# SEALING WATER INFLOWS AND SOLIDIFICATION OF ROCKS BY A CHEMICAL AGENT

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## ABSTRACT

In the Enterprise for Sinking Mine Shafts a new system was developed for sealing water inflows and solidifying rocks by means of a chemical agent. By its use, along with improved technologies, the work of mine construction is to be made safer and more efficient. In the system the equipment, necessary to condition and examine the chemical agent, the testing means, special mixing and injecting heads, as well as pumps are included.

A mono-component injecting agent of new formula was developed. Its viscosity is low nearing that of the water, while the length of time, required for its gelation, is to be modified in broad limits. This new injecting agent, marketed under the trade name Matakril, lends itself to solidify water saturated or other rocks with poor infiltration factor or to seal them, as well as to seal high pressure formation water or thermal water inflows, to solidify the walls of boreholes, to insulate underground constructions and surface buildings.

Some cases for its practical application are described in which this newly developed injecting system was used in past years.

## INTRODUCTION

The works of both developing and extracting deposits containing useful minerals have been performed in ever increasing depths and in more and more severe conditions. On account of the stringent requirements against supporting elements, as well as the elevated rock temperature and the presence of high pressure formation waters, improved technologies and better materials should be indispensably used.

Plastics and chemicals, which found extensive application in every industrial sectors, have contributed in working out new supporting technologies as well as water sealing and rock solidifying techniques.

For sealing high pressure thermal water inflows and solidifying water saturated dispersed rocks the conventional injecting methods are no more efficient. In addition, even the rock freezing method has its technical and economical limits.

For this reason, it seemed reasonable to develop a new water sealing system which, adapted to improved technologies, can make safer and more economical the work of mine construction.

## COMPARISON OF DEWATERING METHODS

Dewatering and rock solidifications are activities independent each of other. Though, from the point of view of mine construction the aim is, almost in every case, at solving by them the same problem. In determining the range of application of the methods of tapping water bearing strata consisting of granulated rocks Hungarian references indicate the requirement, based on own experiences and the results obtained in abroad, that the technical and economic possibilities should be matched [1]. The ranges of various dewatering methods, used by our Enterprise in preparing designs, are presented in Fig.1. They were delimited by benefiting from the results presented in references, as well as from own experiences and measuring data.

According to their aims and technologies the water sealing jobs, undertaken by our Enterprise, are to be grouped into 3 categories:

1. Sealing. — Filling out of cracks, sealing of water bearing strata by the technology "Kipko" applied under licence, using high viscosity bentonite or clay slurries
2. Cementing. — Sealing of water inflows in fissured rocks or sediments consisting of rocks of coarser grains, back-filling etc, by having recourse to conventional technologies
3. Injecting by chemicals — Rock solidification and sealing of water inflows in rocks with poor infiltration factor, in fine sands, sealing high pressure water inflows with chemicals.

In this paper the methods of injecting using chemicals and the experiences collected therewith will be discussed.

## CONDITIONS OF PERFORMING INJECTION BY CHEMICALS AND THE REQUIRED MATERIALS

Rock solidification and sealing by chemicals is to be done reasonably mainly in water saturated, dispersed strata which are movable in hydrodynamic conditions or include colloid particles exhibiting thixotrope properties. In addition, in cases also, where the conventional cement injecting methods are no more efficient. For this reason, mainly low viscosity chemicals are to be used for that purpose, the length of gelation time of which can be accurately controlled in broad limits.

At present, the number of chemicals based injecting agents, referred to in references and the brochures of manufacturers, is almost illimited. It is the reason why some authors try to categorize and select, respectively various injecting agents by point evaluation [2].

In our Enterprise tests started only on chemicals, which could be easily imported from abroad and even their production in Hungary is possible.

In Fig.2 viscosity values are shown for conventional and chemicals based injecting agents. Tests commenced on French made Celtamine injecting agents. Following them a new type of agent was developed and marketed under the trade name of Matakril [3].

Matakril is a mono-component acrylic amide based injecting agent patented by the Enterprise for Sinking Mine Shafts, Tatabánya Collieries and the Laboratory of Natural Sciences of the Hungarian Academy of Sciences. It is a low viscosity agent, the length of gelation time of which is to be adjusted between 10 seconds and 24 hours. It provides an elastic gel. The strength of injected soils doesn't vary with time and they resist chemically to the effect of every type of ground waters. Bacterial and other micro-organisme cannot attack it. Even the gel strength is to be modified in broad limits. Should the gel or the injected rock be dried out, so would its strength be substantially increased. Since it has self--regenerating properties, in case where after its drying out it absorbs again water, it swells to the point where its initial volume is re-established and its insulating properties are re-gained.

Since Matakril has most proper technical properties and is highly efficient and since its production in Hungary can be started in the years ahead, our Enterprise worked out a technology lending itself to its use on industrial scale.

## DEVELOPING THE SYSTEM OF INJECTION USING CHEMICALS

Since the material, equipment and technology, necessary to carry out injections using chemicals, are deviating from those required for conventional methods, an injecting system should be developed, covering preparatory examinations, laboratory and testing equipment needed to define the proper composition of chemicals, the technologies of treating and mixing chemicals and their accessories, special injecting heads and pumps etc. In Fig.3 a schematic diagram of this system is presented.

In the preparatory stage conventional laboratory tests are made on cores or samples taken by other methods in a view of determining their rock physical characteristic for being able to select the appropriate injecting agent. From these tests the examination carried out using a D-II device should be particularly indicated. By it useful data are to be obtained for determining, in the first place, the infiltration factor of sedimentary rocks then the parameters of dilution, adjusting the viscosity of the injecting agent to be used and selecting the optimal injecting pressure. From these tests practical conclusions can be drawn to the re uired amount of injecting agents and the depth of penetration.

