Water storage capacity of rock massif in forecasting the flooding process of mine workings

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Abstract: This paper presents some approaches to the problem of incorporating the water storage capacity of rock massif into predictive calculations of the process of flooding of mine workings including the method for evaluating the water storage capacity of the Upper Silesian Coal Basin Carboniferous strata. The notion of the water storage capacity of rock massif in the analysis of the volumetric components taken for water reservoirs formed in underground mine workings has been defined. The importance attached to the water storage capacity of rock massif in prediction of the process of mine flooding is emphasised.

1 INTRODUCTION

In order to precisely forecast the course of the mine flooding process, the identification accuracy and credibility of the conditions under which this process will take place must be as high as possible. As far as the prediction calculation accuracy is concerned, the water inflow estimation as well as the volume evaluation of all the voids located within the prediction study area are of the highest importance. Depending on many natural and technological factors characterising a given mineral deposit, the calculations may be differently conducted. If the evaluation of void volumes in passageways and goafs can be more and less accurate, the evaluation of void volumes in rock masses surrounding the mine workings, within the limits of dewatering zone, will afford difficulties, both methodical and documental. In practical cases, hydrogeologists agree that the rock mass void volume can essentially influence the evaluation of the aquifer's total void volume and total void volume of underground water reservoir. It has also been found that the value of water volume (defined as the water capacity of rock massif) is one of the most serious causes for calculation errors. It can have the immediate impact on the prediction accuracy of the course of the flooding process of totally or partly abandoned mines. People are of the opinion that the water capacity of rock massif is very essential and that it exerts a significant influence on the course of the mine flooding process, without giving at the same time, a precise scope of the event.

2 SOME APPROACHES TO PREDICTION OF THE COURSE OF THE MINE FLOODING PROCESS AND TO DETERMINATION OF THE WATER STORAGE CAPACITY OF ROCK MASSIF

In recent years, the most widely used approach to the prediction has been totally or partly based on numerical methods. The numerical modelling and prediction procedures of the course of the flooding process of abandoned mine workings have mostly been conducted based on the computer programs and the methods of calculations prepared by their authors (Rogoż, 1994, Fiszer, 1995). The well known software programs such as: MODFLOW, ROCKWARE, INTERGRAPH are mostly applied to simulate calculations - in prediction of the course of the abandoned mine flooding process too (Szczepański et al., 1998). In practical cases, the authors of numerical models agree that, in prediction calculations, the precise evaluation of input data and boundary conditions allowing one to tare the model and, if possible, to accurately obtain the initial state of a transient process is very necessary to score success. The spatial model design itself the basic features of which are the discretisation and the division of a test site into blocks described by properties of geological environment in precisely defined mining conditions, in general, make no serious problems for the relatively simple structure areas. To describe tens or hundreds of spatial blocks so that they can contain sequences of data on the variability of hydrogeological and moisture relationships and frequently, on physicomechanical properties, is often beyond the power of presenting their real image. Some authors of simulation scenarios for the Upper Silesian Coal Basin (USCB) mines argue that the most suitable approach to the mine flooding process prediction development is the numerical modelling allowing multivariant calculations. They also admit that the calculations in the case of mine flooding process predictions for underground mines require more reductions than for open cast mines and the identification of mining induced impacts on natural environment is, generally, pointwise, incomplete and often of little credibility (Szczepański, 1999).

