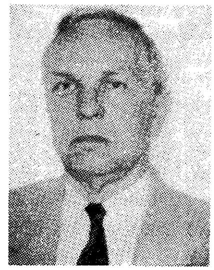
PROPOSAL OF CRITERIA FOR SELECTION OF DEWATERING METHODS IN SURFACE MINING



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ABSTRACT

This paper is addressed to mining engineers and decision makers to help them in selection of open-pit dewatering system. It presents the short characteristics of particular dewatering arrangements and their advantages and disadvantages in different hydrogeological conditions. Also the influence of mining operation system on the selection of the best arrangements to be operated has been shortly discussed. Another proposed criteria are availability of technology and environmental protection. The final criterion is investment and operational cost. If the situation doesn't obviously prejudge the selection of certain method the multivariant study taking under consideration all proposed criteria is recommended.
The presented proposal is based on 40 years experience gained in about 100 surface mining operations planned and designed in the POLTEGOR-Engineering Ltd both in Poland and abroad.

INTRODUCTION

An increased demand for useful minerals, exhaustion of shallow-bedded resources and development of machinery enabling surface mining to be run deeper and deeper are a reason that the dewatering becomes a necessary condition for extraction in ever increasing number of operations.

The ever increasing number of mining companies faces with the necessity of lowering groundwater table and protecting open-pits against water inflow together with keeping of environmental protection requirements both during the new developments and when coming down deeper and deeper from the outcrop. In such a situation, a dilemma arises to select most suitable and cheapest method of dewatering assuming environmental protection. So, this paper being an attempt to systematize different opinions on this subject is addressed, to a lesser extent, to the experienced specialists in this field and, to a greater extent, to those who are to take decisions on these questions, but who are not so widely experienced in that relatively narrow area, which is dewatering of surface mines. A basis to provide the suggested criteria is many years' experience gained at the POLTEGOR-Engineering Ltd in planning and designing more than 100 surface mines of various minerals in Poland and abroad.

CLASSIFICATION OF SURFACE MINES IN VIEW OF DEWATERING

From the viewpoint of the necessity of dewatering and method of dewatering, several principal types of surface mining operations can be distinguished.

Group I includes surface mines, where all the operations are carried out above groundwater table. In these, open-pit dewatering is limited to the control of rain waters, which must take place when the open-pit bottom is constituted by impermeable formations. If the bottom of an open-pit belonging to that group is permeable the rain waters percolate down to the aquifer or unsaturated zone , and they do not require any equipment to be used.

Group II includes surface mines, where operations are carried out below groundwater table and here, two sub-groups can be distinguished:

Sub-group A - operations where the overburden and deposit are constituted by hard rocks, which can be permeable, slightly permeable or impermeable ones. The lowering of groundwater table ahead of starting with mining operations is here often unnecessary and only, it is sufficient to construct and maintain, the installations for intaking and removal of inflowing ground- and rain waters. It results from the fact that, in case of hard rocks, there is a lesser hazard for slope stability due to the waters outflowing from there. However, it is sometimes the case that, in particularly disadvantageous structural conditions (e.g. layers inclination towards open-pit), or if slopes are necessary to be kept for a long time in a good shape, it is not accepted for waters to inflow without control. In this last case rock dewatering or depressurizing arrangements have to be constructed.

Sub-group B - operations where the overburden, or overburden and deposit, or overburden, deposit and underlying layers are loose permeable (sands, gravels) and impermeable (clays) and low permeable (silt) formations. Such formations can occur in different proportions and different spacial distribution. For this subgroup, as mast advantageous can be considered conditions, when the overburden and deposit are constituted by impermeable formations, and only under-deposit formations (mostly being confined aquifers) require to be destressed, to the open-pit bottom. More difficult conditions are encountered when aquifers occurring in the overburden require to be dewatered to warrant slopes stability and ensure safe and efficient operation of heavy machinery. As a rule the most difficult hydrogeological conditions are encountered, when loose water saturated layers constitute both the overburden and partings, as well as deposit and underlaying strata. The importance and size of dewatering operations carried out adequately ahead of mining operations of the open pit are, in this case, a necessary condition for a proper and safe construction and operation of surface mine.