The proportions of mixing various components should be determined in the stage of chemicals conditionment by taking account of the degree of dilution and the temperature. On the chemicals prepared in this way checking tests will be performed on site in a view of knowing accurately the length of gelation time. It is important mainly for injecting works with short gelation time. For determining the length of gelation time a device was constructed in our Enterprise which detects accurately the moment where the process of gelation starts and indicates its progressing in time, as well as its intensity. After having adjusted accurately the catalysts, the injecting agents will be prepared for shipping, by considering the relevant mining or other conditions in which the injection work will be done.

For injecting quick setting chemicals a special 40 l/min capacity and 40 bar pressure pump was developed by our Enterprise in co-operation with the Research Institute of Plastics. For injecting higher volumes of agents another 150 l/min capacity and 80 bar pressure pump was designed by making use of a triplex system IK-150 type pump. Both pumps being operated by compressed air they can be located even in gassy mines.

During tests a self-closing injection head was constructed making unnecessary to apply costly standpipes or carry out lengthy operations. This injecting head is to be run immediately after having drilled the injecting hole. Subsequent to the injecting operation it can be recovered and re-used. The head operates well up to injecting pressures of 80 bar and can be run into holes with diameters up to 80 mm. According to the diameter sizes IB-i, IB-ii and IB-iii types were constructed.

For increasing the efficiency of injections it is reasonable to carry out absorption tests with indicators prior to proceeding to injection work, for clarifying problems associated with the direction of water flow and the inter--communication of underground channels. When injecting water filled caverns or strata, including flowing water, it is necessary to determine the degree of dilution. It is made by a refractometer and a solution of given concentration which is indifferent towards the chemical properties of the relevant strata. After that the solution was added tests are made on the working place for checking the length of gelation time, since the data on large volumes of solution may deviate from those specified for small ones. Before leaving the working place it is reasonable to perform a closing test for being convinced of the success of injection.

## EXPERIENCES GAINED IN OPERATING CONDITIONS WITH THE METHOD OF WATER SEALING AND ROCK SOLIDIFICATION USING CHEMICALS

### Sealing of water inflows and solidifying rocks in Shaft K-IV of Komló

When sinking the Shaft K-IV 118 m long controlling holes were drilled from the loading point at level X. From the sandstone floor strata water outflowed at rates from 300 to 500 l/min with 18 bar hydrostatic head and at 40 °C temperature. Sealing the water was all the more necessary since the shaft should be sunk to 65,7 m below the level X. Lifting waters sould have made impossible to continue shaft sinking on the one hand, and during production they would have led to serious disturbances on the other hand. Injection by conventional cementing methods proved unsuccessful and injecting pressure caused the strata to be fracturated near the bottom. Thus boilings occurred making the cement injection inefficient and hindered to continue work.

Using Matakril first rock solidification on the loading point was proceeded to. Subsequent to this lifting waters were sealed in the following manner.

After having measured the rates and pressure of water and carried out absorption tests, we could locate, using a fluorescein solution, the points of boilings and infiltrations that communicated directly with the boreholes tapping the floor and the lifting waters, respectively. This was followed by measuring the extent of dilution using a sugar solution. At the points of infiltrations, traced by fluorescein, the variations in sugar concentration, as well as in the extent of dilution and in water temperature were measured by refractometer in every minute. Using the data thus obtained the amount, concentration and length of gelation time of the injecting agent were to be determined.

The first problem to face up was to eliminate rock fractures in the surrounding of the level X by strata solidification. For this reason the gelation time was selected as short as to cause the diluted agent to be gelified before it came out with the boils. As indicated by control holes, efficient rock solidification could be performed in this way at depths up to 30 m from the bottom. Consequently, the opportunity was given to seal completely the water bearing sandstone strata at 30 bar overpressure. A schematic diagram of the rock solidifying and sealing operation is shown in Fig.4.

Water sealing by chemicals in the Shaft F-I of Nagyegyháza

In Nagyegyháza Pit, formation fracturing occurred when sealing was performed through the borehole No N 118 and the fed slurry appeared in the maingate No I of the Pit. Subsequent to stopping the work of sealing, karstic water inflowed through the line of break and its rate stabilized at about 400 l/min. This water inrush created hazardous conditions in the mine since it carried a substantial amount of drifts and the cavern formed near the roadway threatened seriously the whole transporting system in Nagyegyháza Pit.

Water was sealed by Matakril fed from the surface through the borehole No 118. Since the section of the line of break at which karstic water inflowed between the borehole and the maingate No I was not known, preparatory measurements should be performed. At first the length of flowing time for the injecting agent between the borehole and the point of water inflow was determined by fluorescein colour. For this time 13 min was given. Dilution measurement by sugar solution indicated a 3,5-times dilution. In conformity with these data the length of gelation time should be selected in such a way as to prevent the gelation from taking place before the agent would be diluted by karstic water. Data on preparatory measurements are presented in Fig.5.

In case, where gelation occurs prior to dilution, the borehole will be closed and no sealing made. In turn, if gelation is produced much later than the process of dilution was carried out, the injecting slurry flows along with the karstic water into the drift without undergoing any gelation. These conditions could be met only by preparing a high concentration stock solution and pressing it in short time into the borehole. Matakril was introduced at 100 bar pressure by a 11 GR-I type injecting pump. Totally 6 cu.m of solution was pumped in by connecting two tanks and 1 pump. This was necessary since the time of gelation has been adjusted by a combined method. The time of gelation for the solution contained in the tanks was 14 min but after mixing in the borehole it take 4 min. The chemicals thus prepared were pressed in through the drill pipe into which a packer was run. The schematic diagram of water sealing operations is seen in Fig.6. Subsequent to injecting the rate of the water inflowed into the mine was diminished to about 30 to 50 l/min and drifts were no more carried by it. Residual waters are to be sealed by injections through short holes drilled underground.

