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THE MECHANISM OF UNDERGROUND CAVITIES FORMATION AND THE METHODS OF THEIR ELIMINATION

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ABSTRACT

The article considers the process of cavities formation, as well as both gravity and enforced flow of mortar mixes during their elimination. It is shown that the grout-stowing mix is fed from the surface in the opening of critical condition by well, where spreads over its floor and fills the goaf. The process of filling the vacant place with highly dispersive mixtures is considered. Based on the fundamentals of the viscoplastic dissolution flow theory, the process of both gravity and enforced flow of the fluid in the opening is shown. It is proved that the pumping of the grout-stowing mix is a step-by-step process, which ensures the layer-by-layer filling of the opening. It is established that in the case of the gravity flow of the grout mix in the inclined fracture, the mix is displaced by gravity along the incline of the fracture. In addition, it is proved that the dissolution pumping into the vacant place of the opening in the gravity flow regime requires the use of the batching technology. The model describing the hydraulic fluid fluctuation in flooded horizontal cavities, unlimited in terms of area, is proposed. The model is based on the postulate of the constant velocity of the hydraulic fluid fluctuation along the radius and its equality to the critical velocity. It is established that the hydraulic fluid discharge at a constant pressure in the supply pipeline decreases linearly in time.

Key words: Mine Opening, Fractures, Grout Mix, Stowing Mix, Design Technique.

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1. INTRODUCTION

Most negative environmental phenomena in existing and closing-down mining enterprises do not prove themselves immediately, but months and years after their shut-downs. Therefore, it is important to foresee the probability of such manifestations in advance, in order to take measures to normalize the environmental situation in decommissioning projects and include appropriate costs in the estimates. However, at many enterprises the unpredictable phenomena occur, requiring additional scientific-research and design studies and, accordingly, expenditures. Therefore, the scientific study of environmental problems, and the development of legal and technical documents on these issues from the very beginning of the industry reform to the present time are the crucial task of scientific and technical support for the coal industry restructuring.

At the present time, research works on environmental aspects during operation, as well as the subsequent coal and ore mines abandonments, continue in the following areas:

- Fight against water (prevention of water breakthroughs to operating mines from abandoned ones, surface submergences, pollution of drinking water sources, contaminated mine waters treatment, use of mine waters for residents and production needs);
- Air pollution prevention (avoiding gas contamination of residential, public and industrial buildings, air pollution by methane, quenching of waste heaps and their reclamation);
- Prevention and management of fallouts from underground fires;
- Prevention and management of negative geomechanical fallouts (the earth's surface displacement, protection of objects on the surface, protection from cave-ins);
- Coal reserve calculations of abandoned coal enterprises;
- Reclamation of mined land and refilling the caves on the surface;
- Regulatory and technical support for the prevention and management of ecological backlash at the abandonment of mines and transverse sections;
- Integrated exploration of the environmental situation in coal-mining regions in the catchment areas of abandoned enterprises.

One of the directions of the prevention and management of the negative geomechanical fallouts is the filling of aged mine openings or large underground cavities with grout mixes.

The visual examinations of cave-ins and karst cavities, especially in the areas of the development of ore and hydrochloric fields, indicate the activation of karstification process. For example, at the mines of the Verkhnekamsky saliferous basin and Stebnitsky state mining and chemical enterprise "Polimineral" the karstification process is at the stage of intensive development, the consequences of which can be very tragic [1-7].

The complex of geophysical surveys (electrometry, gravimetry) confirmed the existence of anomalous zones in the gypsum-clay cap (GCC) – decompression zones. The zone distribution takes place across all over the mine and on depth to mining chambers. In the plan, the decompression zones have irregular shape; however, they are distinctively concentrated around karst cave-ins. The form of decompression zones represents ellipse-shaped figures.

Under the terms of formation, the karst manifestations can be natural and technogenic which were formed owing to water irruption to the mine. It is expedient to subdivide technogenic salt karst into arbitrary and forced [8-11].

