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ARTICLE

ACTIVATION OF A DEWATERING WELL WITH THE SKINAUT CLAY MINERAL DISINTEGRATION AGENT

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Abstract: The drilling of hydrogeological boreholes by rotary methods and with the use of drilling mud impairs the permeability of water-bearing rocks in the near-hole zone. This is mainly caused by the penetration of solids and mud filtrate into the pores or fractures of the drilled rocks. Consequently, the depression increases, and the hydraulic efficiency of the borehole drops, leading to the reduction of well productivity.

As a means of improving the damaged permeability of rocks in the near-hole zone, a clay mineral disintegration agent called SKINAUT was developed and patented. To evaluate its effectiveness in industrial conditions, a test was carried out to activate a dewatering borehole for intaking water from loose formations at the Szczerców open cast. The applied chemical helped to decolmatate the pore medium and lower the hydraulic resistance of the borehole, resulting in a reduction in depression and a significant improvement of its hydraulic efficiency.

Keywords: rock permeability, colmatation, disintegration of clayey minerals, dewatering borehole, borehole activation, hydraulic efficiency of borehole, groundwater exploitation, life of hydrogeological borehole

1. Introduction

When aquifers are drilled with a rotary drilling mud method, rocks in the near-hole zone undergo colmatation. This leads to physical changes in the porous medium due to the deposition of solid phase particles and penetration of the drilling mud filtrate. Then the filtration rate of water in the colmatated parts of the aquifer is lowered, resulting in a growing depression and a drop in the hydraulic efficiency of the borehole. Consequently, the total capacity of the borehole is reduced [1].

The drilling mud circulating in the borehole is also responsible for the formation of clayey deposits on the borehole wall, which also increases the hydraulic resistance to water entering the borehole [1, 2]. When drilling hydrogeological boreholes, the colmatation of rocks in the near-hole zone is also accompanied by clogging of the active surface of the filter when it is installed in a borehole [1, 3].

Currently, the industry practice does not offer any effective way to significantly reduce the colmatation in the near-hole zone during borehole drilling with bentonite muds. One of the best ways to reduce the near-hole zone colmatation is to drill in aquifer formations at the "pressure limit" level. In all countries where strict acceptance criteria for intake and dewatering boreholes are the case, prior to putting the boreholes in operation, activation treatments are mandatory to minimize the degree of damage to rock permeability in the filter zone. Cleaning of the filter zone from filtrate and solids improves the hydraulic efficiency of the borehole, and before all, has a significant impact on increasing borehole productivity and extending its life [2–4]. To improve the damaged permeability of rocks in the near-hole zone, especially with clayey particles, an effective clay mineral disintegration agent called SKINAUT was developed and patented [4]. To evaluate its effectiveness under industrial conditions, a dewatering borehole, drilled with the rotary drilling mud method, was subjected to an activation treatment. The dewatering borehole subjected to the treatment was located within the Szczerców open cast of PGE KWB Bełchatów (a lignite mine).