Sealing operation in Pusztavám South Shaft.

In its first section of 30 m the shaft traversed aquiferous sand formations. For meeting environmental regulations water should be completely sealed when shaft sinking progressed , since any variation in the water table in the environment of the shaft was to be prevented only in this way. By conventional methods this goal could have been achieved only by constructing costly impermeable wallings. Technically it would have made difficult to continue the works of sinking and walling, viewing the fact that the sand layer, dewatered preliminarily under vacuum, was not stable and supporting could be performed by the so-called pillar walling method. Sealing was then carried out using Matakril injecting agent as it follows:

Between the walling of concrete blocks and the extracted rocks /sand layer/ a 10 cm thick infiltrating layer was built-in using gravels 8 to 16 mm in grain size. After a length of advance of 1 to 1,5 m the infiltrating layer was saturated with Matakril in a way as shown by the sketch in Fig.7. After that the gelation completed an impermeable elastic mantle surrounded the walling. Gelation time and solution viscosity were adjusted in a way that the agent filled out jointless the infiltering layer and the loss at wall joints and that due to infiltration into the sand layer were cut to a minimum. Adjusting the viscosity was made by bentonite which, at the same time, contributed to increase the gel strength. Mixing and feeding the chemicals were carried out on surface where also the injecting pump was located, as shown in Fig.8. At places, where no infiltrating layer could be establisbed post-injection was performed by means of a KEVITI type pump disposed on the shaft plateform, by using a two-component quick setting chemical. Injecting was done by an IB-I type self-closing head of new system.

Other water sealing operations

Successful sealing operations were effected using Matakril on the -700 m level of Recsk copper mine. On the treated places drifting work was preceded by conventional cement injection and substantial amount of water inflowed. In many a cases the water pressure exceeded 72 bar. On working places, where water flowed in through fractures, quick setting injection agent should be applied.

In a section of a water tunnel driven under the Danube at Békasmegyer, ring support section were insulated by Matakril. Cement slurry could have been back filled only at high pressure which would have produced fracturing in the layer 6 m in thickness between the bed of Danube and the tunnel. For injecting Matakril only a pressure of 1 bar was needed.

Injecting with our chemical agent was successful even in deep holes. In the North-Borsod area, in a karstic region, mud loss in fractured formations and water inflow into boreholes were prevented by our method. At Mecseknádasd the Matakril injecting method, applied in a hole drilled through a seam, prevented the gas from being flowed out from the coal and also the borehole from being collapsed.

## STUDIES OF ECONOMICS

From the economical comparison of various dewatering methods no conclusion of general validity can be drawn. Such studies should be carried out separately for each problem. Injecting by chemicals are to be applied mainly in cases, where the conventional cheaper methods prove to be inefficient.

As far as the comparison with freezing concerned the costs per cubic meter are nearly identical. In turn, if it is considered that there is no long lasting freezing plant operation and, consequently, no additional costs involved with water insulation or lifting subsequent to melting of the freezed mantle then the method of injection by chemicals is undoubtless to be preferred. Of course, this statement is valid only for places, where rock conditions allow to have recourse to this method. In cases, where complete water sealing is required, i.e. when wetting should be absolutely excluded, only the method of injection by chemicals is to be considered,accidentally combined with other water sealing methods.

The couple of shafts, sunk in North-Yorkshire in the 70', is to be quoted as a good example for comparing technical and economical data,related to shaft sinking,obtained by the methods of freezing and injecting with chemicals, respectively [4]. Cleveland Potash Ltd sank double-shaft system with an inter-distance of 91 m up to the final depth of 1150 m. Work progressed in soft strata through plastic formations and in a 300 m long section in highly aquiferous triassic sandstone. Hoisting shaft was sunk by freezing, the ventilating one by the method of injecting with chemicals. Studies on the economics were not complete since the freezed strata once fractured in the meantime due to which the sinking work was delayed for several months. In addition, the costs of injection with chemicals were recovered only at a later date by the facts that on account of complete sealing no expenses involved with water lifting were given, the damages caused by corrosion diminished and thus maintenance consts were reduced as well.

As regards the savings, achieved by making use in Hungary of the method of injection by chemicals in the above cited cases, the following statements can be made.

Sealing operations performed in Nagyegyhaza Pit did disturb neither producing nor hauling works. The total costs amounted to 500 000 Forints. According to preliminary estimates the expenses involved with conventional methods, i.e. driving an inclined plane from a roadway, would have been over 20 MForints and, in addition, work could have been performed only by limiting the hauling operations.

As regards the costs of insulation at Pusztavam Shaft 40 p.c. savings were realized. Since dewatering the sand formation was only partly successful, the earlier plan /water impermeable plastering and protective wall/ would have been irrealisable. Substantial savings will be expectedly achieved by the absence of water lifting costs when the shaft will be put in operation.

At Recsk copper mine water lifting costs represented about 20 MForints in 1979. Carbonated formations, segregated from water, raised a lot of problems. The rate of elevated water per min. was, according to measurements in September 1980, 2,49 cu.m. By post-injecting chemicals substantial savings could be achieved.

From the operation of sealing and rock solidification completed up to know, it can be concluded that within the mining industry there would be a lot of other cases in which this method could be applied efficiently and economically.

As other possibilities, in addition to make water sealing and rock solidifying jobs for shaft sinking, the following ones could be indicated:

- When water inrushes occur high pressure water, inflowed through cracks or boreholes, can be sealed by local injection.
- In case of accidents, gateways or openings of small dimension are to be driven rapidly by injecting quickly setting chemicals for rescuing men or traversing coal dust accumulations and rocks inclined to collapsing, respectively.
- In water flooded mines properly pressure resistant gel plugs /provisional water dams/ are to be prepared through boreholes near the point of water inflow.

