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Drainage of Coal and Lignite Mines

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INTRODUCTION

The presence of water in mines, and the complications it causes, is a problem that has taxed all concerned since mining began. In early years the miner had to use his ingenuity, since he suffered from a lack of technology and of equipment. Today, the decisive factor in drainage is often economic, especially when the maximum production of coal compatible with minimum water risk is required.

On the other hand, the demand for coal has increased greatly in recent years, primarily as a result of the oil crisis. Furthermore, this increased demand occurred precisely at a moment when, in many countries, coal mining was going into a recession.

This increase in the demand for coal caused further hydrological problems, brought about by a number of factors including the need: to exploit new mines in a short space of time; to reopen others long-since abandoned and in many cases flooded; to deepen existing workings, or to open up more complex areas of coal deposits, below the natural water table.

At the same time, however, the need to combat inflow of water became pressing just at the moment when the importance of the preservation of the environment became a vital public issue. Any drainage process in mines inevitably affects the environment, since it reduces the yield of existing springs and produces waste water that is often polluted.

Thus the influence of mining on existing groundwater systems, the immense amount of water needed to operate the installations used to treat the coal, and the large quantities of residual water that such treatment produces--all are factors intrinsic to coal exploitation and so such mining plays a special part in questions of water economy.

Therefore, there are great risks involved in dealing with a broad and at the same time complex subject such as drainage in coal and lignite mines. I am fully aware of these dangers and I know that this is a task, not for one specialist, but for a full team of highly qualified experts. I would therefore like to point out that this chapter aims merely to present a general survey of the problem--including a presentation of the methodology of the most commonly used drainage systems--based on direct personal knowledge or on evidence gained from the bibliography I have consulted.

It should be made quite clear from the start that, despite frequent claims to the contrary, there is an extremely wide-ranging body of written work on the problem of water in mining, and within this bibliography by far the largest section is that dealing with coal mining (1). The difficulty is to cope adequately with the great dispersion of the worldwide bibliography which, until the SIAMOS Congress (2), had never been collected in one monograph.

The reader interested in these subjects will find further information in the bibliography provided at the end of this chapter. It will enable him to study in greater detail certain aspects of the problem that cannot be treated adequately in a general discussion.

FACTORS DETERMINING DRAINAGE

Lithological Factors

The problems caused by water in coal mines are extremely diverse, depending on such factors as the nature of the surrounding rocks, the existence or absence of waterproofing in the hanging wall, the degree of fracturing in the enclosing rocks, and certainly the anisotropy caused by mining (3).

We can roughly distinguish three main types of mining, arranging them according to the hydrogeological problems they originate:

1) Mining carried out in areas of nonconsolidated detritic materials with the associated problems of a possible inrush of water carrying mud and sand, or of subsidence and interconnection of the aquifers.

2) Mining in consolidated and fractured materials, where the water finds its own channels according to these structural discontinuities, and particularly in the tension fractures, which can form a connection between aquifers in the same system.

3) Mining in karstic areas where the water channels are closely related to solution processes, which in turn can determine the direction of flow (4,5).

We should add the following to these three groups, since they cause similar problems:

4) Mining in nonconsolidated materials, of whatever origin, insofar as water affects geotechnical behavior.

5) Mining in cemented detritic formations that can initiate aquifers through porosity, which in general behave isotropically.

I should point out here, however, that though we have differentiated five basic types of hydrogeological systems, according to lithology, we can of course find complex systems--a mixture of two or more of the above--and especially multilayer systems, where the aquifers are to be found between semipermeable materials.

Structural Factors

In all cases structural features play a vital role as far as water flow is concerned, since we have seen in a great number of cases that water inflow takes place primarily along structural discontinuities, such as faults and the fractures related to them (6), and especially in tension fractures. For example, the studies carried out in Dorog Mine (Hungary) demonstrated that 80% of the water inflow took place at faults; 16% in areas of fractures; and in only

4% was it impossible to establish the role played by tectonic factors (7). Thus we can see that a structural geological study is always necessary.

The flow of water toward mining works can take place downward from higher aquifers, or upward from captive underlying aquifers (8), or it can take place sideways in structural discontinuities. It is obvious that drainage systems are determined by the characteristics of this water flow.

