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PLANNING AND REALIZATION OF A CONSTANTLY INCREASING PREVENTION SYSTEM AGAINST UNDERGROUND WATER IN MINES

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ABSTRACT

Water hazard occurs in the majority of the mines in Borsod brown coal basin. Method of prevention is water level lowering by means of mine wells. K/1/a. longwall of Feketevölgy mine required active prevention. For the case of a protective layer in the roof we defined an optimum height of water column that resting in the sand would not be dangerous anymore. During planning of water level lowering it could be assumed that the fault near the longwall panel is an impermeable surface. Our estimation was resolved with two different theoretical methods. However in practice the wells enter the water yield not at the same time, but in a gradually increasing system. Water level sinking takes shape in compliance with it. The part of fault was also important it really proved to be impermeable. Technology of well construction followed the given circumstances but can be amended with further planning and experimental work. Computer simulation of water prevention is under realization that gives new opportunities for a correct planning, for applying an optimum preventive system.

INTRODUCTION

The majority of the coal mines in Hungary work under water hazardous circumstances. Borsod Coal Mining Company operates in Borsod brown coal basin that can be found in the North-East of Hungary. Most of its mines are hung over water hazard due to water bearing sedimentary rocks.

Borsod brown coal basin is built up mainly from Neogene layers, the coal seams occured in Miocene age. The strata are built up from unconsolidated sedimentary rocks. The strength of layers between and next to the coal beds is little, they are impermeable aleurits and permeable sands, gravel sands, clayey sands. Characteristic feature of these layers is that the ratio of aquifer rocks is 4o-7o per cent and they always contain stressed table water /water under pressure/ in their primary state. The above fact causes the main hazard for mining in Borsod.

The influence of tectonics is also very disadvantageous for mining. The tectonics of the territory was formed by the later stages of Alpine orogenesis during Miocene and later ages. The Neogene layers are blocked by large systems of faults. Tectonics takes a prominent part also in hydrogeology and water prevention. The thick sand layers that were originally connected are blocked into independent aquifer systems by one of the big faults.

Mining operations are usually hung over by the water bearing sands on the hanging side /in the roof/. The appearance of water hazard is different in that case where the sand layers are found next to the coal bed from the one where there is a protective layer having suitable feature between the sand and coal.

In several mines of Borsod Coal Mining Company active prevention have to be applied, namely, the water reservoirs have to be emptied in advance to an optimum degree. In these mines water inflow into the set of workings cannot be allowed either from safety, economical or both point of view.

From among the opportunities of active prevention it is the method of mine wells that is applied first of all. As against the method of aerial wells its advantages are the required relatively low charges of establishment and, above all, its flexible conformity to the different requirements of water prevention.

Our paper discusses a special question of water level lowering with mine wells. So as a concrete case is presented, the exemple of water prevention of K/1/a longwall at Feketevölgy mine.

GEOLOGICAL AND HYDROGEOLOGICAL STRUCTURE OF THE SURROUNDINGS OF K/1/a LONGWALL AT FEKETEVÖLGY MINE

Feketevölgy is one of the nine operating mines of Borsod Coal Mining Company. Its output is almost 2o % of the production of the whole Company. The recovered coal bed is 5 meter thick in average, the upper 3 meters of it is extracted. The breast of K/1/a longwall is 12o meters with hungarian made shield support. The direction of the advance of longwall face is parallel to the trend of the faults and opposed to the rise of the coal bed.

The geological structure won't be given in details only as far as it is necessary from hydrogeological and water preventive point of view.

K/1/a was the first longwall in a recently recovered mine-sector. It can be seen in Fig.1. that this sector is connected to the main entries and roads of the mine with openings can be be used as extraction drift later. Fig.2. shows the longwall and its surroundings. The longwall is sited near a 2o meter big fault. This fault is the boundary of the sector. Fig.3. shows the layers near the coal bed important from the view point of water hazard. In Fig.4. the geological structure of the surroundings of the longwall can be studied with the aid of a blocksection. This figure shows also the road and air opening of the panel. Water hazard is due to the sand strata marked with "3". The strata are cut up by two impermeable benches, but they are lensing deposits. It is proved, because the different stages of the sand strata are connected with eachother. The highest sand bench is gravelly having coarser grains. Its transmissibility is higher than that of the lower stages. The foot of coal bed is weathered clayey agglomerated rhyolite tuff.

Our longwall panel is surrounded by other panels partially extracted or being extracted. But in the directions of East, South and South-West it is connected with unmined territories. This fact is well showed by the primary pressure of sand layer that is given in bar in Fig.1. referred to the coal bed level.

The average thickness of the sand strata is m_3 = 26 m, coefficient of transmissibility is $T = (km_3) = 3.9 \cdot 10^{-4}\ m/s$.
Between the coal bed and sand there is an aleurit protective layer of 12 meters average thickness. This layer can ensure perfect protection for the drifts in its primary, unbroken state.

REQUIRED MEASURE OF WATER PREVENTION

Water hazard arises in case of thickness decreasing or breaking of the protective layer. The former takes place along faults but it is outside of our question. It is the caving method that causes the breaking of the protective layer. Exclusively this technology is applied at Borsod Coal Mining Company.