- For mining works and underground construction ones water can be sealed rapidly and efficiently.

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## R E F E R E N C E S

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2./ Muljokov E. I. Present situation and development of ground solidifications by chemicals. Österreichische Ingenieaur-Zeitschrift. 1979. Februar.

3./ Bajkay: Ground solidification by chemicals in the French collieris and civil engineering. / Report 1980 /.

4./ Shaft sinking at Cleveland Potash Ltd. in Boulby mine Institution of Mining and Mettallurgy Mining Industry 1975. Januar. No. 818.

# F I G U R E S

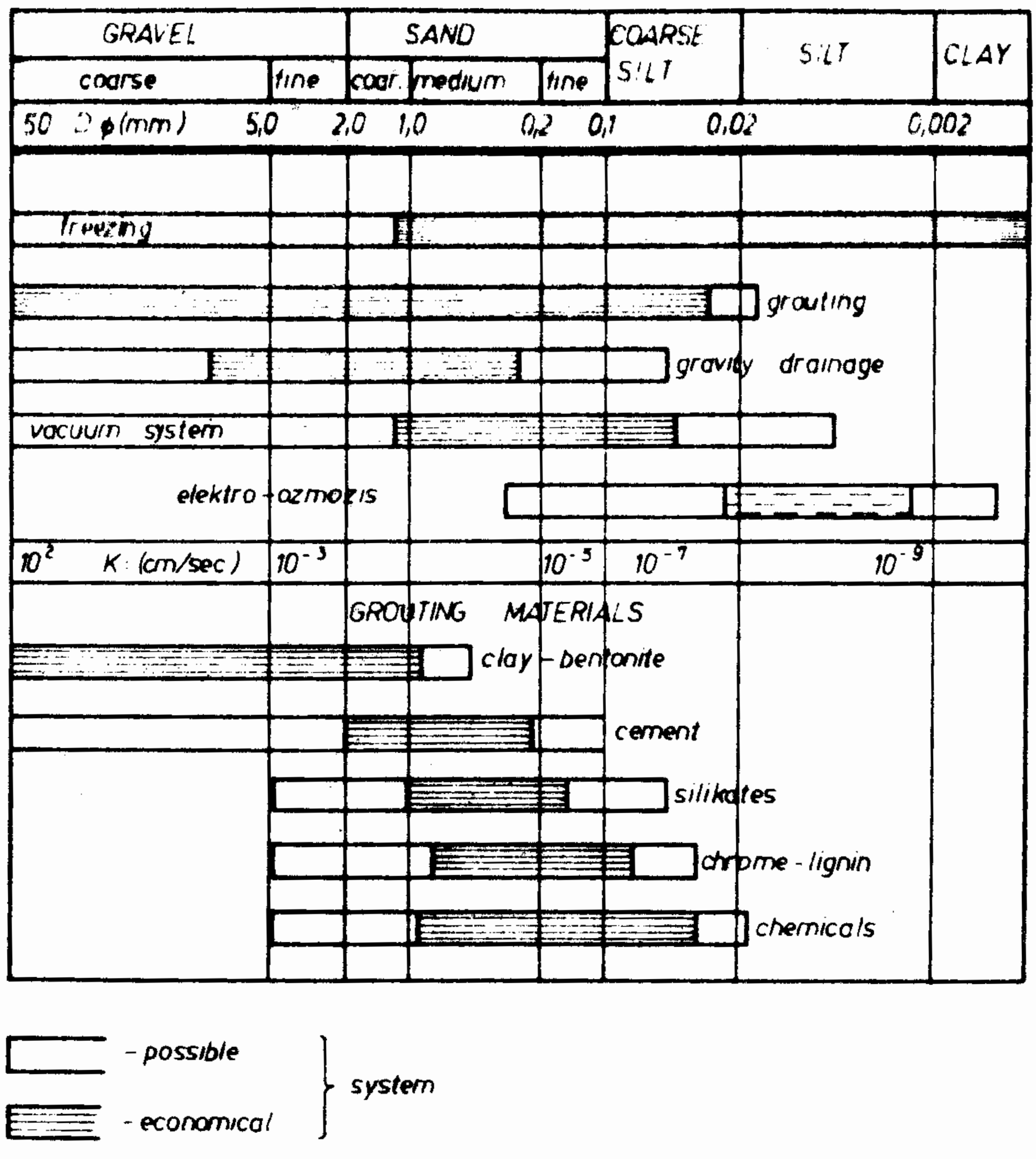
GRAVEL
SAND
COARSE SILT
SILT
CLAY
coarse
fine
coar.
medium
fine
50
φ (mm)
5,0
2,0
1,0
0,2
0,1
0,02
0,002
freezing
grouting
gravity drainage
vacuum system
elektro - ozmozis
10²
K (cm/sec)
10⁻³
10⁻⁵
10⁻⁷
10⁻⁹
GROUTING MATERIALS
clay - bentonite
cement
silikates
chrome - lignin
chemicals
- possible
- economical
system

FIG. 1.