Hydrological Factors

The waters that flow into a mine, and must therefore be drained off, are generally fed from the rainfall, or from rivers; and in these cases a "delay" may be observed, which may be for a greater or smaller period according to the hydrodynamic characteristics of the hanging wall and surface. This means that it may be necessary at times to drain very high water inflows, far above the average yield.

Hydrogeological Factors

The obvious need for adequate protection against, and subsequent drainage of, water inrushes necessitates in turn a close examination of the characteristics of the aquifer systems; especially of: the speed and direction of the water flow; the connection between the source area and the discharge area; the placing of any depressions or hollows; the barrier in the system that forms obstacles to the water flow, and so on.

Anthropic Factors

Finally, it is important to emphasize the significance of the human element, since a mine in itself forms an obvious conduit for the transference and flow of water; and to this must be added the question of the overall capacity of the working. This is particularly important when there are abandoned flooded mines near the mines still being worked and also in the rainy season, especially when the workings are relatively shallow (9).

In this respect, the systems of mine working, which are of many types, certainly determine the importance and effect of water, as well as the drainage possibilities.

On the other hand, when a mine is no longer worked it can pose a threat to active workings which will then have to bear the increased cost of drainage (10). The problems due to the closeness of old underground or open workings, or to the existence of underground aquifers (11), also occur when mines are closed down and subsequently used for storing water underground (12). Sudden inflow of water to underground workings can produce extremely dangerous situations, especially since such inrushes are sometimes accompanied by quantities of mud and sand, which can rapidly erode the rocks enclosing the working and can bring about collapse (13,14).

This influx of mud can originate in nonconsolidated materials or in the fillings of old mines, or in settling basins on the surface (15).

The drillholes, and sometimes abandoned gas or oil boreholes, which cross coal deposits are also a potential menace, because of the possible inflow of water into the mine workings.

Given all these factors, then, it is frequently necessary to take water out of mine workings in quantities even greater than those of the coal that is mined (16), and we find workings with a very high flooding coefficient (17).

As examples of what we have stated above, we can consider the following: for instance, the drainage in the coal mines of Upper Silesia (Poland), where more than 10 cubic meters per second of water is pumped; or the inrush of water in the Julia Mine in Czechoslovakia, together with 250 grams per liter of very fine sand, which took more than a month to bring under control (18). A series of accidents in collieries in England, which had a significant effect on the laws governing the measures necessary to prevent such accidents, have been described (11,19). In Great Britain the nationalization of the coal mines has led to a detailed government-financed study of the drainage systems of old mine workings.

Very detailed studies have also been carried out in the Sokolov Basin in Czechoslovakia, where the lignite workings of the Antonin Coal Field have affected the famous hot springs of Karlovy Vary, producing a drop in the water flow at the same time as the inflow of water into the mines. Again, the drainage of the Joseph Seam caused a gradual reduction in the flow of the springs. These were later restored to their full yield after the mines were flooded (20).

In this case, the water inrushes took place along fault lines and the effect could have been the result of a loss of gas (CO_2) in the water, or of a drop in the level due to long-term pumping.

In view of this, it seems that there is a clear need to carry out more detailed studies, especially in those deposits where we can foresee flooding problems. These studies should allow us to collect the maximum amount of information on technical and practical aspects of possible protective measures, within the context of the relevant geological processes and of the action of the miner himself; all of these factors determine the movement of the water.

DRAINAGE PLANNING

Basic Considerations

In general, it is impossible to work below the piezometric level unless there is a protective layer, or unless suitable techniques are used to prevent water from entering the mine workings.

Therefore, the most important task of the hydrogeologist with regard to mining is to calculate, if at all possible, the probabilities of water inflow and to draw up preventive measures, based on a detailed study of the situation, using all the technology available to applied hydrogeology. The purpose of this study is to set up the appropriate drainage system, according to the local hydrodynamic characteristics and geometry.

The fight against water is as old as mining itself; therefore, to combat possible water inrushes, coal mining has developed an advanced technology, which is adjusted to the particular circumstances of every specific case. This technology has been recorded in detail by several specialists (21). The aim of this highly developed technology is to foresee inrushes of water and to take protective measures, especially in cases of violent inflow which can have catastrophic consequences.