A confined aquifer bearing stressed table water with some bars overpressure can cause catastrophic phenomena if the required preventive water level lowering fails to come about. In such a case water and sand together flows into the mine and only the quantity of sand can be thousands of cubic metre. Such disadvantageous behaviour of the sand is underlined by the Fig.5. and the granulometric characteristics displayed on it.

It is the harmful effect of water that have to be prevented by lowering the water level in the required measure. The total dewatering of the reservoir would mean a perfect safety. However the optimum safety allows a certain water column left behind in the aquifer that has become unstressed /unconfined/. In this case water won't flow into the set of workings, it appears in the broken down area. Thus working places cannot get watered in case of a longwall advance opposed to the rise of coal bed.

The limit of security is the situation when the longwall reaches a unit advance - in our case 1 meter - during the same time while the water flows through the broken protective layer. This phenomenon is sketched in Fig.6. by a section of principle.

The seepage velocity of water according to Darcy's low: $v_v = k_{3s} \cdot I$.

The secondary coeffincient of permeability of the aquifer sand after getting fissured according to JUHÁSZ's [4] tests is increasing in a high degree compared with its primary value: $k_{3s} \approx 20\, k_{3p}$.
The broken protective layer is getting far more permeable $(k_{2s} > k_{3s})$, thus the part of sand will be defining. The hydraulic gradient (I) is according to the figure:

$$I = \frac{m_1 + m_2 + h_0}{m_2} \quad \text{, where}$$

h_0 is the optimum height of water column can left behind, this value is wanted to define.

The equality of appearence of water and progress of longwall is:

$$\frac{m_2}{v_v} = \frac{\Delta l}{v_f} \quad \text{, where}$$

v_v is the gravitational velocity of water flow, m/d,
v_f is the velocity of longwall advance, m/d,
Δl is the unit of longwall advance, m.
Thus the velocity of water:

$$v_v = k_{35} \cdot I = k_{35} \, \frac{m_1 + m_2 + h_0}{m_2} .$$

The allowed height of water column and the velocity of longwall advance are in linear connection /directly proportional/:

$$h_0 = v_f \frac{m_2^2}{\Delta l \cdot k_{35}} - m_1 - m_2 .$$

In practice the determination of height of water column is done in drifts by pressure measuring with manometer, namely the thickness of protective layer has an effect on the immediate reading. Hence the measured value is proportional with the rearranged formule below:

$$h_m = h_0 + m_2 = v_f \, \frac{m_2^2}{\Delta l \cdot k_{35}} - m_1 .$$

If the data of K/1/a longwall are substituated into the equation above the relation shown in Fig.7. can be obtained. The advance of longwall was mainly $v_f = 4$ m/day during the lifetime of it. It means that the allowed height of water column is about $h_0 = 7$ m, or the equivalent pressure in the drift is $p_m = 1.9$ bar.

PLANNING THE PROCESS OF WATER LEVEL LOWERING

The estimations and planning of water level lowering give us the following data:

- the required capacity of sumps and pumps, the required pipes of water delivery,
- length of time of water level lowering,
- the suitable schedule of drift driving,

Two methods - practically of the same value - can be applied for the analitical measurement. This time, as a comparison, both will be outlined in a few words adding the evaluation of results. Using both methods two further cases can be separated according to the different interpretation of geological - hydrogeological structure. The fault run along the longwall panel can be interpreted as an impermeable surface in spite of the fact that - according to Fig.4. - connection of the sand on the two sides of the fault hasn't been entirely broken off.

"Large equivalent well" method for unconfined aquifer

In our calculation the source was that the draining wells operate in a given geometrical arrangement. They can be substituted - taking into consideration their territory for a large equivalent well, namely for an aquivalent radius (ϱ_{ep}). Fig. 2.

$$\varrho_{ep} = \sqrt{\frac{F}{\pi}} \qquad , \text{m}$$

where F the territory under discussion. [5]
In this way DUPUIT-THIEM equation can be applied for determining of rate of water flow

$$Q_t = \frac{2(k m_3)\pi s_p}{\ln \frac{R_t}{\rho_{ep}}}$$ /Fig.8., curve 1./

The radius of influence is: $R = \sqrt{2.25 \cdot a^x \cdot t}$, the coefficient of piezoconductivity from it:

$$a^x = \frac{(k m_3)}{(\sigma^x + \beta^x)\rho_v m_3 + \frac{2\omega}{s_p} \cdot t}$$

The applied symbols:

- s_p: the average drawdown of the territory requiring for getting the aquifer unconfined
- σ^x: coefficient of compression according to JUHÁSZ [3] , m^2/kg
- β^x: coefficient of volume expansion according to SCSELKACSEV [7] , m^2/kg
- ρ_v: water density, kg/m^3,
- ω: coefficient of infiltration proportional to a constant water supply, m/s.

