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GROUTING OF POROUS AQUIFERS DURING SHAFT SINKING

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ABSTRACT

The paper describes a new advanced grouting technique for porous aquifers using clay-cement grouts during shaft sinking. This technique is characterized by creating in a porous water bearing strata a network of artificial, interconnected fractures employing hydrofracturing with subsequent grout injection.

INTRODUCTION

Domestic and foreign mine construction experience indicates that water inflow shut-off during shaft sinking in porous aquifers presents a serious problem. The conventional cementation technique would fail in achieving the needed results because the grout, as a rule, does not penetrate into pores either due to the bigger size of cement particles or due to infiltration of a liquid phase from the cementitous suspension that results in formation of cement plugged zone around the injection hole.

The application of the chemical grouting technique at great depths is in the design stage and has not been applied on an industrial scale. The freezing technique gives positive results but it is extremely costly and requires much time both for carrying out freezing operations and for subsequent tubbing lining.

Imperfection of special techniques for porous rocks results in considerable residual water inflows, as has been observed, for example, during shaft sinking at the Krasnoarmeyskaya-Kapitalnaya, Gorskaya, Cheluskintsev, Juzhnodobasskaya and some other mines in Donbass, USSR. The residual inflows in the shafts at these mines achieved 15-90 m^3/hr.

Complexity of the water shut-off problem during shaft sinking in fissured-porous and porous strata calls for developing effective grouting techniques based on principally new technological processes of strata sealing together with new grouting schemes.

BASIC FEATURES OF METHOD

Sealing barrier formation around shafts in the intervals of water bearing zones has been carried out according to the scheme which envisages creation of a intersecting system of artificial cracks by means of hydrofracturing technique through the holes drilled from the surface, and filling them under pressure with the grout (Fig.1).

The process of sealing barrier formation around a shaft requires implementation of the following technological patterns and operations :

o calculations, utilizing special methods, of sealing barrier formation parameters comprising the length and development value of hydrofracturing and hydrowidening artificial cracks, the required quantity of hydro-sand-jet perforation channels, the number of injection points and grout holes. These calculations are based on the physical-mechanical properties of rocks, bedding depth of an aquifer, strata water pressure heads etc.

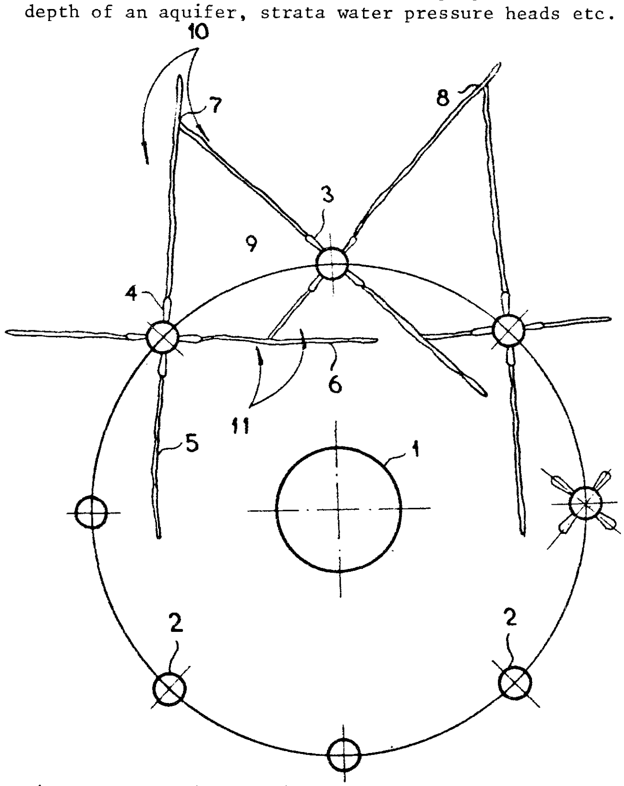

Figure 1. Sealing barrier formation scheme around a shaft in porous rocks

1 - Mine shaft, 2 - Grout hole, 3 - Hydro-sand-jet perforation channels, 4 - Artificial cracks
1,2...12 - Numbers of boreholes