The methods to be employed are generally closely related to local conditions and can be classified according to the effects they have on the environment and on the length of time needed for their implementation. However, it is more usual to classify them according to whether they are defensive or offensive, that is, whether they are restricted to control or elimination of water inflow once it has occurred, reducing the damage to a minimum, or whether, on the other hand, they lead to a systematic protective action against water.

In general we distinguish between prevention and passive and active protection. We should also add the aspect defined as instantaneous protection (22).

Prevention

Preventive methods aim to prevent or delay water inflows; or to reduce their intensity. For these preventive measures to be effective, the following conditions must be fulfilled: nontectonic formations must be present, together with an impervious layer of adequate specific thickness.

In important structural discontinuities, it is necessary to leave isolating protective pillars.

Passive Protection

The oldest method of protection is the so-called passive method. This is the attempt to evacuate the water that has infiltrated the mine by means of pumping (generally progressively increasing in volume), or by closing off the flooded area, or again by sealing off the fractures through which the water has entered. The fact that this method is old does not mean that it is not used at present.

On the basis of this passive protection, it is possible to plan mining works with a predetermined safety level, which directly affects the preparation costs. We must nevertheless bear in mind that, in the event of a water inrush, these technical points of view must take second place to the risk of danger to human lives--naturally, an aspect that cannot be taken into account in economic or mathematical calculations.

The hydrogeological survey of the coalfield and its environment should provide concrete information, allowing us to judge the degree of danger from possible inflows. The aim is to prevent those inflows that can have catastrophic results, and to do this by means of an adequately planned protective system.

Active Protection

The active protection system is based on an attempt to influence the piezometric level in the surroundings of the mine in such a way that the workings are not threatened by any water inflow.

In general, the technique is to reduce the water pressure by means of pumping from wells. This technique is especially effective in tectonic or karstified zones, or in deposits with no protective layer or one that has limited influence.

Owing to the fact that the volume of water to be drained is considerable, it is necessary to prepare active protection systems some time ahead; they should also be continued while the mine is being worked, which means that they are particularly costly, especially if we take into account the extent of the area that has to be protected and the costs of maintaining the system.

The active protection system also has a considerable and quite long-lasting effect on the hydrological balance. Thus there comes about a regional influence on the hydrological surroundings that can cause environmental disturbances--which at the present time are of great public concern. For this reason the use of this method of protection must be very carefully planned.

Instantaneous Protection

There is a constant drive to implement new protective methods that will incorporate the advantages of the methods previously described while avoiding their disadvantages. Kapolyi, for example, has described a method that he calls "instantaneous" (22). This method does not attempt to eliminate the water by means of regional drainage, but rather by means of a partial reduction in pressure, effected by local drainage works in the area immediately surrounding the mine works. In this case, the volume of water to be drained is considerably less than that involved in the active protection method; at the same time, the water inflows are not so intense as those that can occur in a system of passive protection. The volume of water drained and the changes that have to be made in the aquifers are also less significant. According to this method, the preventive work needed to raise the water, and to reduce water pressure, is carried out in the area of the mine, with no delay.

Instantaneous protection offers the possibility of using the changes in the state of the lithological materials as a factor that can impede the transport of liquids, since the size of interstices in the rock and the corresponding possibilities of water flow clearly depend on the mechanical state of the rock. It is well known that as regards the state of pressure of liquids in situ some strata are porous, but as the water pressure is reduced, so is the porosity. It is even more obvious that impervious rocks become pervious and water-carrying as a result of fracturing. So we have to take into account the correlation existing between these two means, as regards the state of the rock as well as that of the water, since the degree of porosity and water conductivity govern the existence and movement of fluids. As these factors vary with time, we should consider them as stochastic processes.

Comparison of the Various Methods

In order to make a comparison between the various methods as to their effectiveness in affording protection against water, Kapolyi undertakes a theoretical study, though with a practical slant, of all the essential factors that can be involved in the problem. He does this in such a way that his method of calculation can be applied to a specific model.

Starting from the establishment of a mathematical model, he develops a numerical analysis that allows him to study the volume of water that enters mining works protected by:

a) the passive protection method;

b) the active method with a lowering in the piezometric level;

c) the instantaneous protection method.

He reaches the conclusion that the costs of the various protection methods depend on the infiltration factor; this presumably means that there is an optimum situation for the application of each of the three systems respectively.