In general, the two basic parameters, such as: water inflow Q and total void volume V of both rock massif and mining excavations, can be used for prediction calculations. In order to incorporate the water storage capacity of rock massif into the model in addition to the known volumetric parameters of mining excavations, the data will often be chosen so the final results can be as expected. The authors of such prognoses, generally, can't provide reliable data especially as far as the rock massif is concerned and, therefore, have to use a multivariant selection of parameters for the determination of void volumes in rock massif. Petrič M. and Janež J. (1997) use in the prediction, in addition to the water inflow rate, the so called rock effective porosity comprising the three kinds of porosity with regard to: rocks, backfilled goafs and not backfilled goafs. These authors argue that in the case of the lack of information on the extent and porosity of water bearing formations and mining induced void volumes, the effective porosity of the total rock void volume can only approximately be assessed. In the Mercury mine flooding prognosis (Slovenia), six variants for three values of ground porosity (mineral deposit's dolomite void volume coefficients ranging from 0.5 to 1.0 %) and for three values of mine workings porosity ranging from 10 to 40 %, given the known values of water inflow rate, have been used. The simulation process resulted in fitting the theoretical curves of mine flooding process to the real curve of the mines deepest level section flooding process. The experience gained in flooding the mine's deepest level section was used in formulating a flooding process prognosis for the near surface mine workings with the variable water inflows taken into account (Režun & Dizdarevič, 1997). Formulation and correction of the mine flooding process prediction for the "Wałbrzych" coalfield (Lower Silesian Coal Basin in Poland) were made in the same way (Fiszer, 1995, Fiszer & Winnicki 1999). A similar procedure has been used in formulating the prognosis for the "Konrad" copper ore mine (Poland) in which the information on the water inflow into the mine was used. The approximate values of the coefficient of void volumes in old workings and in roof rock fractures (0.5) and the values of the rock fracture coefficient for deeper and shallower parts of rock massif (from 0.03 to 0.05) were used as well (Downorowicz, 1999). The mine flooding time curve, that would be verified only after partial mine flooding, was obtained. It should be noted that such a considerable simplification of the calculation model could only be permitted if no water hazard were imminent over active mine openings and the surface. A special attention should be paid to the way the parameters are chosen, especially those needed for the prognoses that can in situ be verified. It appears to be a large temptation of fitting realities to model and not model realities, even by uncritical choosing of such input data and boundary conditions so that the results of the prognosis can agree with expectations. Therefore, simple methods for flooding prediction that are based on good theoretical principles and findings as well as the computer programs prepared for the prediction purposes by their authors, frequently with good research oriented capabilities can often be the most suitable to solving concrete problems under concrete conditions.

Considering the earlier notified remarks on the inaccuracy of defining a number of notions and parameters, the author would like to point out that the notion of prognosis may very often be identified with its verification. These prognoses are based on all available prediction and calculation data relating to areas planned for flooding. The future multivariant fitting of the prediction calculations to measurement results will be the prognosis's verification.

3 VOLUMETRIC COMPONENTS OF UNDERGROUND WATER RESERVOIRS

Vaselič M. and Norton P.J. (1997) presented a comprehensive characterisation of volumetric components of underground water reservoirs and changes in water inflows into mine openings based on British, Slovenian and Polish experiences. After studying a number of case histories of abandoned mine flooding, they arrived at the conclusion that due to the lack of accessible database containing results obtained from real measurements and investigations, the generation of wrong information and erroneous effects, especially in numerical modelling, might occur. They suggested that the prediction should be based on the monitoring process and experiments.

In prediction calculations, due to the variable nature of void spaces capable of retaining groundwater, the total void volume consisting of partial void volumes may mostly be used (Figure 1).

The volume of post mining void spaces as defined by the volume of water (V_m) consists of the total void volume of passageways (V_p), goafs (V_g) and post-mining fissures (V_f) expressed in the form:

$$V_m = V_g + V_p + V_f \qquad (1)$$

The volume relating to the ground natural void spaces in the rock masses (V_{rm}) will also be taken into account. This classification is, generally, consistent with the approach used by Vaselič M. and Norton P.J. (1997).