- drilling of grout holes to the total depth of a shaft until all the aquifers be intersected, installation of borehole casing and subsequent grouting the casings; in the course of drilling a programme of hydrodynamic investigations is carried out to reveal and study all the aquifers encountered,

- execution of a directional hydro-sand-jet perforation in the zones of porous aquifers to obtain preliminary alotted and pointed channels which control the development of artificial cracks,

- hydraulic fracturing of rocks in order to form artificial cracks from each borehole; efficiency of hydrofracturing is controlled by subsequent hydrodynamic investigations in an aquifer,

- grout injection into artificial cracks to form water sealing barrier-curtain.

Technological operations on treating each water bearing zone are successively repeated in each hole.

The above mentioned sealing technique for fissured-porous and porous aquifers envisages employment of manufactured equipment for hydro-sand-jet perforation and hydro-fracturing comprising the 4AN-700 pump units, ZPA-4 sand-mixing units, SKC-2M control station with the 1BM-700 manifold unit, standard borehole collar equipment, AP-6M-80 hydro-perforators and pumping-compressor pipes according to the oil industry standards. The clay-cement grout injection is carried out by means of the CA-320M pump units, 2SMN-20 cement-mixing units, SKC-2M control station, special equipment for clay-cement grout preparation and DAU-1 packers.

LABORATORY STUDY

During grouting the fissured-porous aquiferous rocks, and also porous rocks (with 'man-made' fissuring), filtration of a liquid phase from the grout occurs in the course of its movement in the fissures with permeable walls. This phenomenon contributes to the alteration of density and rheological characteristics of the grout in time and length of the flow.

Successful and good-quality grouting depends much on the accuracy of estimating the grout propagation radii around each hole. When calculating the grout propagation radii, it is necessary to know hydraulic resistances during the flow of a viscoplastic liquid in the fissures with permeable walls.

To accomplish hydraulic calculations of the grouting process for porous rocks, the alteration of rheological parameters and density of clay-cement grouts during filtration of a liquid phase from them have been obtained experimentally. The alteration of rheological parameters and density versus permeability coefficient of a permeable medium and grout propagation radius is presented in Fig.2.