Certainly, the above classification is very simplified, and a degree of complications of hydrogeological conditions, which decide on the selection of dewatering methods and arrangements is also influenced by such factors as:

- permeability and specific yield of particular aquifers and the degree of their variation,
- spacial distribution of layers of different permeability (it is advantageous, when the layers of higher permeability occur under those of lower permeability),
- thickness of particular aquifers,
- all disturbances in the occurrence (foldings, faults, etc.),
- hydraulic contacts between particular aquifers,
- conditions of hydraulic contacts between particular aquifers,
- conditions of hydraulic reacharge, and particularly if non-sealed rivers and lakes are present in the vicinity,
- rainfall rates and their distribution during the year time.

All those factors, must be examined to a corresponding accuracy during hydrological and hydrogeological exploration. They are a requisite for the selection of most suitable method of dewatering in view of maximum efficiency. In turn, the degree of the efficiency of dewatering results from geomechanical and mining operations requirements. The geotechnical requirements determine a degree of dewatering necessary for the slopes' stability, whereas the mining requirements result in the necessary degree of stability of particular slopes and benches including ground pressure of machinery.

REVIEW OF DEWATERING MEASURES IN USE

For the lowering of groundwater table before the mining operations, for prevention of groundwater inflows in-to the open-pits and for ground- and rain waters removal from the open-pits, many methods and engineering actions are used.

D r a i n a g e w e l l s - depending on requirements, there are used wells drilled from the ground surface, or from the benches within open-pits, to a depth from 20 m to 400 m. The drilling diameters, depending on the depth and foreseen capacity, can vary from 350 to 1200 mm. The yield of particular wells varies, in extreme cases (depending on the transmissivity) from less than 0.1 m^3/min. up - to about 10.0 m^3/min. These are limit values but in the most cases, the yield of particular wells varies, f.ex., from 0.2 m^3/min. to 1.5 m^3/min. The wells are located in the open pit surrounding external barriers, which cut out the inflow to the open-pit and in internal barriers pumping static groundwater resources. as a rule, these wells are fitted with submersible pumps having adequately selected characteristics (capacity, lifting head, etc.).
The example could be here for instance a Bełchatów Lignite Open-pit in Poland (second largest all over the world), where a system of 400 drilling wells equipped with submersible pumps has total capacity of 400 m^3/min. The wells of depth of 120 to 350 m, and diameter 500-1200 mm enabled draw-down of groundwater table by 220 m on the area of 8 km2 in

11 years period. Three interconnected aquifers: Quaternary-sands and gravels, Tertiary-fine sands and Mesozoic Limestones - are drained to provide stability of slopes of an open-pit, where 110 mill. m^3 of overburden and 38 mill. tons of lignite is mined per year.

C u t - o f f w a l l s are one of the best methods of open-pit protection against inflow of dynamic ground-waters, particularly overburden. The cut-off walls of different type can be used. So-called dug ones are most easy to make. They are made as a narrow (approx. 0,4 m to 0,7 m) ditch dug by special excavator. The trench is being made as filled with thixotropic suspension to avoid wall falling. Then, the trench is filled with a sealing substance, which can be appropriately refined thixotropic suspension. The cut-off walls of such a type are most leakproof and most reliable but depth of their application is limited to the possible operating range of excavator, i.e. to max. 70 m. another type of cut-off walls are made by grouting. The chief point of this method is that boreholes are drilled, through which special sealing substances are injected under pressure into the aquifer. These substances should be characterized by a liquid consistence during injection and by an adequately determined time of solidification after injection into aquifer. An advantage of this method is its possible use to even great depths (e.g. 300 m) but disadvantage is its extreme complication (particularly in difficult and variable hydrogeological conditions) and lack of certainty as for its precise execution on big areas.
Such isolation is a very useful method for the overburden aquifers, but only when the cut-off wall can be made down to the roof of impermeable layer, thus enabling groundwater flow to be closed entirely through the whole section of the active aquifer. When the groundwater flow can not be closed over its whole thickness the cut-off wall loses very much its advantages, because it causes damming up of groundwaters and increases flow velocities through the non-sealed section. Besides inflow, it can also produce geomechanical problems. The use of cut-off walls is particularly recommended in the aquifers of high permeability being in close contact with surface waters recharging them (the close proximity of rivers or lakes). An additional advantage is to avoid development of the cone of depression outwards the drained area and thus, to protect flows in the streams and also to reduce drying of fertile soils. From the economic viewpoint, the cut-off walls are more expensive than other methods during the construction but they reduce expenses for continuous water pumping in the period of operation. The cut-off walls are used in Poland among others, in one operation to cut de inflow of water to open pit from the gravel filled river valley on the length of 5 km down to the depth of 10-25 m. Another example is an open-pit of sulphur, where this type construction has been made in the Vistula River terraces.