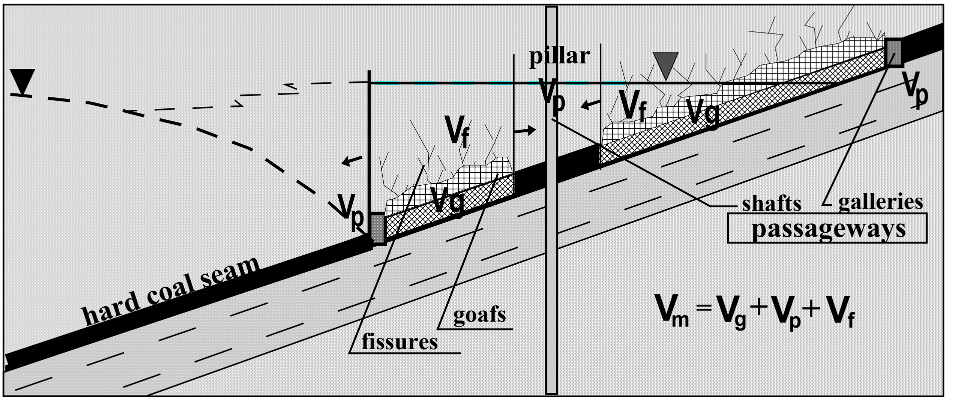

Figure1 Schematic hydrogeological cross-section presenting volumetric components of mining induced void spaces in the underground water reservoirs formed in flooded mining excavations

The water capacity of abandoned mine workings (goafs, galleries and shafts) can be calculated using the mine workings state prognosis involved technique with respect to local mining and geological conditions (the methods of mining and goafs space abandoning and by the load overburden exerted on goafs and other mine openings). This type of void volumes can, generally, be assessed. In the case of USCB coal mines it was evaluated for both caved in and backfilled goafs by means of empirically determined depth related coefficient of water capacity of the goaf (c) (Rogoż, 1978, 1994). This coefficient has successfully been used in the mining practice for calculating of goaf capacity for underground water reservoirs. Just as in the case of the water capacity of goafs, it would be possible to divide the water capacity of passageways, based on their state and the performed observations, into their capacity of robbed and unrobbed galleries and backfilled and not backfilled galleries and shafts. Considering the value of water capacity of passageways, one should take into account their little participation in the total water capacity of water reservoir. In the case of the coal mining methods used in the USCB, the water capacity of passageways is, generally, of minor importance as far as the values of water capacity calculated for post-mining excavations are concerned (it is nearly 5% of capacity of goafs). The water capacity of post-mining fracturing can similarly be assessed, although its greater participation in aquifers formation would become pronounced in the case of caving system of mining in the environment of much stronger rock massif. The more tectonically engaged is the area, the greater part of it generally takes in the total water capacity of underground water reservoir. The total water capacity of fracturing (V_f) can be assessed based on the volume of subsidence trough with the coefficient of water capacity of goafs (c) determined according to the Rogoż's approach (1978) taken into account. Separate parameterisation of natural fissures and the fissured altered by the impact of mining operations conducted at shallow mines is practically impossible to achieve without making the measurements in openings and at outcrops.

In Poland, among the parameters used in calculation of underground reservoirs capacity the water capacity of rock masses was defined as the amount of water confined to the void volumes in rocks mostly as the intergranular void volumes. It would be the amount of water the rocks located above the mine workings could store (between mine opening area and forecasted water level in the goafs).

The predicted total water capacity of underground water reservoir formed in abandoned mine workings (V_c) was calculated as the sum of mining induced void volume (V_m) and natural void volume in the rocks (V_r) considered here as the intergranular void volume (rocks under mine openings). And so the predicted (calculated) total void volume (V_c) in reservoir can be estimated from the following formula:

$$V_c = V_m + V_r \tag{2}$$

The water capacity of rock masses as deduced from the rock volume or from the rock vertical profile using the gravity drainage index or gravity storage coefficient can, according to the author, be a constituent of the water storage capacity of rock massif.

4 WATER STORAGE CAPACITY OF ROCK MASSIF AND ITS CONSTITUENTS

The water storage capacity of rock massif is assumed to be the ability of the ground block (pores and fissures) dewatered by drainage operations to absorb certain amounts of water after the groundwater recovery. The notion of water storage used in hydrogeology can be defined either as the fissures or intergranular water storage if the nature of ground porosity is taken into account or as the molecular or for example hygroscopic water storage if the type of water is taken into account. The water storage capacity of rock massif is the definition describing the rock mass storage capacity consisting of all the partial water storage capacities of the mining deformed rock massif.