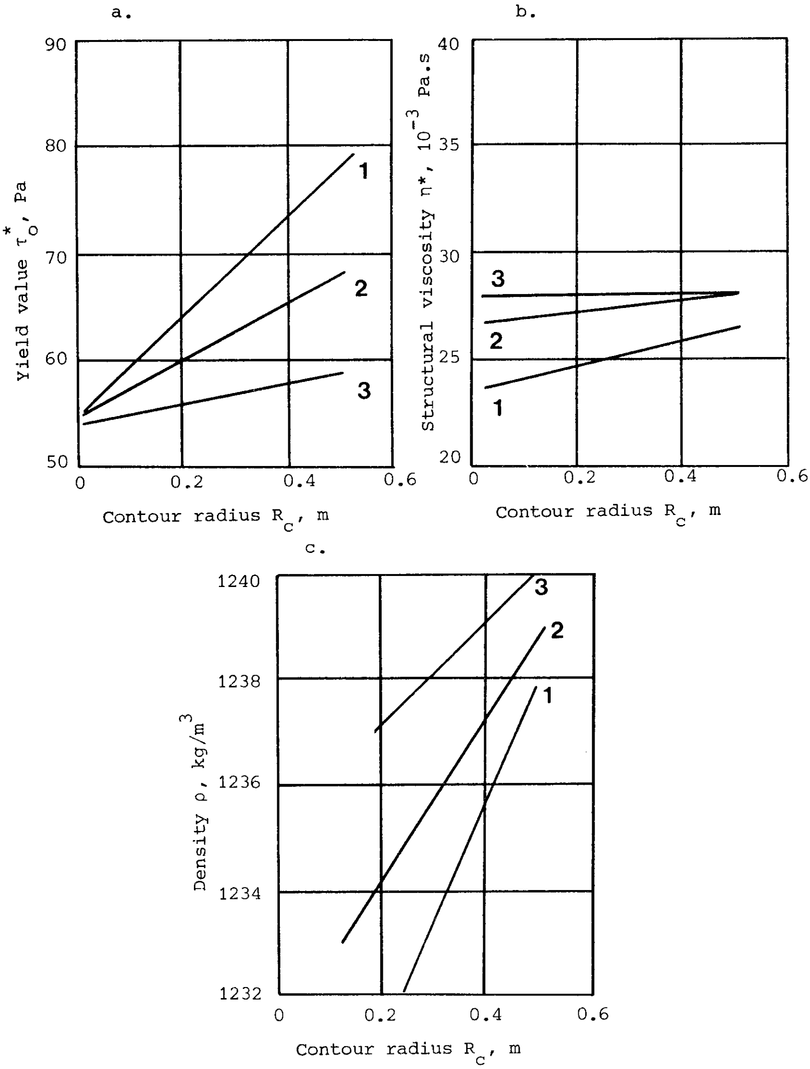

Figure 2. Alteration of rheological parameters (a,b) and density (c) vs. grout spread radius (1 - K = 0.245 x 10^{-6} m/s; 2 - K = 0.132 x 10^{-6} m/s; 3 - K = 0.053 x 10^{-6} m/s)

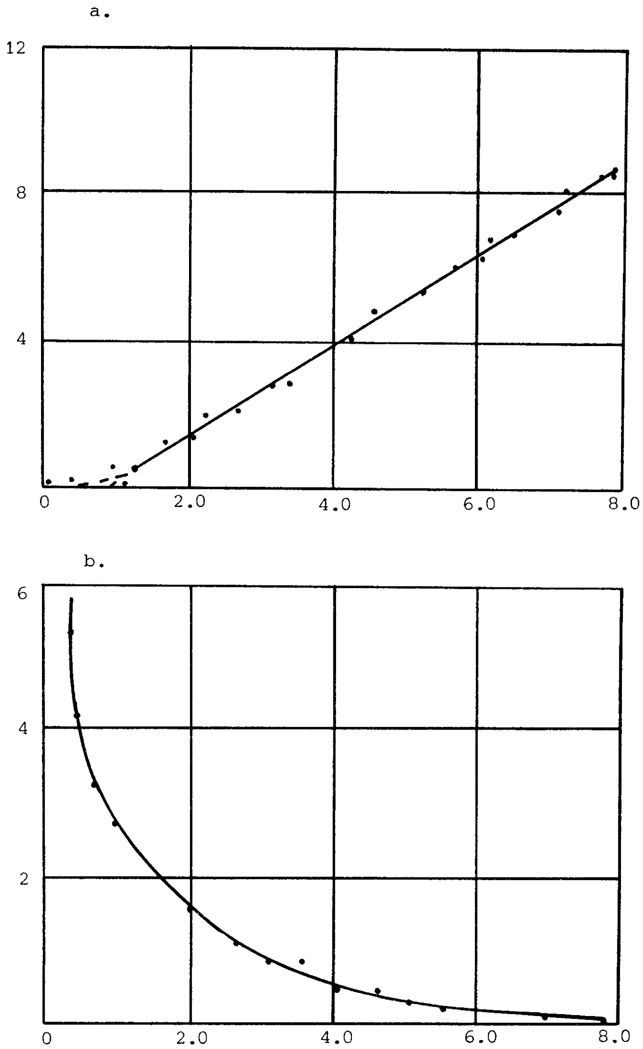

Figure 3. Relationship of initial gradient (a) and filtration factor (b) of a grout barrier vs. barrier formation pressure

Water sealing properties of a barrier-curtain are determined by filtration parameters of the grout which builds its structure under pressure in fissures. The experimental studies performed made it possible to obtain dependancies of an initial gradient and permeability coefficient of a grout versus barrier formation pressure. These dependancies are presented in Fig.3.