2. Characteristics of geological and hydrogeological conditions of drilling works within the Szczerców open cast area

The Szczerców open cast rests in the western part of the "Bełchatów" lignite deposit, and is situated within the latitudinal Kleszczów trench, 40 km long and 1.5–2.0 km wide, formed in the Jurassic and Cretaceous strata. Three elements of different structure are distinguished in it – the western one with a length of 8 km within the "Szczerców" deposit, the middle one with a length of 12 km within the "Bełchatów" deposit, and the eastern one within the "Kamieńsk" deposit [5]. The "Szczerców" and "Bełchatów" deposits are separated by a salt diapir, while the "Kamieńsk" and "Bełchatów" deposits are separated by a fault zone – the Widawka fault. Such a tectonic structure causes that within the "Kamieńsk" deposit the depth of occurrence, formation and its thickness differ from the remaining two outcrops [6]. The oldest documented formations, i.e. the Lower Carboniferous Culmic facies, developed as claystone, siltstone, black clay shale and greywacke, and the Permian formations represented by the Rotliegendes and Zechstein sediments developed as salts and associated gypsum and anhydrite, are related to the existing salt diapir with an average thickness of 775 m and a width of about 550 m [5]. This structure pierces the Upper Jurassic and Cretaceous and the eroded Tertiary strata. The subcoal complex of the Lower Miocene is sandy and silty-silty, with layers of lignite coals. The thickness of these sediments varies from 10 m to 130 m, with a maximum of 270 m [5, 6]. The coal complex dated to the Middle Miocene is the most important part of the whole system. The bottom is formed by a layer of tuffites, 3–5 cm thick, above which is a thin seam of lignite with quartzite sands overburdened. Higher up is the main lignite seam with a thickness of 40–60 m, and the depth of the bedrock is 170–300 m [6]. The "Bełchatów" deposit, with resources of 1.2 billion t, contains lignite, defined as proper, detrital, and weakly layered. The seam thickness is 30–70 m, in places 100 m, and even 230.5 m [4]. Within the "Szczerców" deposit, 750 million t resources, and a seam thickness of 12–140 m, proper and proper-xylitic lignite occurs. The top part of the complex is formed by clay-carbonaceous and clay-sandy sediments of the supra-coal series [6]. The Tertiary sediments are strongly reduced outside the trench area and their thickness does not exceed 50 m. The depth of freshwater ranges from 400–600 m b.s.

Three aquifers can be distinguished in the lignite area, i.e. Quaternary, Tertiary and Cretaceous-Jurassic [5]. The Quaternary horizon mainly consists of sands and gravels with a thickness of 20–40 m, locally decreasing to zero. In the Kleszczów trough, the thickness reaches 150 m. On the northern side, parallel to the axis of the ditch, there is an erosion trough, where sands and gravels overlie Mesozoic sediments reaching an average thickness of 155 m (locally 300 m). In natural conditions, the water of this complex was supplied by precipitation. The depth of occurrence of the first aquifer was 0–2 m b.s. in river valleys, and 5–10 m b.s. in morphologically elevated areas. This complex was characterized by a free water table. The Tertiary floor is built up by fine- and medium-grained sands above the lignite seam, within the seam and in the subcoal complex. The thickness of the latter is 0–200 m (average 35 m). The Cretaceous-Jurassic strata, composed of limestone, marl, sandstone and sand, are characterized by the occurrence of fractured and fissure-karst waters, which distinguishes them from the others. The Tertiary and Cretaceous-Jurassic horizons are characterized by a pressure head and, in places, free water table. They are located at similar depths as the Quaternary horizon and are supplied by infiltration and/or hydrogeological windows. As in the case of the Quaternary complex, the watershed areas of the Widawka River basin were the recharge zones for both of these horizons.

3. Design and technology of performing a dewatering borehole

The dewatering borehole, which was subjected to the activation treatment with the new SKINOUT clay particle disintegration agent, was drilled by the rotary method with reverse mud circulation to a depth of 170.0 m. The borehole was drilled using a Wirth L4 drilling rig.

The borehole was drilled with a 1.16-m-diameter pipe bit to a depth of 8.0 m, where the surface casing ϕ 0.92 m was installed. After this column was cemented to the top and the cement slurry set, further drilling was carried out to the planned depth with a ϕ 0.76 m cutter bit. Afterwards, a steel pipe filtering column with a nominal diameter of 0.356 m was installed, followed by a resin-bonded gravel-packed filter, of the following design:

- overfilter pipe 55.0 m long, outer ϕ 0.356 m,
- I filter section 9.0 m long, outer ϕ 0.45 m,
- interfilter pipe 6.0 m long, outer ϕ 0.356 m,
- II filter section 13.0 m long, outer ϕ 0.45 m,
- interfilter pipe 270 m long, outer ϕ 0.356 m,
- III filter section 10.0 m long, outer ϕ 0.45 m,
- subfilter pipe 40.0 m long, outer ϕ 0.356 m.

The annular space between the borehole wall and the filtering column was filled with gravel pack of granulation 3–5 mm.