2. METHODS

2.1. Analysis of karstification processes

The natural karst is formed in the solids of the GCC and on the hydrochloric mirror owing to the natural circulation of underground waters. This process, by all means, develops very slowly as the density of brine is more than the water density which infiltrates, and, therefore, the brine on the hydrochloric mirror surface remains almost immovable. However, the minimal pressure gradient, causing the flow of water in the mine, induces salts solution and the formation of filtration channels along argillo-arenaceous layers. The mode of the water-bearing formation dramatically changes. At the beginning, the drainage of the static reserves of brines on the hydrochloric mirror occurs, whereafter the flowing decreases. After this, the flowing of low-mineralized waters from the porous massif of the GCC and from the surface begins, which dissolves salts along percolation paths. As a result of this, the hydrostatic levels depression occurs in the GCC, which extends to the boundaries of the water-bearing formation of the external reservoir boundary, which is almost coming to the surface. After that, due to the surface waters infiltration, the flowing to the mine increases due to the permeability increase of the GCC body. At this stage, the decompression zones are formed and well-defined. The carrying-out of insoluble particles all round large near-vertical cavities into the mine openings is the reason of the zonal decompression in the GCC body.

The decompression zone begins to develop from the hydrochloric mirror "from the bottom up" and reaches the surface or insoluble layers in the GCC. The decompression in mountain massif works for two types: the increase in porosity or fracturing formation. There comes the moment of limiting decompression and surface achievement by zone – a sinkhole is formed with carrying-out into chambers. In course of time, the edges of sinkhole cave in, and the sink is formed. The deformation process extends to the dependent areas of the GCC in which fracture stresses of fault and fissure are developed.

Thus, the six-stage geological and physical model of the hydrochloric karst is offered on the basis of karstification genesis studying.

1st stage – exposure of the permeable zone with mine openings. The permeable zones are most often limited to the contact of potash deposits with salts of breccias. The brine output with high mineralization increases, the brine comes out of ancient karst cavity.

2nd stage – formation of mushroom-shaped cavity. From GCC solids, the water of separate drops and freshnets drips to the hydrochloric mirror and it is filtered towards slope to the permeable zone. The permeable zone extends and turns into near-vertical washout – a stipe (of mushroom). The mineralization of brine decreases owing to damp-proofing of the hydrochloric mirror with the insoluble constituent.

3rd stage – cave-in. The sizes of cavity reach the value when the stability of GCC solids is broken, the collapse of roof occurs, representing the form of ellipsoid. The decompressed solids easily pass the surface water down that is followed by the dissolution of gypsum in the GCC. The caved-in solids fill a cavity in the hydrochloric deposit. Alongside with the dissolution of walls, the washout of the caved-in solid starts and the hydraulic fluid is carried out to the openings. The decompression zone pushes over and reaches a surface.

4th stage – extinguishing or washing out. At this stage, if the openings are bounded with bulkheads, the caved-in solids fill them, the inflow of water decreases and the process extinguishes. Otherwise, the process of karst and suffosion formation obtains acceleration, the cave-in extends and reaches the surface watercourses. The quantity of cave-ins increases sharply; the shear of the whole surface occurs.

5th stage – flooding openings with water and erosion. If the cave-ins reach surface watercourses, the water penetrates to the cavities, a washout, fault and disolution of salts occur. The huge conical depression is formed.

6th stage – flooding of the cave-in with water. The water from the water-intaking area around a cave-in fills it to the bottom elevation on the contour of cave-in and starts to outpour into drainage network. The shoreline of the lake is formed – ***an environmental disaster occurred***.

At present, the karst development at the mine is mainly at the third stage; there are manifestations of the 4th stage. Therefore, the further development of process and the chain reaction formation of a cave-in are impermissible. For this purpose, it is necessary to use the stowing technology and grouting of karst cavities and decompression zones.

Studying various karst forms and features at the mine [9, 12-13] (visual observations, geophysical exploration, laboratory modeling, etc.) allowed developing the classification of karst cavities (Table 1). The classification is of great importance for the choice and substantiation of a special way of the stabilization of the mountain massif and grouting measures. It should be noted that the classification of cavities into groups is based on the scientific approach.

Table 1 The classification of karst cavities

Group	Type of cavities	Exposure of cavities
	Chambers, panoramas	> 10÷ 1
I	Caverns, washouts, channels	$1 \div 10^{-1}$
II	Fractures, leached pores and decompressions	$10^{-1} \div 10^{-5}$ >

Under natural conditions, all types of karst cavities are interdependent and transform into each other, especially in case of looking at karst development over a period of time.