The time change of head is determined by the MUSKAT equation:

$$s_t = \frac{Q_o}{4(k m_3)\pi} \ln \frac{2.25 \cdot a^x \cdot t}{\rho_{ep}^2}$$ /Fig.8., curve 6./

Here Q_o is the rate of water flow belonging to the reduced time.

According to the estimation unconfined state comes into being after 42 days from the start of water head drawdown. After 175 days - when the longwall actually securely started still almost 2o m water head should have been assumed above the longwall panel.

"Large equivalent well" method with impermeable fault

In this case the starting point is that the water table sinks on the fault as on impermeable contour, as if another well with the same discharge worked on the opposite side of the fault. This can be assumed on the basis of summing up the flow potentials. [5] Fig. 9. - that gives a theoretical sheme to the estimation - shows that the equivalent well is substituted for a normal well. The well - known equation in this case changes as follows:

$$Q_t = \frac{4(k m_3)\pi s_p}{\ln\left(\frac{R_t}{\rho_{ep}}\right)^2 - E_i(-u)}$$ /Fig.8., curve 2./

The argument of Eiry-function is given by the further equation:

$$u = \frac{D^2}{a^x \cdot t}$$, where

D is the distance from the fault to the well, m

Using MUSKAT - formula the water head drawdown is given by:

$$s_t = \frac{Q_o}{4(km_3)\pi}\left[\ln\frac{2.25\cdot a^x\cdot t}{\rho_{ep}^2} - E_i(-u)\right] \qquad \text{/Fig.8. curve 7./}$$

According to this calculation the aquifer is getting unconfined in 2o days, but on the 175 th day there is a lo m water head in the sand layer.

"Well - gallery" method for unconfined aquifer

Wells operate in two parallel drifts, they can be considered as a gallery. Thus using the equations of hydrodinamics referring to galleries is allowed. The gallery has to be considered limited as the inflow from the two ends is unambiguous. This is demonstrated by the equipotential and flow lines seen in Fig. lo. The facts above must be taken into consideration because the ratio $(\alpha = R_t/b)$ of the radius of influence (R_t) and half - length of the gallery (b) varies between 1.6-2.8. According to CIOC [2] the estimated discharge of both sides of the gallery:

$$Q_{1t} = \frac{(km_3)\pi\cdot h_p}{\ln\left[\frac{R_t}{b}+\sqrt{1+\left(\frac{R_t}{b}\right)^2}\right]}$$

The new symbol is $h_p = s_p$.
Two galleries operate in the system. Thus the above equation is valid for both galleries only until the radius of influence between them reaches the half of breast ($2R_o$), namely $R_t = R_o$. According to our estimation this occurs very quickly, within one day. From this time onwards the above equation can be used in the case of each half - gallery. Between the drifts the aquifer has been already unconfined where the water discharge:

$$Q_{2t} = 2bq_o e^{-2\alpha t} \qquad \text{, from that}$$

$$q_o = \frac{k\cdot H^2}{2R_o} \qquad \text{and} \qquad \alpha = C\frac{a}{R_o^2 \ln\frac{R_o}{1.5r_o}}$$

For the constant according to our earlier estimation [1] C = o,68 value is obtained for this certain, given geometrical situation. The coefficient of piezoconductivity is:

$$a = \frac{(km_3)}{n_o}$$

Further symbols: $H = m_3$, m
r_o : radius of mine wells, m.
Hence, the pressure release between the drifts passes off very quickly, that's why the curve3. in Fig.8. practically equals to $Q_t = Q_{1t} + Q_{2t}$ value. The equation describing the drawdown:

$$h_t = H\cdot e^{-\alpha t} \qquad \text{(Fig.8., curve 8.)}$$

The result of estimation is that about lo m water head is expected in the aquifer after 175 days from the start of drainage.

"Well - gallery" method with impermeable fault

Curve 8. of Fig.8. is also valid now because the drawdown between the two galleries is equivalent to that of former case. One part of discharge is calculated by transformating with Eiry-function that had been introduced earlier:

$$Q_{1t} = \frac{(k m_3)\pi h_p}{\ln\left[\frac{R_t}{b} + \sqrt{1 + \left(\frac{R_t}{b}\right)^2}\right] - E_i(-u)}$$

The other part of discharge is given by the above Q_{2t} equation of drainage between the galleries. The summarized discharge is seen in Fig.8., curve 4.

ESTIMATION COMPARING TO GENUINE PROCESS

The fundamental principle of dimensioning is that the geometric arrangement of draining wells is idealized, thus sizing only approaches the reality. However theory and practice are decisively different as theory assumes a line of draining wells starting their work at the same time. But the wells are getting ready in time succession creating a gradually increasing system. In our case from 41 finished wells 38 were getting ready constantly during 3 months. Further difference is that the origius of estimation are often average data, and the error of data cannot be always well defined. On the other hand the genuine parameters are very variable according to horizontal coordinates.

