	10000
3	-70,0	2	1	22712	2031	21770	44482	10000
4	+150,0	4	5	22643	4355	10000	32643	500000

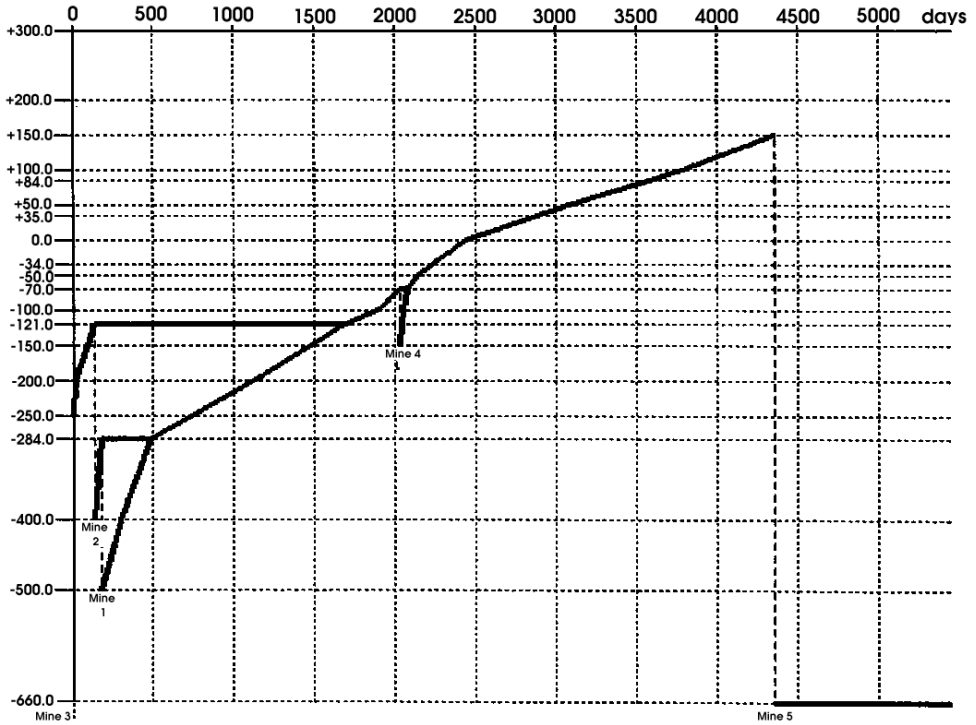

Figure 3 Graph of the course of flooding the mines in time

The sulphuric acid originating as a result of pyrite oxidation may decompose other, not sulphide minerals occurring in surrounding rocks, and above all liberating the heavy matals (Becker et al., 1997).

Besides the chemical processes occurring in the goaf, the processes of infiltration and exchange of water have a substantial contribution to the formation of chemical composition of water in flooded workings. Intensity of these processes depends on the depth of flooded workings and on the hydrodynamic conditions in the neighbourhood of the flooded mine.

The rate of water inflow to the mine after its flooding will depend on the height at which will stabilize the water table in flooded workings. In the case of separate mine the water table will stabilize at the average height of the piezometric level of underground waters and the water inflow to the mine will

decline. In the mine workings and their surrounding will form a new hydrodynamic balance. In the case of a joint mine, the water table will stabilize at the height of the lowest connection with adjacent mine and the inflow rate will be function of this height.

The another factor influencing the chemical composition of water in flooded workings is the degree of exposition of the Carboniferous structure, on which depends the possibility of alimentation of Carboniferous layers drained by mine workings. In general may be stated, that there is a very distinct difference of the chemical composition of stagnant waters resting in reservoirs in goaf and the waters in reservoirs in which flow takes place. The lower water mineralization is also observed in reservoirs situated near the seam outcrops or at the small depths, in the zone of intensive water exchange.

The waters flowing through goaf may be in general divided into two basic types, depending on the HCO_3^- and SO_4^{2-} ions contents: the HCO_3-Ca-Mg type and SO_4-Ca-Mg type. The contents of HCO_3^- and SO_4^{2-} ions in waters changes depending on occurrence of hydraulic contacts, that make possible alimentation of goaf from infiltration zone. Such conditions occur in the areas hydrogeologically exposed, where the mine workings form a vast net draining water-bearing horizons in the overburden deposits.