Within the ground block overlying the mine workings and in vicinity of the mine workings, the ground structure can so much be disturbed (mainly due to the mining with caving) that most often the water capacity of rock massif including conventionally defined intergranular and fissured void spaces can't be involved. It will be out of the question because the conventionally defined water capacity relates to the water bearing strata and their ability to store water. The water capacity of rock massif or the aquifer void volume (V_r) can usually be defined as the ratio of the amount of water discharged or stored in a ground rectangular parallelepiped with the unit base and the height equal to the aquifer thickness, caused by the groundwater table unit change, to the unit rectangular parallelepiped volume (Kleczkowski & Różkowski et al., 1997). The water capacity of rock massif with the free groundwater table approaches the storage coefficient (μ) - in this definition. The mining defined water capacity is the ratio of the water volume a given ground volume can store to this ground volume. In many cases, the notion of water capacity of rock massif relates, generally, to the intergranular void space volumes, which is evidenced by the use of the storage coefficient. This notion was used in many studies on mine flooding (Rogoż & Posyłek, 1993, Rogoż, 1994), although as far as the rock saturation process is concerned, it was also applied to the rock absorption capacity (Fiszer, 1995). To obtain the water capacity of rock massif in the whole dewatering area with respect to the variable nature and structure of the voids in rocks, one must conduct both the field and laboratory based storage coefficient determinations. The best results would provide the field determined storage coefficients for aquifers and rock masses. It can only be performed in the mining intact areas. In the mining disturbed areas, due to difficulties in using field tests and due to the extensive networks of mine openings, the laboratory tests based investigations can chiefly be conducted. It should be noted that, in the case of the laboratory tests, the results of volume calculations considerably depend on the storage coefficient determination method used. Depending on the determination method used, the values of storage coefficient may differ by as much as several hundred percent. Different values may be obtained using either the field or the laboratory based methods. Different laboratory methods may also produce significantly different values. For example, the values of storage coefficient obtained using the centrifuging method at time t = 20 minutes will differ from those obtained using the same method but at another time interval. Also the capillary drainage method developed by T. Bromek in 1977 and the evaporation method developed by E.S. Messer in 1951 may produce different values.

Using the field methods, one would obtain the best results in determination of the water capacity of rock massif, but in the case of the mining deformed rock environment (overburden) the laboratory determined storage coefficients for the water storage prone commonly been used. The natural fracturing parameters were so much altered that they must be separately assessed.

Without questioning the validity of methodical steps each laboratory method for storage coefficient determination has assumed an open question is to find the current extent of ground dewatering. The laboratory found storage coefficient only accounts for a part or the whole of void volume capable of storing free water, or has generally been overestimated by an unknown amount of laboratory drained capillary water. In Poland, since the sixties, the laboratory determined parameter drainage index (Wilk & Szwabowicz, 1965) has been used. It denotes a difference between the moisture of rock samples collected from mine workings and the rock open porosity. It is assumed to be the best parameter that allows determining the volume of the drainage dewatered pores. However, the serious problem in applying this parameter to the calculation of the water capacity of rock massif would be, in general, an impossibility to collect a rock sample that could represent an average value of the rock moisture.

The water capacity of rock massif in simplification close to that corresponding to natural environment could roughly be related to the part of rock massif located beyond the outlines of mine workings up to the limits of the cone of depression area or the mining drained rock zone. This simplification involves an unknown horizontal extent of disturbed ground around the mine workings. On the other hand, the assessment of the real values of the water capacity of rock massif for that part of ground could not be possible without the field tests or could be bound to serious errors, especially as far as the fissured-porous and the fissured rock aquifers are concerned.