T h e u n d e r g r o u n d g a l l e r i e s together with gravity flow filters in the overburden and with overflow boreholes at the floor for drainage of underlying aquifers are also sometimes used for drainage.
The gallery systems are effective f.ex. in disturbed and discontinuous aquifers, at low water

yields from particular wells. Also, they are effective at low permeability aquifers because they are not so sensitive for water containing sand, as wells with submersible pumps. This method in common use in the 50's and 60's is still used now, however, more and more rarely owing to the mining hazard, labour safety and higher costs. However, its use can be still considered, but only when, on the deposit planned to be drained and operated with surface method, an active underground mine exists hawing the skilled staff, or even an abandoned mine is there located, which can also put again into operation.
This method is still used but on smaller and smaller scale in old operations, where galleries has been driven in 10-12 m thick lignite seam on the depth of 50-60 m. Groundwater inflow from the aquifer underlaying the seam is about 40 m^3/min. per pit (there are three open-pits drained this method over there).

T h e h o r i z o n t a l d r a i n s are very useful particularly if used as depressurizing ones together with the main system lowering generally the groundwater table. They are drilled from working benches of open pits towards the slopes, where groundwater inflow is anticipated, or where such an inflow has been already occurred. They are especially helpful in areas of slide hazards effected by groundwater occurrence. The length of horizontal drains can attain 150 m, and the diameter 100 mms. Also, they can be filtered by a perforated pipe made of PVC, and this is especially recommended for sandy layers.

T h e n e e d l e f i l t e r s are perforated pipes od 50 mm in diameter in most cases and of about 10 m in length driven or wash-bored into the soil to de dewatered. A group of such needle filters, f.ex. in a number of 20-30 pieces spaced 2-4 m, connected to one centrifugal pump makes it possible to lower the groundwater table by 6 to 7 m. These arrangements are used mostly used, where special additional dewatering is required (f.ex. along the ????? roads).

T h e d i t c h e s within the open-pit are designed mostly to take rainfall and residual groundwaters outflowing from the slopes. In some cases, e.g. in very uniformly grained sands, a general advance lowering of groundwater table providing the slope stability can be also achieved with adequately designed system of ditches. They are made as stationary structures on the long term slopes and benches and as a temporary structures (lined with the fascine) on worked benches. With these ditches, the water is fed to the stationary and shiftable pumping stations. This method is used in Poland with satisfactory effect in backfilling sandpits where groundwater drawdown is down - to 30 m and volume of water reaches 50 m^3/min.

T h e p u m p i n g s t a t i o n s equipped with sumps and centrifugal pumps located at the lowest points of open pits are designed to remove rainfall and groundwaters penetrating into the open-pit. According to Polish Mining Regulations they should have capacity for rain of 10 percent probability (once per ten years) and a sump of capacity to keep 4 hours rain, if all pumps are not operated.

The other actions consists in the relocation of streams outside the area of open-pit operations, in sealing of stream beds within the reach of the cone of depression (in order to avoid infiltration of surface water into the mine), and in the construction of circumferential ditches protecting the mine against water inflow from the surface watershed.

As can be seen from the aforesaid, despite not so wide range of arrangements used for dewatering of mines, it is necessary to make corresponding techno-economic analyses for selection of optimum method.

CRITERIA FOR SELECTION DEWATERING ARRANGEMENTS

The selection of main dewatering system should be based on the multi-variant comparative studies. This is of course actual for difficult hydrogeological conditions. Very often the conditions are such that the selection is obvious without any studies.

The proposed criteria for selection of dewatering method are as follows:

- hydrogeological conditions,
- technological design of mining operations and types of used mechanization (working and handling),
- availability of dewatering arrangements and experience already gained,
- environmental protection,
- labour safety requirements,
- capital and operating costs.

Hydrogeological Conditions

1. In the operations, where the overburden and deposit are hard rocks, with water-logging of a fissure type, mostly a sufficient dewatering measure are sumps and pumping stations located at the lowest place of an open-pit.
   Only seldom other arrangements as wells with submersible pumps or horizontal drains are used. This takes place in the areas where geological structures (faults, or folds, or dipping of strata) with water logged fissures create the hazard of slope slides.

2. In the loose and thick aquifers of permeability higher than 1 m/d ???/ and hydraulic contacts between particular aquifers the wells with submersible pumps aided with horizontal drain, ditches on the benches and pumping stations are recommended.