The waters having hydraulic contact with aquifers in overburden are usually of the type HCO_3-Ca-Mg and often are exploited by communal intakes of important yields. There is however to be emphasized, that in regions of exposed Carboniferous layers the waters in workings may be additionally contaminated with some pollutants migrating from storage yards of industrial and mining wastes.

In the old workings with limited alimentation and small flow of infiltrating water as well as in workings situated at the greater depths, waters of SO_4-Ca-Mg type dominate. There are some premises indicating the dependence of sulphate content in water on the time of coal exploitation. It may result from the differences in exploitation's methods being in use and from leaving parts of coal seams not exploited.

In the analysis of influence of hydrodynamic conditions on chemical composition of water in old workings, the temperature factor should be also taken into consideration. Besides the local fires in mines, that may change the chemical composition of water, the sock temperature resulting from the geothermal degree may play an important part. In the case of great differences of mine workings depths, the phenomenon of convective flow may occur. This phenomenon may render difficult the restoration of a natural hydrochemical stratification of water in mine workings, in accordance with aquifers in the surrounding rock masses, and also may activate the chemical processes occurring in waters filling the workings. There has been stated, that the convective flow in mine workings occurs, when the average temperature of water exceeds 30^0C. At present in the Upper Silesian Coal Basin the closed mines are still drained, therefore the depths differences of flooded workings are relatively small and it may be recognized that the convective flow in the workings does not occur.

5 SUMMARY

The closure of mines may cause changes of hydrogeological conditions on important areas and especially the uncontrolled water flows from flooded mine to the adjacent ones may occur, causing water hazard for them.

For the correct prognosis of the course of water rising in a mine the substantial is the difference between the separate mines and the joint ones.

Switching off the pumps in a separate mine causes flooding the workings up to the piezometric level of water in the surrounding rock masses. In some cases it may cause the land inundation.

The switching off the pumps in a joint mine causes flooding the workings up to the lowest connection with an adjacent mine, after which water flows by gravity from the flooded mine to the adjacent one. The adjacent mines not always are prepared to receive the additional water inflow and in such case there is necessary to continue pumping water in the closed mine.

In the northern part of the Upper Silesian Coal Basin, within the reach of Chief Saddle and Bytom Trough, 38 coal mines are interconnected. Therefore, in spite of closure of some mines, cessation of their drainage is not possible. The drainage of closed mines causes, that in the near future the quantity of mine water disposed into rivers won't decrease.

To minimize costs of closed mines drainage, the central pumping stations are projected and replacement of stationary pumps with deep-well pumps is predicted. The pumps would be hanged in suitably prepared shafts. Such solution is expensive as to the investment costs, but the operating costs are much lower, then by stationary pump stations.

Evaluation of flooding time of the particular mine levels needs the determination of water capacity of workings and drained rock masses as well as knowledge of the rate of predicted water inflows to mine workings. Calculations of flooding time of a group of mines are usually troublesome and time-consuming, therefore the computer program LIKOP has been elaborated in the Central Mining Institute. The program enables numeric simulation of the time course of flooding of a group of interconnected mines.

Chemical composition of the water in flooded goaf changes due to the dissolving of the products of pyrite oxidation, infiltration and exchange of water. Substantial is the degree of exposition of the Carboniferous structure, on which depends the possibility of alimentation of Carboniferous layers drained by mine workings.

In the case of great differences of mine workings depths, the phenomenon of convective flow may occur, caused by temperature differences. This phenomenon may render difficult the restoration of a natural hydrochemical stratification of water in mine workings, in accordance with aquifers in the surrounding rock masses.

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Problemy hydrogeologiczne związane z likwidacją kopalń w GZW

Marek Rogoż, Ewa Posyłek

Streszczenie: W artykule została przedstawiona ogólna charakterystyka połączeń między kopalniami usytuowanymi w północnej części Górnośląskiego Zagłębia Węglowego, w rejonie siodła głównego i niecki bytomskiej oraz wynikająca z tych połączeń konieczność odwadniania kopalń zlikwidowanych. Omówione zostały sposoby odwadniania dotychczas zlikwidowanych kopalń oraz projekty ich modyfikacji. Szczególny nacisk położony został na przewidy-wane w najbliższym czasie zastosowanie do odwadniania zlikwidowanych kopalń pomp głębinowych oraz związane z tym problemy techniczne i prawne. Omówione również zostały prognozy dotyczące kształtowania się jakości wód w zrobach zatapianych kopalń oraz możliwości ich gospodarczego wykorzystania.