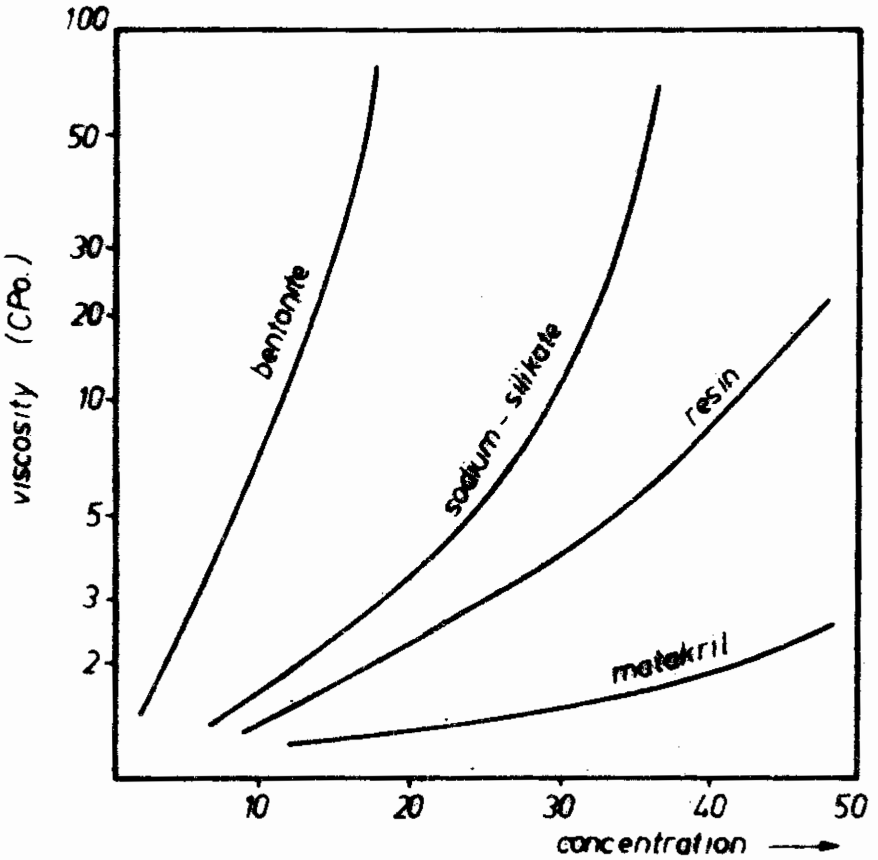
100
50
30
20
10
5
3
2
viscosity (CPo.)
bentonite
sodium - silikate
resin
metakril
10
20
30
40
50
concentration

FIG. 2.

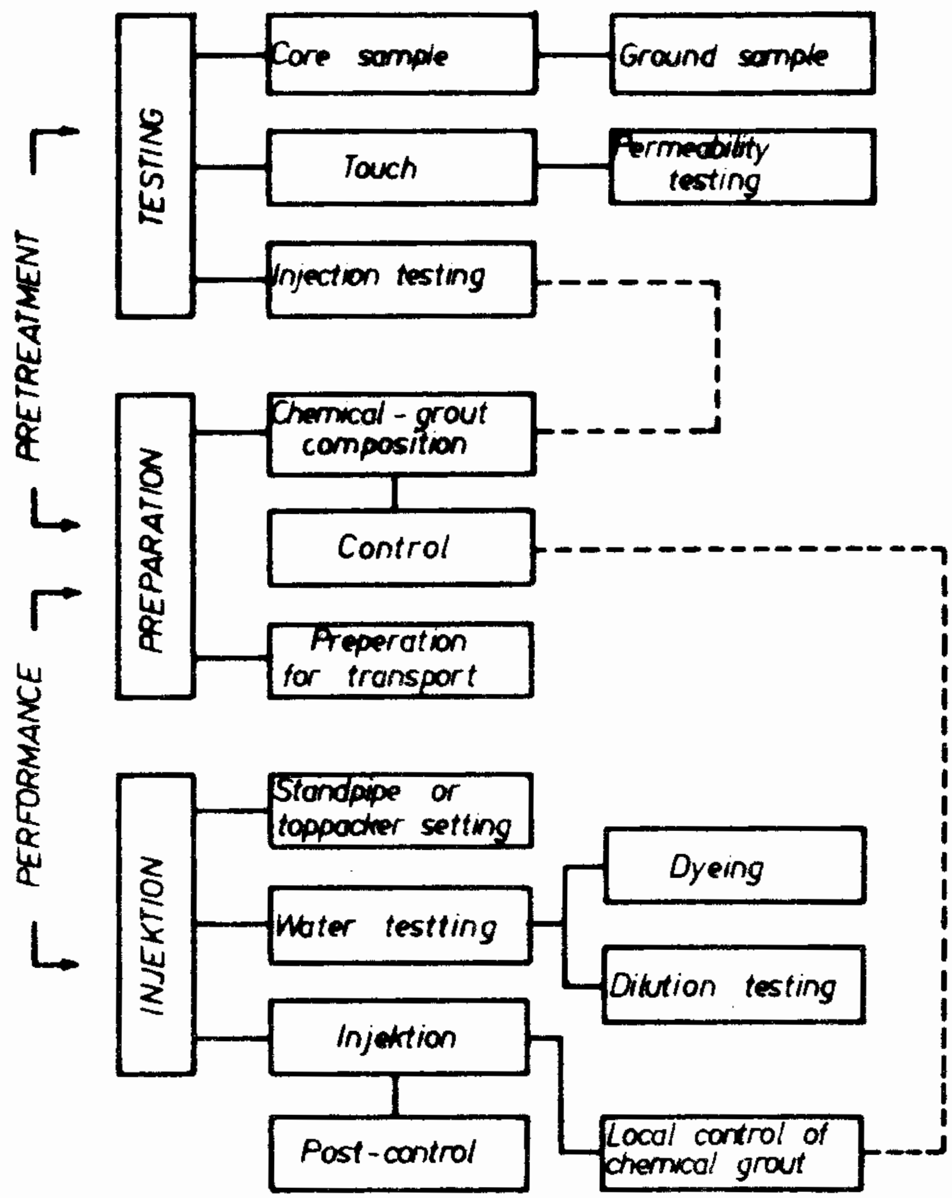
PRETREATMENT
PERFORMANCE
TESTING
Core sample
Ground sample
Touch
Permeability testing
Injection testing
PREPARATION
Chemical - grout composition
Control
Preperation for transport
INJEKTION
Standpipe or toppacker setting
Water testting
Dyeing
Dilution testing
Injektion
Post-control
Local control of chemical grout

FIG. 3.