To summarize, the water volume related water storage capacity of rock massif (V_{rm}) for both the past and the present mining areas can, according to the author, be composed of two basic and evaluation feasible types of the water capacity of rock massif. These are the water capacity of rock masses (V_r) being deduced from the storage coefficient weighted mean values for the vertical ground block situated within mine workings up to the maximum groundwater table rise level (Figure 2) and the additional capacity – (V_a). Additional capacity roughly reflects the natural water capacity of rock massif beyond the mine workings - water capacity of rock massif for the marginal parts of the cone of depression. The water volume that may be stored in the ground during the mine flooding process can be defined as the sum of the two above quantities (Formula 3).

$$V_{rm} = V_r + V_a \qquad (3)$$

This equation describes the water volume related to the water storage capacity of rock massif and may also describe the total rock or aquifer void volume (Vaselič & Norton, 1997).

The real total void volume of an underground reservoir (V) is consisting of the sum of the mining induced void volume (V_m) and the water storage capacity of rock massif (V_{rm}) (not only water capacity of intergranular void volumes for the rocks overlying mine workings). The real total void volume is defined in the formula 4:

$$V = V_m + V_{rm} \tag{4}$$

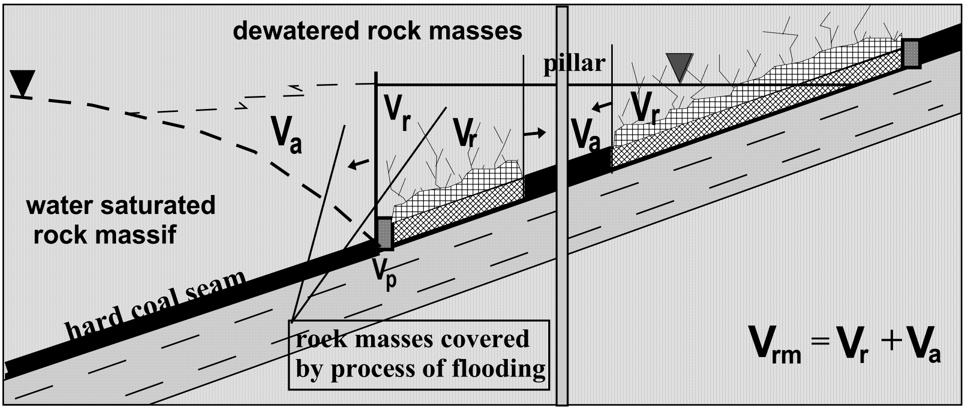

Figure2 Hydrogeological cross-section presenting volumetric components of water storage capacity of rock massif in the underground water reservoirs formed in flooded post-mining excavations

The majority of authors, who reported prognoses of mine flooding process, consider the correct void volume calculation as difficult. Vaselič and Norton (1997), agreed that the errors related to the rock void volume calculation mostly resulted from difficulties in estimating the mining drained rock body volume and the total prediction error related to the model component determination error could amount to several hundred percent. Considering the USCB hard coal mines test results, Rogoż M. and Posyłek E. (1993) confirmed that the water capacity of rock massif would considerably exceed the water capacity of goafs and the other mine workings. From the field observations and prediction estimations conducted in eight reservoirs observed in eight coal mines in the USCB it was found that the water storage capacity of rock massif would significantly take part (around 50%) in the formation of underground water reservoirs (Bukowski, 1999). This participation ranged from 35% to 75% (Figure 3) relative to the local mining, geological and hydrogeological conditions.

5 EVALUATION OF THE WATER STORAGE CAPACITY OF ROCK MASSIF FOR THE UPPER SILESIAN COAL BASIN (USCB) COAL MINES

The approach to the evaluation of the water storage capacity of rock massif was based on the field investigations into the selected, existing groundwater reservoirs, conducted according to the well established criteria (Bukowski, 1998, 1999). To perform that task, the mining data set collected from the maps drawn at