INDUSTRIAL EXPERIMENT

The Spetstamponazhgeologia association has carried out, on an industrial experimental scale, the advanced grouting of porous aquifers during sinking the skip shaft of the Krasnoarmeyskaya-Zapadnaya Mine. The sealing barrier formation around the shaft in the intervals of porous aquifers was accomplished by creating a closed system of artificial cracks through the holes by means of hydrofracturing and hydrowidening technique, and filling the cracks under pressure with the grout.

According to a hydrogeological report, the designed 716 m deep shaft of the Krasnoarmeyskaya-Zapadnaya No.1 Mine was in complex hydrogeological conditions. Fifteen artesian aquifers were revealed through a geological section of the skip shaft, the total predicted water inflow was 194 m^3/hr. The predicted water inflow from separate aquifers amounted to 35-40 m^3/hr.

Laboratory tests of core samples determined that rock porosity in the shaft section is in the range of 5-23%. The greatest porosity of 14-23% is encountered in sandstones (Table 1).

Table 1 - Parameters of aquifers in the skip shaft of the Krasnoarmeyskaya-Zapadnaya No.1 Mine

Water bearing zone, m	Total porosity, %	Filtration factor, 10^{-12} m^2	Predicted water inflow, m^3/hr	Residual shaft inflow after sinking, m^3/hr
79.1-101.7	13.75	0.136	5	-
110.3-122.6	5.68	0.180	5-7	-
151.3-173.0	10.9	0.154	22	1.5
174.0-210.0	6.68	0.227	12-13	-
226.7-230.0	13.24	0.046	5	-
242.7-243.5	-	0.122	3-5	-
278.0-292.2	20.52	0.035	10	1.7
302.0-306.5	6.95	0.121	10	-
312.0-368.1	14.66	0.073	40	0.5
376.0-463.0	10.10	0.379	7-11	1.5
445.0-479.1	13.89	0.031	25	1.0
513,1-557.6	9.63	0.135	10-16	2.0
563,7-582.0	19.11	0.022	10	0.2
588.4-608.0	18.88	0.016	10	19
629.0-682.0	13.46	0.028	5	-

To carry out a grouting programme around the skip shaft, there were drilled 12 grout holes with a depth of 690 m.

The number of grout holes was determined on the data of development depth calculations for artificial cracks created by the hydrofracturing technique in porous rocks.

The process of porous rock hydrofracturing for each aquifer was monitored with a printout of pressure variations employing the SKC-2M control station, and the effectiveness of hydrofracturing - by the alteration of strata permeability prior and after hydrofracturing. On completion of hydrofracturing, filtration factor increase 8-14 times.

The grout injection into each aquifer was carried out separately from the bottom and up employing the DAU-1 packers. As a grout, there was applied the clay-cement grout. The total volume of injected grout in the skip shaft amounted to 7560 m^3.

All operations on hydrofracturing and grouting the porous rocks were completed prior to the commencement of sinking and were combined with the preparational jobs for shaft sinking.

RESULTS

The accomplished grouting operations produced positive results which was proved by the shaft sinking data.

In the skip shaft the inflow from the porous aquifers was :

- 1.7 m^3/hr (with the predicted inflow of 10 m^3/hr) in the range of 278.0-292.2 m,
- 0.5 m^3/hr (with the predicted inflow of 40 m^3/hr) in the range of 312.0-368.1 m,
- 0.2 m^3/hr (with the predicted inflow of 10 m^3/hr) in the range of 563.7-582.0 m.

SUMMARY

The results of the skip shaft sinking indicated that for the first time in the field of deep shaft sinking through highly porous strata, grouting made it possible to eliminate tubbing the porous zones, to increase sinking rates and hence reduce shaft sinking costs.