Comparing the estimation methods to practice the water quantity estimated and measured for the 175 days fromn the start of drainage to that of the longwall the following:

"large equivalent well" method	552.2oo m^3,
"large equivalent well" method with impermeable fault	364.4oo m^3,
"well-gallery" method	619.9oo m^3,
"well-gallery" method with impermeable fault	43o.9oo m^3,
output in reality	315.8oo m^3,

The row of results by itself refers to the right supposition of the impermeable fault. It also shows that supposing the fault the "equivalent well" method seems to be better, because it gives only 15 % higher quantity of water than the genuine one.

We've already seen in Fig.1. that significantly various kinds of starting pressures dominated on different points of the longwall panel. That's why the expected rates of water flow from different directions must be various. Supposing the impermeable fault even more increases this tension. An important fact can be laid down deviding the longwall panel into three parts. It can be seen in Fig.11. After this we can separately examine the rates of water flow summarizing in each part in both drifts. The two most typical rows of data were chosen from-they are the 116th and 15oth day-and the result below is obtained:

Part of the panel	Wells	Water discharge 116th day	15oth day
Northern	A(14-18)	4.2	4.2
	B(17-22)	37.7	37.2
Middle	A(6-13)	8.2	8.5
	B(1o-16)	79.5	62.7
Southern	A(1-5)	12o.5	5o.3
	B(1-9)	53.8	54.7

Summary in a Table well shows that the wells signed "B" on the side of unmined sector drain the rate of flow of permanent origin. "A" wells in the Northern and Middle part unambigously reflect a situation along an impermeable fault. The wells in the Southern part were established last of all. They still started with high discharges from the unmined sectors, but were rapidly decreasing until a permanent flow envolves.

Fig.11. shows the water tables can be measured and constructed in the two given points of time. The values give the piezometric pressure referred to the coal bed in bar. It can be seen that a huge change had been taken place for 116 days compared with that of origin. /Fig.1./ During the following 34 days possibility of longwall start has already got closer. /The constructions completing the pressure measuring were made by applying the tests of FAHMY and SZABÓ for interference of the two galleries [2.] /

From our former estimation /Fig.7./ is seen that the allowed value of pressure in case of this longwall panel is $p_m = 1.9$ bar. Thus starting of the longwall after 175 days was safety and allowable from the respect of water prevention.

The facts above enlighten that the significant deviation between analitical sizing and genuine process of water level lowering - in order to schedule the mine workings to the best - makes the usage of computer essential. Nowadays the establishment of a simulation system is under implementation. This system is going to observe the hydrogeological and mine water preventive processes from planning to the end of extracting the panel.

OPERATION AND FUNCTIONNING OF WELLS

The draining wells partially penetrate an aquifer with 5-7 bars piezometric pressure in primary state. It must be taken into consideration that the uppermost bench of sand has the highest transmissibility, /Fig.3./ That's why the wells must penetrate the whole strata that is a technical difficulty. Several good solutions for building wells are applied in the mines of Borsod Coal Mining Company. In Feketevölgy mine keeping the roch structure in original state around the well hasn't been securely solved. The problem - as it has been mentioned - is caused by the fact that interbeddings in the sand strata having higher compression strength /4-5 MPa/ with orders must be penetrated. For such a case still we haven't got a tool suitable for drilling and being filter at the same time.

The actual two-stepped technology is simple but there is a certain risk of the fact that implementation won't be perfect. The hole is drilled all along with d=9o mm diameter, using stuffing box, through cementated /gouted/ casing. This can be seen in Fig.13.1. After the drilling tool had been run out, temporarely free outflow is allowed from the borehole, while an iron or plastic filter is placed against the water and sand stream. The filter is fixed to the casing and finally a suitable armature is fixed on the hole. /Fig.13.2/ The diameter of the filter is d=6o mm, 15 % of its surface is slitly perforated. A screening cloth - suitable in function with the grain characteristics - is fixed on the filter.

The risky point of this technology is the temporarely free opening of the borehole. Namely at that moment a large quantity of sand can outflow of the hole. Skilled borers usually can avert this phenomenon but disadvantageous cases can occur, found out during operation of the well. In the pheriphery of the filter structure of sand varies, fine fractions can gather round the filter [6] . In this case water discharge often quickly decreases apparently without reason.

In Fig. 12 some characteristic water discharges varying with time are seen of the working wells. The curves of B-2, B-2o, A-1 and possibly A-1o wells can be regarded as having normal running off. The abnormal time change of discharge points to technological problems mentioned above: 21 % of the wells established in the drifts of K/1/a longwall were giving acceptable volume of rate of flow only for a short time, then they settled at a minimum discharge. Curve of B-21 and A-4 well are good examples of this. Often notable increasing can be found according to the initial discharge within a few days that later dicreases in accordance with the natural trends Diagrams of B-4, B-14, A-5 wells are characteristic examples of the above case. Examining the curves of B-14, B-4 wells enlightens that during their long operation these wells produced more big decreasings and increasings of discharge. These phenomena refer to the fact that the mentioned arrangement around the well causes choking effect from time to time. The repeated discharge increase comes into being so that the increased pressure around the well causes the "exploding" of the sand gathered together around the filter.