4. Types of drilling mud

The dewatering borehole was drilled with the bentonite-polymeric mud, ensuring smooth and uncomplicated drilling process. However, in the course of drilling through loose formations, this mud is responsible for the formation of a compacted sediment on the borehole wall and the mechanical colmatation of the pore space in the near-borehole zone of the aquifer. As a consequence, the permeability of the near-borehole zone is decreased in the aquifer and the resistance to water flow into the well grows [1, 3, 6]. The recipe of the mud used for drilling a dewatering well was the following:

- bentonite – 3%,
- polymer – 0.3%,
- Na_2CO_3 – 0.5%,
- Na_2HCO_3 – 0.2%,
- NaOH – 0.2%.

To improve the conditions of water filtration in the near-filter zone, the activation procedure was performed with agents disintegrating clayey minerals and removing them during treatment pumping operations.

5. Methodology for assessing hydraulic efficiency of a dewatering borehole

For the purpose of evaluating the quality of dewatering borehole construction and the effectiveness of activation treatments to improve water flow conditions in the filter zone, Jacob and Hantush methodics was used [1, 3]. Here the magnitude of total depression in the hydrogeological borehole, coming from laminar flow resistances in the aquifer as well as turbulent flow resistances in the near-filter zone, and the borehole itself, can be described with the formula below:

$$s = BQ + CQ^2 = s_w + \Delta \qquad (1)$$

where:

- s – total depression in a hydrogeological borehole with water pumping capacity of Q [m],
- Q – pumping capacity (output) of the hydrogeological borehole [m^3/h],
- B – resistance coefficient of laminar flow in the aquifer [h/m^2],
- C – coefficient of turbulent flow resistance around the hydrogeological well, in the filter and in the filtering column; [h^2/m^5]; the C-factor is called the well resistance coefficient,
- BQ – actual depression, resulting from the laminar flow of water in the aquifer,
- CQ^2 – hydraulic drop.

It can be assumed for this model that the zone of turbulent motion, in which the nature of the flow changes from turbulent to laminar, is constant and independent of the pumping rate.

This theory was put into industrial practice after it was greatly simplified by Bruin and Hudson [1]. According to this methodology, Jacob's initial formula (1) was written in the form:

$$\frac{s}{Q} = B + CQ \tag{2}$$

and after its transformation the equation assumes the following form:

$$C = \frac{s - BQ}{Q^2} = \frac{\frac{s}{Q} - B}{Q} \tag{3}$$

Equation (3) can be solved graphically, as visualized in Figure 1. The graphical representation of unit depression *s*/*Q* in the function of *Q* rate helps determine coefficients *B* and *C* [1, 3, 4].

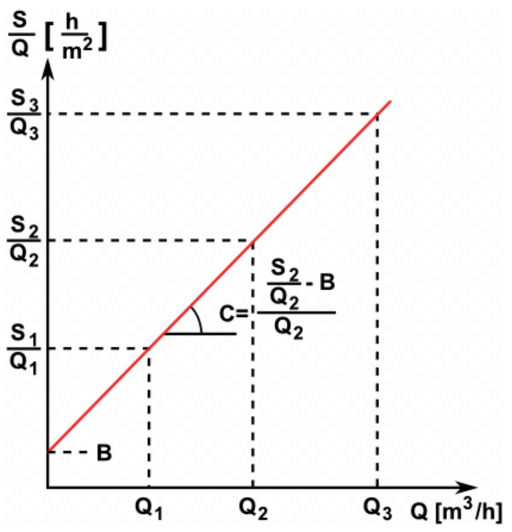

Fig. 1. Graphical method for assessing hydraulic efficiency of a hydrogeological borehole, after Bruin and Hudson procedure (2)

Having the results of multistage pumping, the values of s_1/Q_1; s_2/Q_2; s_3/Q_3, etc. for successive stages of pumping are plotted on the axis of ordinates of the aforementioned diagram, and corresponding values of well discharge Q_1; Q_2; Q_3, etc. on the axis of abscissa. The plotted points should form a straight line, whereas its extension to the intersection of the axis of ordinates determines the numerical value of the hydraulic resistance coefficient of the aquifer B. The value of the tangent of the angle of inclination of the determined straight line defines the numerical value of the hydraulic resistance coefficient of well C, in compliance with the formula:

$$C = \frac{\frac{s_2}{Q_2} - B}{Q_2} \tag{4}$$

The value of the *C* indicates the amount of hydraulic resistance in the infiltration zone and in the borehole itself, so it can be considered a measure of the hydraulic condition of the borehole. Below are given values of *C*[h²/m⁵] corresponding to various degrees of hydraulic efficiency of hydrogeological boreholes [2, 6]:

– properly designed and constructed – $C < 0.00015$,
– moderately contaminated or colmatated – 0.00015–0.00030,
– advanced contamination or colmatation – 0.00030–0.00120,
– considerably contaminated or colmatated – >0.00120.

6. Treatment pumping

After the filtering column was installed in the borehole and gravel pack introduced, drilling mud was removed from the borehole with an air lift. Then a 72-hour treatment pumping was followed with a pumping unit at three degrees of depression. This pumping was aimed at cleaning the porous space, prefilter zone of the aquifer, gravel pack and the filter, from the deposited material from mud in the form of fine cuttings and clayey minerals. The results of the treatment pumping of the intake well are shown in Table 1.

Table 1. Results of treatment pumping

Pumping degree	Rate *Q* [m³/h]	Depression *s* [m]	Unit depression *s*/*Q* [h/m²]
I	50.0	4.72	0.0940
II	100.0	10.61	0.1060
III	150.0	17.97	0.1193

The calculation of the efficiency factor $C = 0.00034$ h²/m⁵ with Walton method reveals that the completed dewatering borehole belongs to Class III, i.e. a borehole with advanced contamination. Thus, prior to being put into operation, the borehole absolutely requires an activation treatment to improve its efficiency.

7. Activation of a dewatering borehole using SKINAUT agent

In order to decolmatize the filter zone of the aquifer and improve the conditions of water inflow to the watering borehole, an activation procedure was performed using a new clay mineral particle disintegrating agent called SKINAUT. For this purpose, a solution of above-mentioned agent was gravity-injected into the filtering column through the string at a distance of up to 0.5 m. After the solution of the SKINAUT clay mineral disintegrating agent was injected into the filter zone, a 24-hour shutdown followed. Then, after the pumping unit was installed in the well, the treatment pumping was repeated at three degrees of depression. The obtained results of this operation are shown in Table 2.

Table 2. List of results of treatment pumping followed by clayey mineral disintegration treatments

Pumping degree	Rate Q [m^3/h]	Depression s [m]	Unit depression s/Q [h/m^2]
I	70.0	3.12	0.0445
II	140.0	6.93	0.0495
III	210.0	13.15	0.0626

The analysis of the obtained results of treatment pumping, following the dewatering borehole activation procedure and the performed calculations of the well efficiency factor $C = 0.00023$ h^2/m^5 indicate that the borehole should be classified as Class II, i.e. moderately contaminated or colmatated. The results of treatment re-pumping demonstrate the high efficiency of the agent for disintegration of clayey mineral particles and its applicability aspects in hydrogeological drilling.

8. Concluding remarks

When dewatering boreholes are drilled by the rotary method with the use of drilling mud, the permeability of the rock in the near-borehole zone is damaged as a result of the colmatation of the pore space of the drilled aquifer with the solid phase of the drilling mud.

In Poland, the most common method used for this purpose is purge pumping carried out for 24 or 72 hours at three degrees of depression. Though this procedure is simple to perform, it remains relatively ineffective, and in most cases does not allow for effective unclogging of rocks in the near-well zone, especially of the clayey material.

For the purpose of increasing the effectiveness of treatments to activate hydrogeological boreholes drilled with rotary drilling mud, a new agent for the disintegration of clay minerals called SKINAUT has been developed. The procedure carried out to activate the Szczerców open cast dewatering borehole reveals that a method relying on a new clay mineral disintegration agent called SKINAUT is one of the most efficient ways to decolmatize the near-filter zone. This treatment has significantly improved its hydraulic efficiency and reclassified the borehole from Class III (a borehole with advanced colmatization) to Class II (a borehole with moderate colmatization).

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