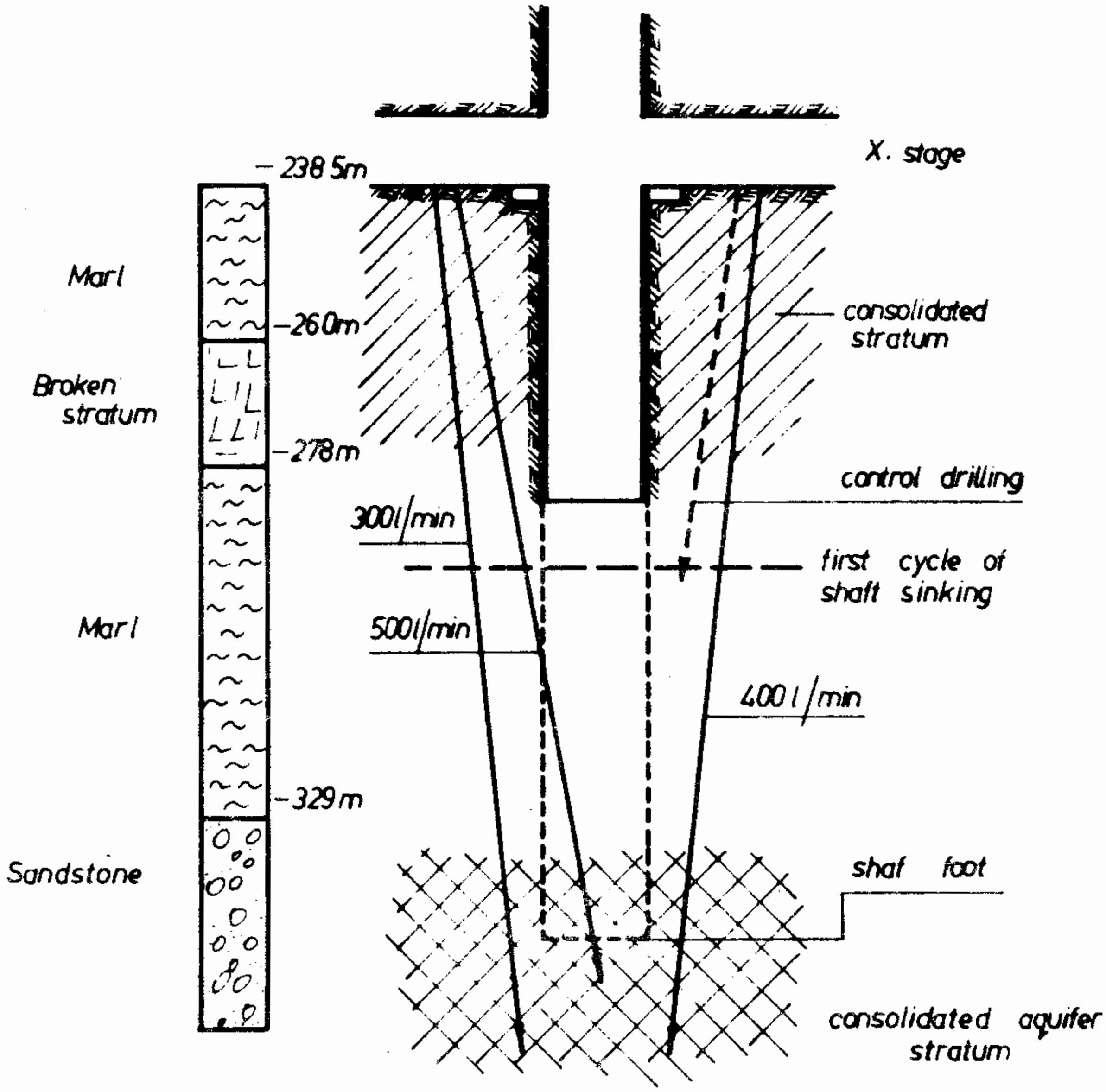
X. stage
-238.5m
Marl
-260m
consolidated stratum
Broken stratum
-278m
control drilling
300l/min
first cycle of shaft sinking
Marl
500l/min
400 l/min
-329m
Sandstone
shaf foot
consolidated aquifer stratum

FIG. 4.