According to the above - mentioned the technological problems significantly define the effectiveness and economy of water preventive works. However the described effects above can not be confused with the case of decreasing discharges for the reason of standard well hydraulics. This can be avoided by the comparison and analysis of data. However the evaluation with computer immediately separates the phenomena caused by different things with perfect security.

FURTHER TASKS

Summing up can be proved that the theoretical and practical methods of planning and establishment of water level lowering are suitable for the realization of a water prevention system in Feketevölgy mine. This statement is right in spite of the technical faults and inexactness are present in planning.

Our task is to study better the geological, hydrogiological structures during investigation /e.g.behaviour of faults in the respect of permeability/. They essentially define the water preventive system establishing.

We have already done the first steps for preparing a simulation system with computer that will observe the mine water prevention from the investigation to the total extraction of the secovered coal bed and will give basis for an optimal solution.

Finally we have taken steps for the solution of technical problems of operation. In detail we are using our efforts on preparing a new technology that is suitable for operating "good wells" in hydraulical respect. The wells will be placed in roof layers in case of a geological structure of Feketevölgy or similar to it.

LIST OF FIGURES

Fig.1. Map of surroundings of K/1/a longwall.
1.fault, 2. extracted part of K/1/a, 3. extracted area, 4. main drifts and driving openings, 5. piezometric pressure bar referred to the coal bed.

Fig.2. Map of K/1/a longwall .
6. mine opening and draining wells, 7. height point of opening above sea level, 8. rise and hedding angle of coal seam, 9. direction of advancement of the longwall.

Fig.3. Log section of the strata above the coal bed.
1. coal bed, 2 aleurit /impermeable/, 3. sand /permeable/, 3/a gravel sand /having higher permeability/, 3/b. aleurit interlayer, 4. clayey weathered rhyolite tuff.

Fig.4. Geological block section of the surroundings of a K/1/a longwall.
1. coal bed, 2.aleurit, 3. sand layers, 4 clayey, weathered rhyolite tuff, A: road of the longwall, B: air opening of the longwall.

Fig.5. Curve of grain size interval of aquifer sand layer

Fig.6. Theoretical figure for water flow through broken protective layer.
m_1 : thickness of breaking, m_2 : thickness of protective layer, m_3 : thickness of sand, k_{2p} : coefficient of permeability of protective layer in primary state, k_{2s} : coefficient of permeability of broken protective layer, k_{3p} : coefficient of permeability of undamaged sand layer, k_{3s} : coefficient of permeability of fiswured sand layer, β : contact angle of fissured zone, v_v : velocity of water flow, v_f : velocity of longwall advancement, h_o : allowed head, h_m : allowed head of the longwall panel.

Fig.7. The allowed head in function with advancement velocity of langwall.

Fig.8. Time change of water level drawdown (6,7,8) and estimated water discharge (1,2,3,4) with different methods and the genuine water discharge (5)

Fig.9. Theoretical figure for water level lowering calculation along impermeable fault with "large equivalent well" method.

Fig.1o. Theoretical figure for calculation with "well-galleries" method.
1o.1: in case of unconfined aquifer.
b: half length of gallery, $2R_o$ distance of galleries, R_t : radius of influence changing in time.
1o.2: in case of impermeable fault.
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Fig.11. The water level change above K/1/a longwall.
1. mine opening and draining well, 2.fault, 3. pressure value non-changing during drainage, 4. piezometric preasure after 116 days, 5. piezometric pressure after 15o days, 6.line separating the territory into parts.

Fig.12. Water discharge changing in time of each well in the drift of K/1/a.

Fig.13. Technological draw of draining wells.
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13.2 wells in final state
1.standpipe, 2. cement mantle, 3. blow-out preventer with stuffing box, 4.distance piece with gate valve, 5. drill-pipes, 6. crown, 7.gate valve, 8.producing pipe, lo.filter, a: impermeable rock, b: sand layers.

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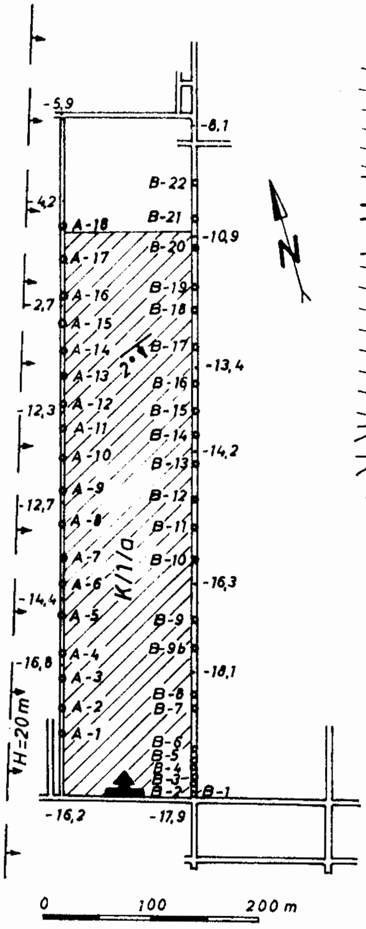
Fig. 2.