The planning of work by the instantaneous method, and its implementation, clearly gives rise to problems that are much more complex than those posed by the active or passive methods. For the passive method, it is necessary to know only the immediate surroundings; and for the active method we need to take into consideration the behavior of the whole water layer. For the instantaneous method, however, we have to take into account both the above factors, and give equal importance to each.

Practical Considerations

We must always remember that any mining activity changes the characteristics of the rock formations where it takes place. So, even if there is a protective layer, any fracturing of the rocks, and especially due to tension, will favor the movement of water; the presence of water will in turn produce changes in the pressures of the strata, having a direct effect on its geotechnical behavior (23).

One complex problem that generally occurs in any preventive treatment is to determine the proper thickness of the hanging wall protective layer placed between the mine workings and the aquifers (24). Experience has shown that a specific thickness of at least 1.5 meters per atmosphere is needed to achieve an efficient protection (17), providing there are no faults that may be particularly suitable for the flow of water.

In the working of new coal resources under the sea, in the deposit found to the east of Durham (England) with a roof formation of Permian dolomites, a protective layer of 100 meters has been left; this gives an adequate safety margin. As a matter of course, the position of the Permian and of the adjacent aquifers is determined by means of core drilling (25).

The size of crown pillar has led on occasion to economic difficulties that have proved insoluble (26).

As regards room and pillar mining under the sea, special precautions are needed as far as the dimensions of the pillars, the thickness of the protective layer, the length of the working faces, and so on, are concerned (28).

Furthermore, when there are boreholes that can connect the deposit with aquifers, a protective pillar is needed around these holes, and this may mean the loss of an important amount of coal. So it is most desirable to seal off these abandoned boreholes. Gas is occasionally used as a tracer to check the effectiveness of this sealing (28).

If older workings with voids are found above the new working, coal washing plant slimes can be injected, from boreholes, to form a sealing screen.

The methods used to combat water when an inflow has occurred are very wide-ranging, particularly in underground mining. They include: the construction of filtering dams; the drilling of boreholes for injection; the establishment of a drainage station; the cleaning of the area and extraction of sand, and so on (13, 14).

Underground dams can also be used to create a series of water storage containments when we are dealing with an operating mine that has large mined out areas with many water inflow sources. A detailed knowledge of fissure systems is needed for the correct design of these dams; and this knowledge should include not only the degree of porosity but also the mechanical properties of the rock in question (29).

Dams to seal off water inflow can be built in underground workings, and they have been used in different situations with varying degrees of success. Filtering dams have been used when dealing with water inflows containing a considerable volume of solids in suspension. In general the problem is to establish adequate stability conditions to resist the water pressure. This is one aspect of the careful selection of an appropriate site for the dam emplacement and of a well-adjusted relation to the water pressure, the tensions of the surrounding rocks, and the geomechanical characteristics of the rocks, apart from injections that seal the retraction fissures with cement. The bibliography on this subject is extensive (30, 31, 32, 33, 34, 35, 36).

In the case of shaft excavation with water problems, we often use preliminary sealing injections, through boreholes, and sometimes high pressure injections of chemical products in liquid state that form a solid and sealing barrier by means of catalysis in the surrounding formations. This system has been successfully used in flooded pits in Australian coal mines, worked at a depth of 180 meters under Lake Macquaire (37), and in other mines. The necessary complement to this method is still the installation of appropriate pumping systems (38).

In any case exploratory boreholes should always be drilled, sometimes from a concrete dam at the front of a gallery (39). This is particularly advisable in workings that are rendered especially difficult by the presence of water

The recovery of flooded workings and the rescue of trapped miners gives rise to extremely complex working conditions (40). For this reason, the experience that has been gained by specialists should serve as a guideline in the adoption of adequate precautionary measures, designed to reduce such risks.

Despite the obvious technological complexity of drainage, the economic outlay needed for establishing an adequate protection system is very profitable, if we take into account the economic advantages that arise from efficient drainage. This is particularly true if one considers the fact that any inflow of water not only represents an immediate expense, but also brings with it a drop in production and, occasionally, the forced abandonment of the working.

We should not forget, however, that it is not only financial resources that we need in order to solve these drainage problems: an adequate intellectual investment is also vital. So we should really take to heart Niels Bohr's well-known phrase: "Gentlemen, we are poor; so we must think."

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