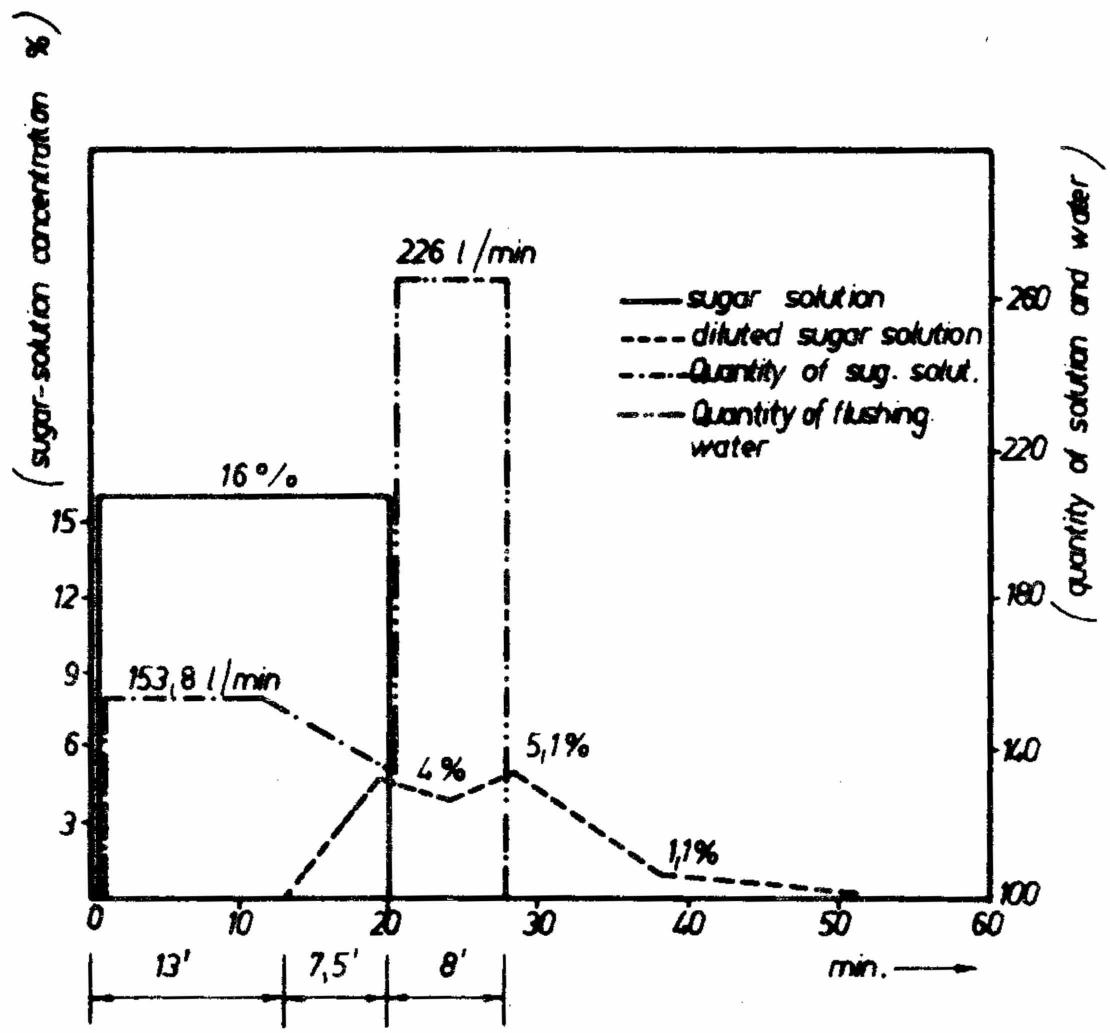
(sugar-solution concentration %)
(quantity of solution and water)
226 l/min
sugar solution
diluted sugar solution
Quantity of sug. solut.
Quantity of flushing water
16 %
153,8 l/min
4 %
5,1 %
1,1%
15
12
9
6
3
0
10
20
30
40
50
60
260
220
180
140
100
min.
13'
7,5'
8'

FIG. 5.

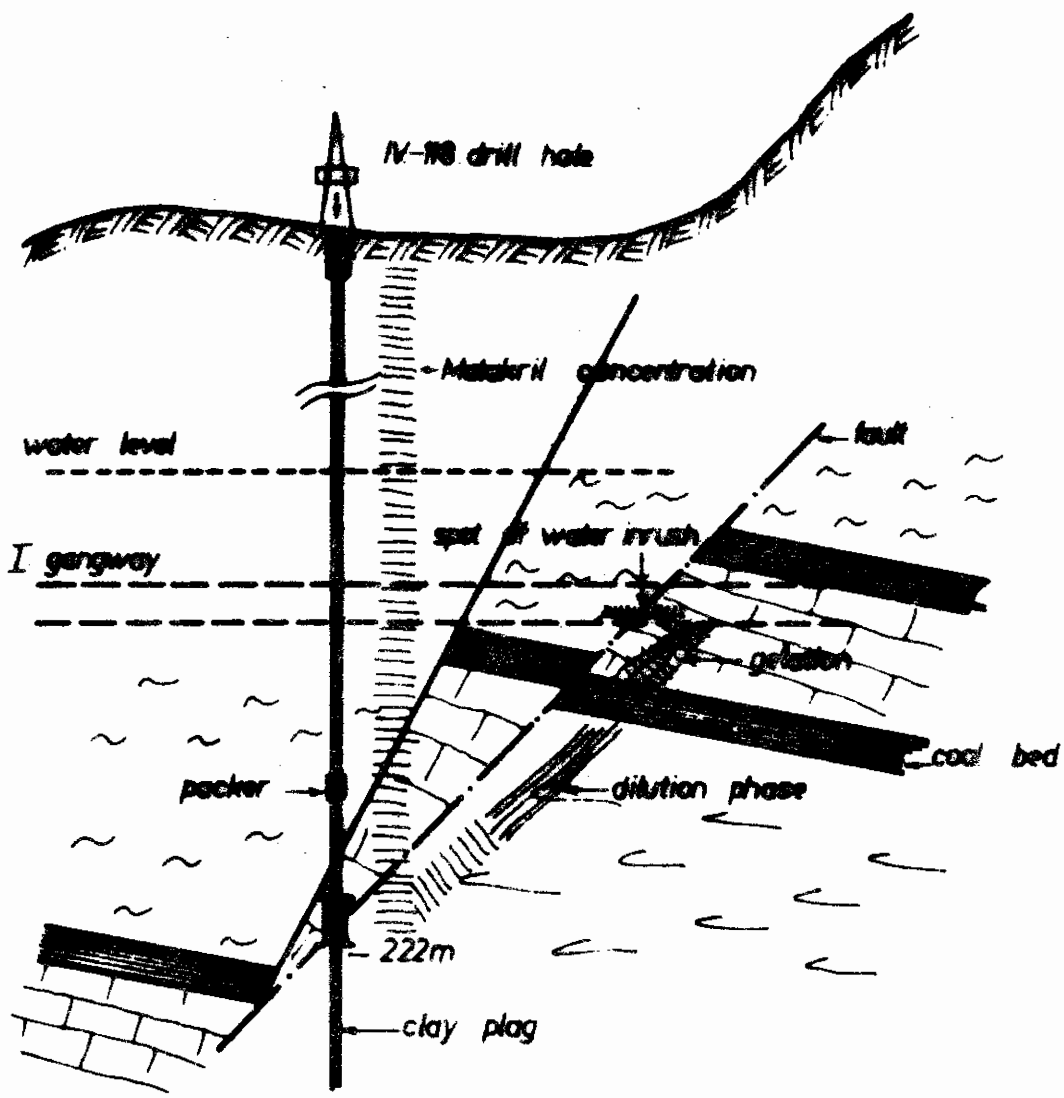
IV-118 drill hole
water level
I gangway
spot of water inrush
fault
gelation
coal bed
dilution phase
packer
222m
clay plag

FIG. 6.