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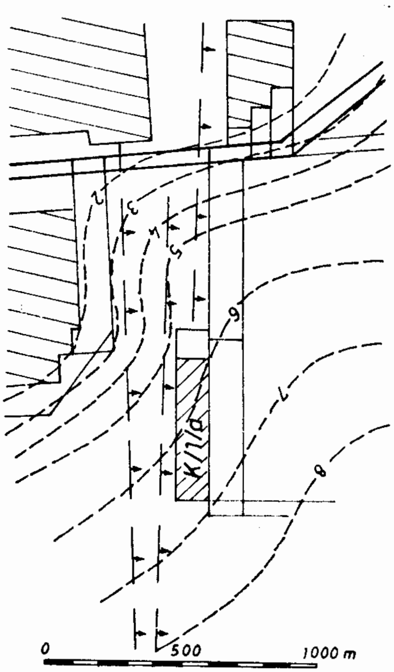

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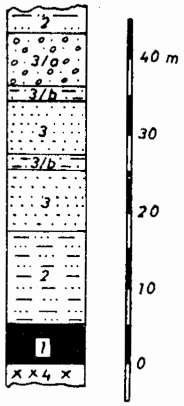

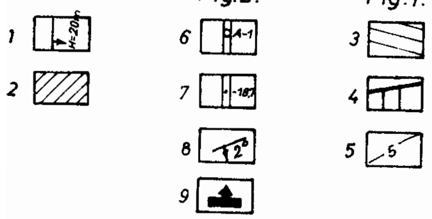

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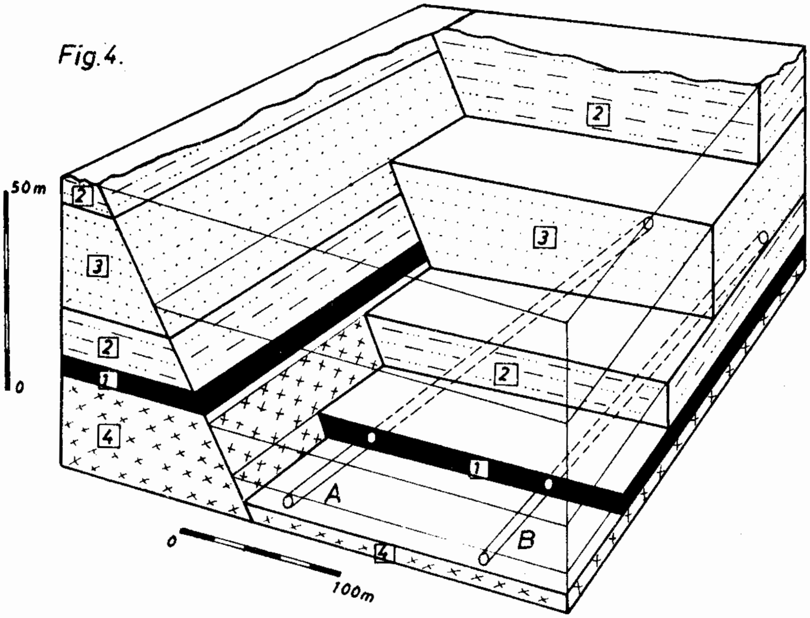

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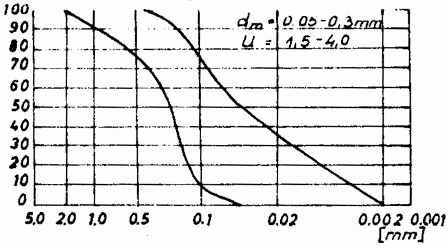

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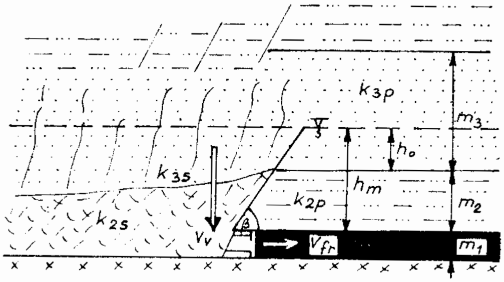
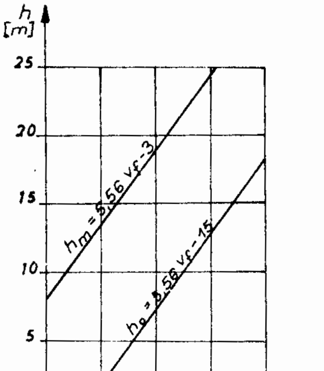
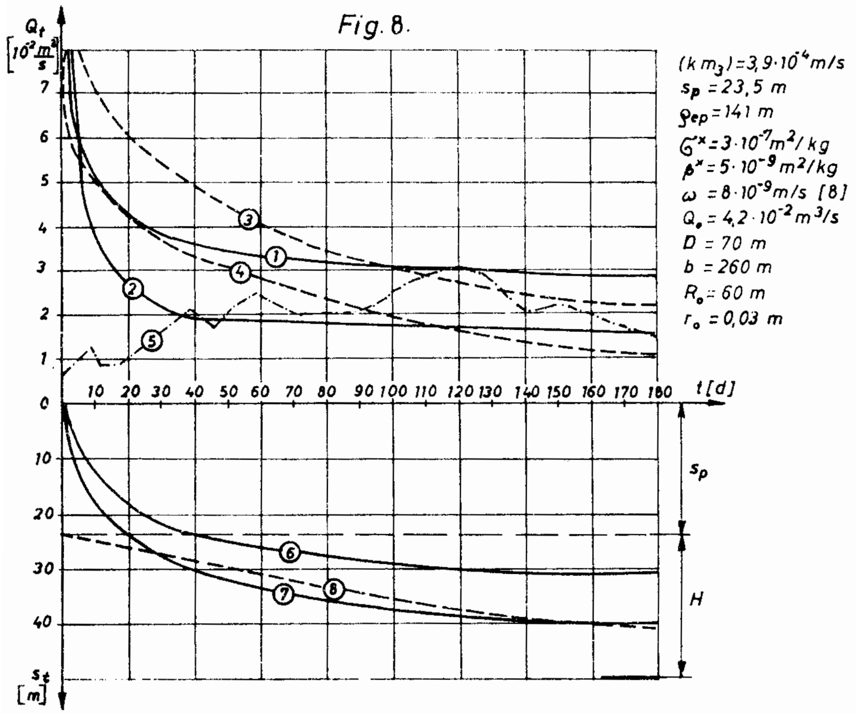