3. The existence of streams of a privilaged flow, such as zones of high permeability, the proximity of rivers and lakes, and possible deepening to the roof of an impermeable layer prefer to use the impermeable cut-off walls.

4. The presence, particularly in the water saturated overburden, of numerous closed water-bearing structures, disturbances in the regular occurrence of aquifers (foldings), low and variable permeability, makes it that the system of galleries, in connection with the flow filters and overflow boreholes, can be more effective. However, it is conditional upon a suitable rocks for galleries construction and their isolation from the aquifers, to protect the miners against an uncontrolled inflow of groundwater.

5. The horizontal drains may be used only when dewatering is not required ahead of the operation of basic machinery. Within existing open pit, they are very useful as supplementary arrangements to the above basic systems, or in situations described in p. 1.

6. The ditch systems in connection with pumping stations can be used only in hard rock operations and exceptionally for lowering of the main groundwater table in the surface mines, where sandy layers are uniformly grained, and the slope stability is high.

Mining operations

The assumed mining operations impose a required reliability of slope stability and, in consequence, a degree of dewatering effect. the main criteria which must be considered here are the following: selection of basic machines, height of cut, width of benches and disposable time (the operation of dewatering should advance the introduction of basic machines by 1 to 2 years to loose aquifers), open-pit face advance, possible reconstruction of wells sheared by particular working benches, an extent of wells necessity. So, f.ex. an open pit operated in loose water saturated formations has many not very high benches, with a quick face advance it can be an important difficulty for reproduction of sheared wells on each bench together with their electrical supply and water removal installations. It is because of disposable time ahead of the approach of a new face. This time being possible to be too short for these operations and for the wells to be efficiently operated. In this case the external barriers of wells with submersible pump surrounding open-pit and horizontal drains within operations work well. Also, an important factor of equipment selection can be requirements on extremely thorough dewatering of some most important parts of the open-pit (e.g. ??? roads, main inclined planes for belt conveyors, etc.). In such places additional arrangements as for instance needle filters are used. These operational criteria must be taken into consideration both for the selection of dewatering method and for determination of number and area distribution of particular arrangements.

Availability of Arrangements and Experience are an essential criterion for selection. For instance if grouting cut-off walls have not been made till now to a larger scale and devices and substances were to be imported, but from the other hand there is a technical base and experience in the wells drilling, this can prejudge for wells application, even if grouting would be more effective. The existence of an abandoned underground mine and a skilled miners' staff on the area planned to be worked by open-pit can prejudge the choice for the underground galleries system.

Environmental Protection requirements are one of the basic criteria to be taken into consideration. Two aspects play here the main role. One of them is the influence of depression in the mine on drying of streams, water intakes and soils in the vicinity. The second is pollution of mine waters. From the first viewpoint, drawdown of groundwater irrespective of dewatering method affects the environment in the same way. Only the use of impermeable can avoid this effect or restrict it to a considerable extent. From other point of view , the cleanest is water obtained from dewatering wells with submersible pumps and most polluted is that water which was flowing-off over the surface of easily washable or soluble rocks in the open-pit itself or in the underground galleries . Such mine water has to be purified before its discharge.

Labour Safety indicate that most disadvantageous is underground galleries system which produces difficult and often dangerous working conditions, while all another systems are not constrained to bring people underground and so are of similar small hazard.

Capital and Operating Costs is in most cases such as ultimate criterion when criterions considered previously do not give an univocal answer. In general, most expensive, in view of capital costs, are the impermeable cut-off walls and underground galleries systems, and in view of operating costs, the most expensive are wells with submersible pumps having a highest rate of energy consumption for water pumping.

CONCLUSIONS

The analysis of selection of dewatering measures leads often to the final choice of combined methods, e.g. using impermeable cut-off walls and wells, or wells and underground galleries, or wells with horizontal drains etc.

A basis for taking decisions must be the knowledge of hydrogeological conditions basing on the previous investigation. The mining operations system must be also planned ahead, and type of machines, their areal distribution, in the open-pit, face advances in the time as well. Also, the equipment availability on the local market, and experience should be discussed. The environmental protection requirements have to be analyzed in detail, and particularly those concerning purity of water discharged from the mine and damage in the environment which can result from the groundwater lowering.

Besides the above technical and natural criteria, the capital and operating costs of suggested alternatives are to be compared.

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