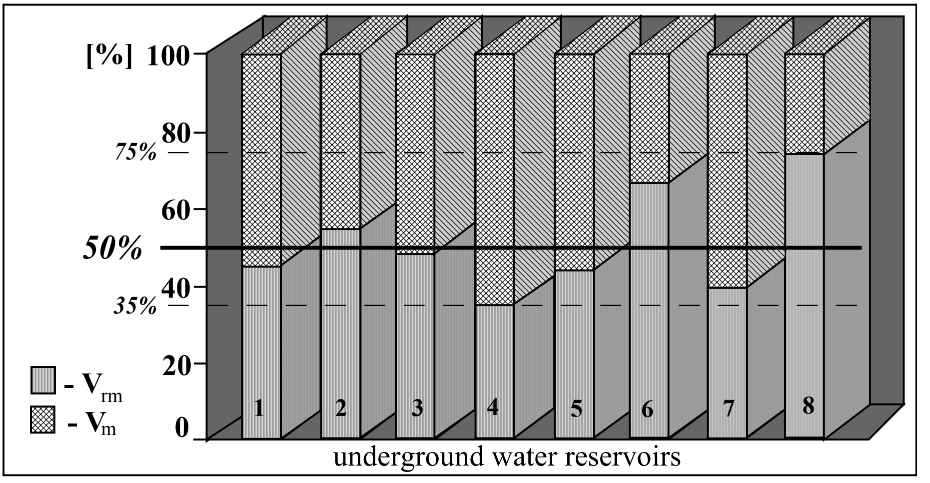

Figure3 Schematic diagram presenting percent participation of water storage capacity of rock massif and mining induced capacities in underground reservoirs formed in flooded post-mining excavations.

scales 1:5000 or 1: 2000 and the hydrogeological data on the already water filled void volumes were needed. The coefficient of water capacity of goafs (c) was calculated based on the information about the depth, spatial location and the area of mining as well as the height of mining and the dip of coal seem obtained from the mine maps. From the geological observation data, the passageway closure or backfilling or caving ratio characterising the coal seam available void volume at the given depth could be defined. The total water capacity of post-mining fracturing overlying the flooded mine workings and the available void volume to be filled with water inflow after obtaining a given rise level were estimated. In the rock disturbance interpretation and in the mine void behaviour determination, especially in that of the residual mine void behaviour, the rock strength and petrographic study results might be used as well. From the above data, the water capacity of the mining induced voids (V_m) could be estimated.

From the borehole study results, a lithologic profile and the likely water storing rock volume composition above goafs could be defined. The storage coefficient determination could be made based on the rock samples collected from the aquifer strata in the area of an underground water reservoir. The determination procedures were conducted using the new method developed in the Central Mining Institute in 1999 (Bukowski, 1999, 2000). The aforementioned approach could be used in determining maximum over-capillary rock pore volumes and, thus, the maximum values of the “storage index”. The storage coefficient values would next be used in calculating the water capacity of rock masses (V_r). The obtained, in this way, sum of the mining induced water capacities (V_m) and the water capacity of rock masses overlying the mine workings (V_r) would be the expected water volume that could fill all the mine voids up to the predicted maximum groundwater level. The temporal mine flooding process determination would be possible using the information on variable water inflows monitored by coal mine recording stations both prior to and after the void volume flooding to the planned groundwater level or, for instance, to the overflow level.

Comparing the monitoring and prediction calculation results for the already filled up void volumes (Figure 4), it has been found that a signification discrepancy appeared to be between them.