Fig. 7.



$m_1 = 3m$
$m_2 = 12m$
$k_{3s} = 3 \cdot 10^{-4} m/s$
$\Delta L = 1m$

Fig. 8.



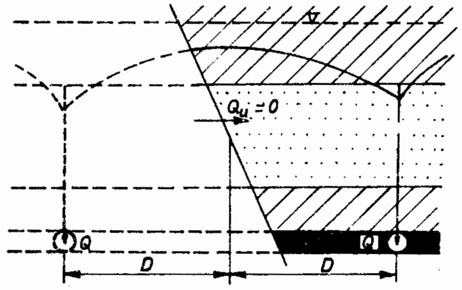


Fig. 9.

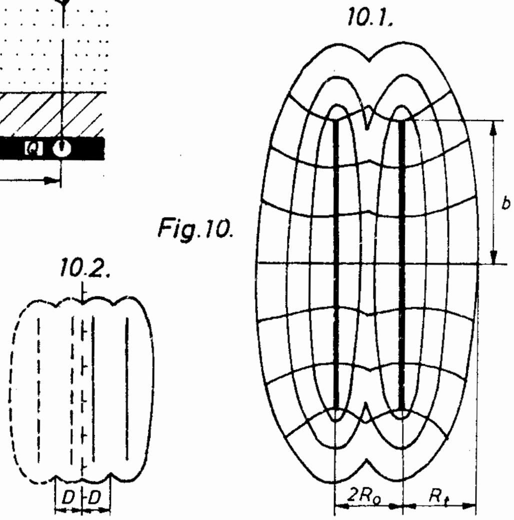
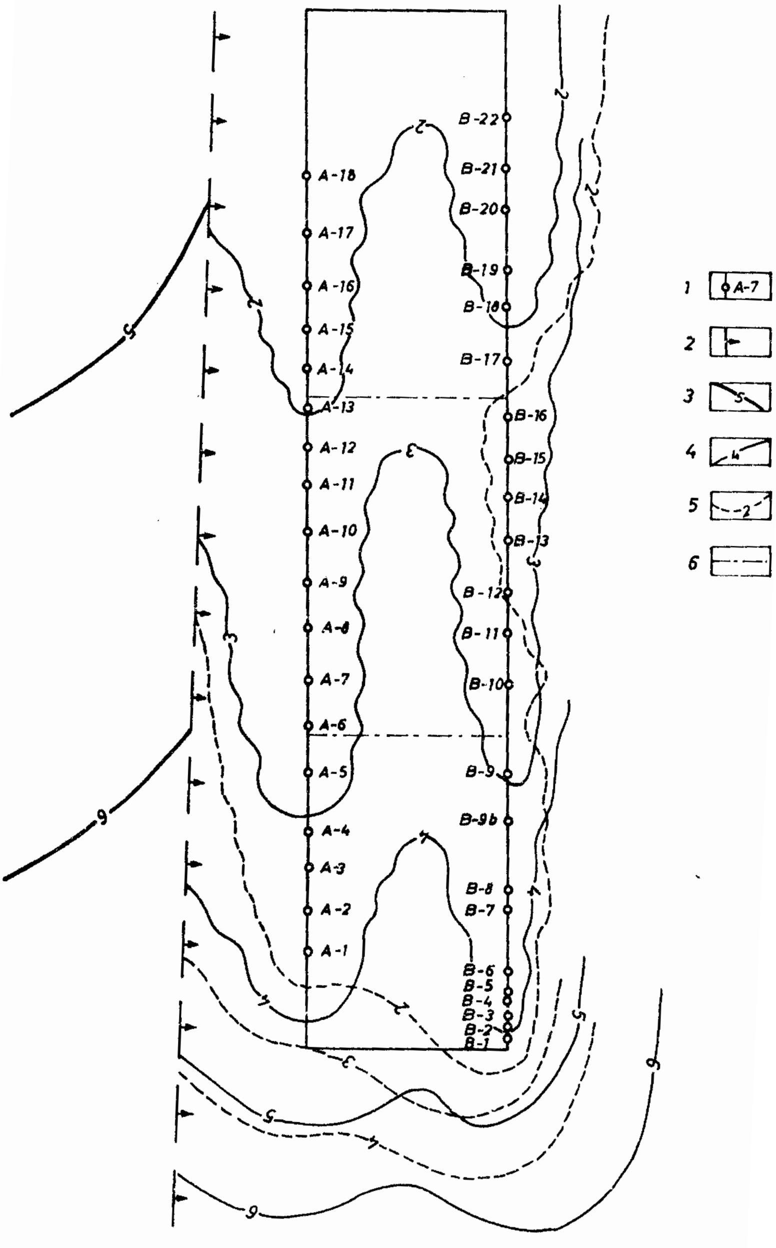