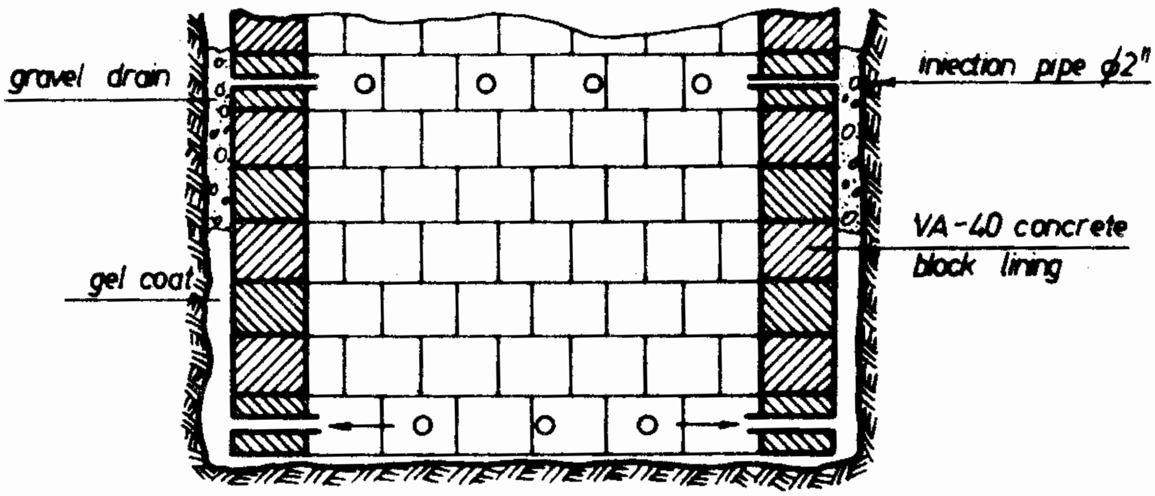
gravel drain
injection pipe ϕ2"
VA-40 concrete block lining
gel coat

FIG. 7.

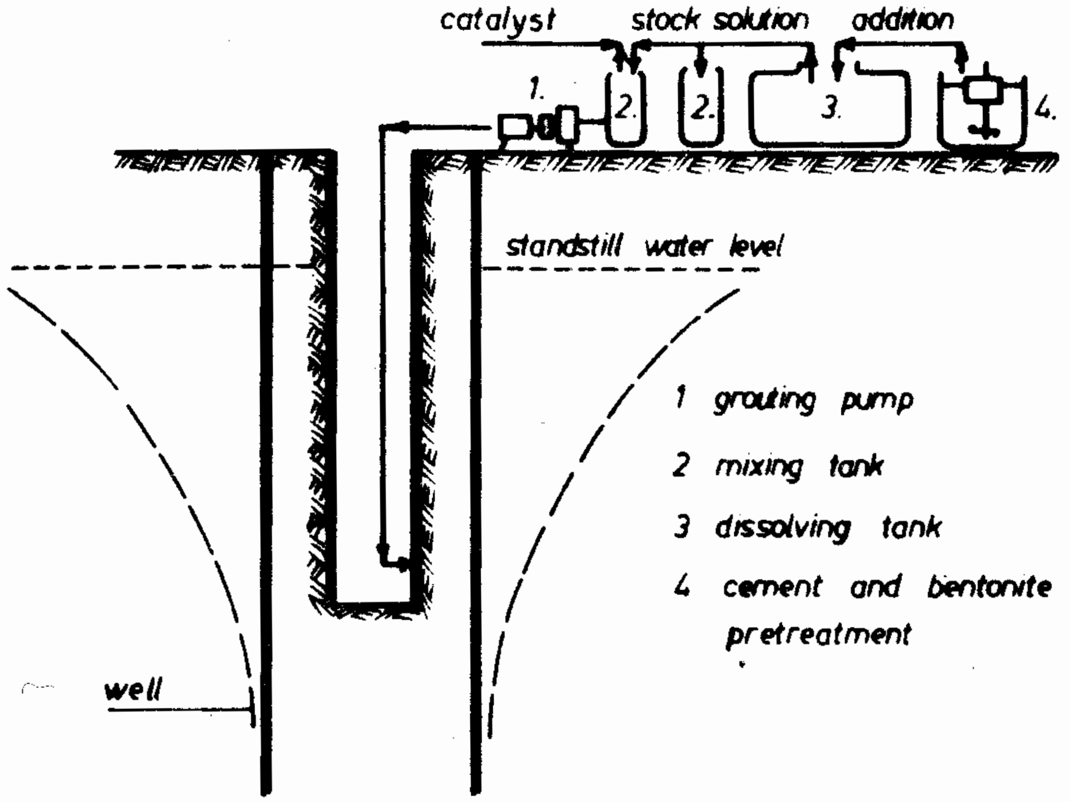
catalyst
stock solution
addition
1.
2.
2.
3.
4.
standstill water level
1 grouting pump
2 mixing tank
3 dissolving tank
4 cement and bentonite pretreatment
well

FIG. 8.