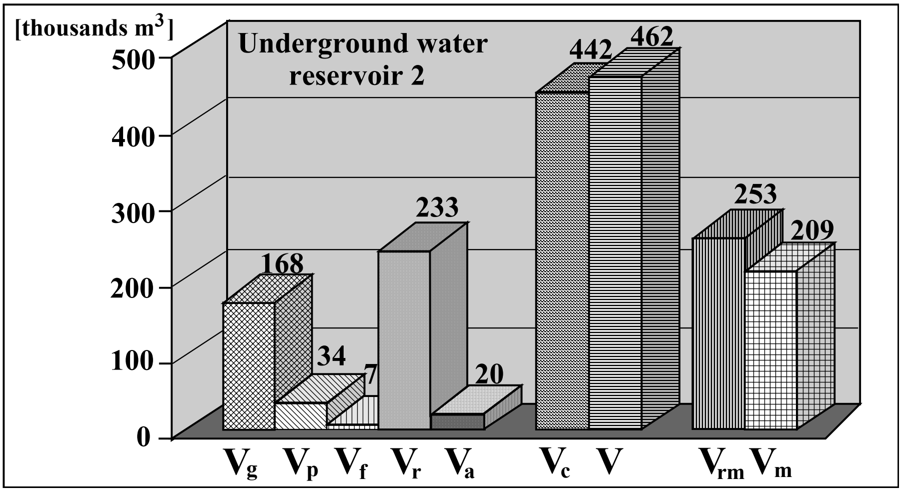

Figure 4 Schematic diagram presenting participation of kinds of capacities in total capacity of underground water reservoir - water reservoir formed in mine 2 (Figure 3).

This discrepancy may have difference arisen from the water inflow into the drained water storing prone Carboniferous strata situated beyond the mine opening limits. It is hard to define the extension of ground water table raised in mine workings and in the surrounding strata, especially in the regional drainage like that of the USCB. The volume of water which delayed the formation of underground water reservoir was defined as the additional water capacity of rock massif (V_a) and was confined to the part of rock massif situated beyond the mine openings limits and yet within the cone of depression and groundwater rebound areas. That volume was taken as the between the predicted (calculated – V_c) total reservoir void volume and the volume of water inflow into mine workings during the time from the start of flooding to its completion and calculated accordingly. The calculation results are shown in figure 4, which is comparative plot of predicted volumes of water and calculated on the base of water inflow into reservoir region. The comparative studies have been performed for the underground water reservoir formed in the flooded mine workings with marked groundwater inflow stability confirmed by the measurements and continuous groundwater table level monitoring and the known duration of the water bearing structure formation. Because of the complexities of the USCB geologic and tectonic structural situation, the simplifications used in the additional void volume calculation which, to some degree, could rectify possible void volume calculation errors, have become a principle for making the coal mine flooding prediction more real (Bukowski, 1999). The obtained results of such conducted comparative studies show that the water storage capacity of rock massif can essentially influence the formation of underground water bearing structures, particularly during the period of flooding process of all available void volumes.

6 CONCLUSIONS

As follows from the presented results of investigations into a selected series of underground water reservoirs (Figure 3), the evaluation of the drained rock void space volumes can be as much important as the evaluation of those void volumes formed immediately after the mineral substance extraction. That evaluation would be possible if the additional water capacity of rock massif was determined using the results of field studies involving the predicting calculations and conducting a careful analysis of the abandoned mine flooding monitoring results. Such computation involved research investigations should be based, if possible, on accurate archival information (maps, descriptions, measurements, etc.) and on basic direct data (results of field observations and laboratory studies) obtained from the studies conducted prior to the elaboration of the prognosis. Despite some unavoidable simplifications used in the rock characterisation of underground mining areas, the notion of water storage capacity of rock massif assessing the proneness of rocks to saturation appears to be the most adequate for defining the nature of abandoned mine flooding processes.

In the author's opinion, the mine flooding process prediction could only be successful if the nature of the process taking place in the flooded mine workings were examined. Similarly attempts to determine the void volume parameters such as the coefficient of water capacity of goafs (c) were made and the direct, experimental active mine void volume determination efforts were undertaken. Performing the numerical prognosis without good identification of the current process of mine flooding conditions, leads to wide simplifications and freedom in choosing the parameters and consequently to significantly erroneous prognoses.

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Chłonność wodna górotworu w prognozowaniu zatapiania wyrobisk górniczych

Przemysław Bukowski

Streszczenie: Przedstawiono niektóre sposoby uwzględniania zdolności chłonnych górotworu w obliczeniach prognostycznych przebiegu procesu zatapiania wyrobisk górniczych , w tym sposób oceny chłonności wodnej górotworu karbońskiego w Górnośląskim Zagłębiu Węglowym. Zdefiniowano pojęcie chłonności wodnej górotworu na tle składowych pojemnościowych podziemnych zbiorników wodnych w kopalniach podziemnych. Określono znaczenie chłonności wodnej górotworu dla prognozowania procesu zatapiania wyrobisk górniczych.