Fig. 10.

Fig. 11.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A-5
A-4
A-3
A-2
A-1
B-22
B-21
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B-19
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B-14
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B-9b
B-8
B-7
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B-5
B-4
B-3
B-2
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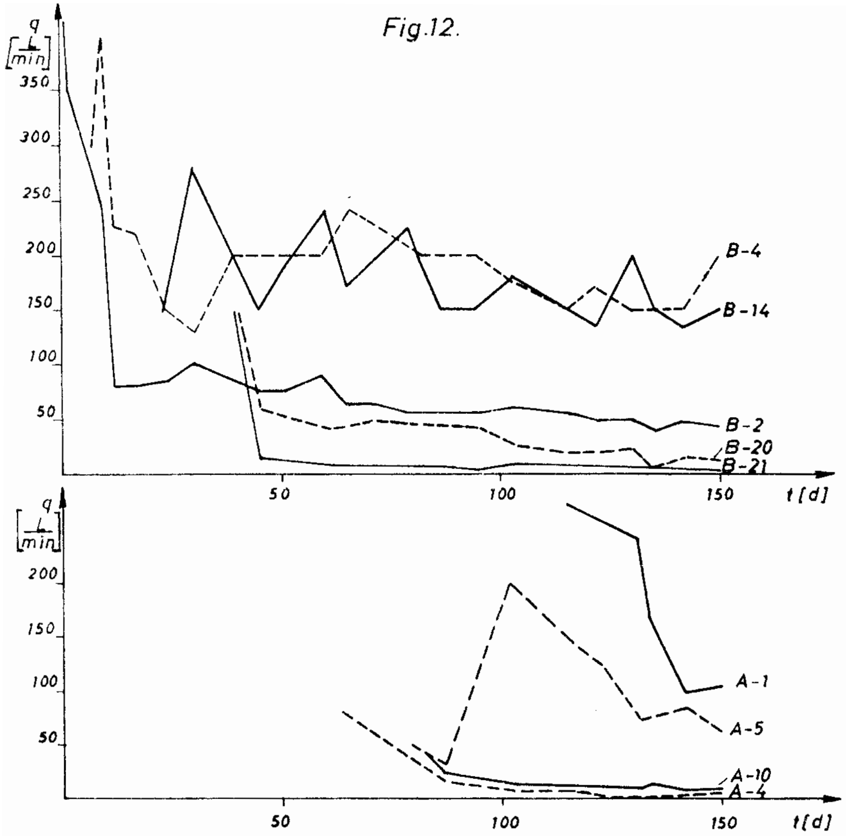
3
4
5
6
1
A-7
2
3
5
4
4
5
2
6

Fig.12.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300
250
200
150
100
50
B-4
B-14
B-2
B-20
B-21
50
100
150
t [d]
q [L/min]
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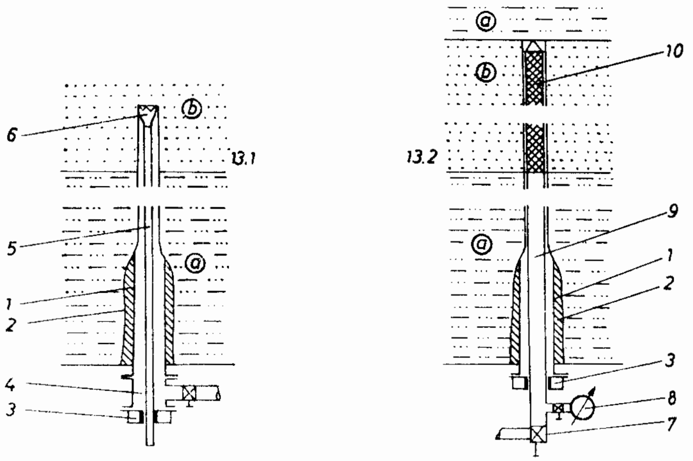
150
100
50
A-1
A-5
A-10
A-4
50
100
150
t [d]

Fig.13.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3
8
7