On the assumption of karst cavities exposure and physical patterns of hydraulic fluid flows, it is possible to recommend:

For the elimination of the I group of cavities – stowing with high-concentrated hydraulic fluids;

For the II group – stowing and grouting;

For the III group – grouting with highly-dispersive clay-cement mortars.

The success of taking antikarst measures depends largely on studying the mining-and-geological conditions, but in a greater degree, on the science-based choice of the technological parameters of the stowing operation and grouting of cavities. At the elimination of karsts of different types, it is very important to reach a high degree of cavities filling with stowing material, terminations of filtration crossflows of brines, mountain massif strengthening.

Hydraulic fluids pumping into karst cavities can be made for the creation of grout curtains (GCs), for solid waste disposal of various production units, as well as for prevention of the land surface cave-ins over karst cavities.

2.2. The study of flow conditions of grout mixes

It is necessary to consider analytically the process of vacant place filling with highly dispersive mixtures for the development of a science-based design technique of the technological parameters of underground cavities elimination. Based on the fundamentals of the viscoplastic dissolution flow theory, it is necessary to consider the process of both gravity and enforced flow of the fluid in the opening [14-16]. It is caused by the fact that in the opening of critical condition, the grout-stowing mix is fed from the surface by well, where spreading over its floor, fills a goaf. The pumping of grout-stowing mix is carried out step-by-step, which ensures layer-by-layer filling of the opening with the spreading radius *R*. Thus, in view of the high plasticity of dissolution, approximately it is possible to consider that the formed beds of mortar have the form of rectangular parallelepipeds of the width *a* and average height *h*.

It is known [17] that the flow condition of viscoplastic dissolution is defined by the slope angle of the opening and by fluid properties and it can be estimated by formula:

$$\delta_{kr} = \frac{2\tau_0}{\rho g \sin\varphi} \quad (1)$$

where δ_{kr} is the average exposure of filtration channel, m; τ_0 is dynamic shear stress, Pa; ρ is dissolution density, kg/m^3; φ is the angle of gradient to horizon of the opening, degree.

At the values $\delta_{kr} < \Delta h$, the mode of dissolution flow is gravity-feed, and at reaching the values $\delta_{kr} > \Delta h$, the mode of dissolution flow transfers into enforced, where Δh is the characteristic dimension of the exposure of the cavity.

It is established that in the case of gravity flow of grout mix in the inclined fracture with the exposure $\delta > \delta_{kr}$, the mix by gravity displaces along the incline of the fracture. Herewith the angle of depositional gradient for the mix makes [7]:

$$\beta = \frac{\pi}{2} - \arccos\left(\frac{2\tau_0}{\rho g \delta_{\max} \cos\alpha}\right) \tag{2}$$

and the volume of grout mix is calculated by the formula:

$$V = \frac{tg\beta}{tg^2\beta - tg^2\alpha}\left(\frac{R}{\cos\beta} + \frac{M}{\cos\alpha} - \frac{l}{\cos\alpha}\right)^2 Lm_T \tag{3}$$

where R is the minimum distance from the pumping point to the curtain contour, m;

l is the distance from the center of the grouting opening to the top horizon, m;

L is the length of the grouting area, m; and m_T is the porosity of mine rocks;

β is the depositional gradient of the mix, degree; M is the magnitude of the water body, m.

By further studies, it was established that when grouting a single water-bearing fracture of a large exposure, the process of solution pumping happens in the gravity mode; therefore, the volume of solution is calculated by the equation:

$$V = b\left(2MR + \frac{M^2}{tg\beta}\right)\delta_{\max} \tag{4}$$

where $b = 1.4 – 2$ – solution loss factor by thin fractures.

Thus, all executed studies and their results considered the process of waterproof curtains formation in the fractured mountain massif. In our case, it is necessary to consider the dissolution flow in an opening or a large cavity.

Assume that as a result of a stationary flow of viscoplastic fluid under the action of only body forces on the lying wall of the opening, having a slope angle φ, on all its width the rectangular parallelepiped was formed with the sides *a, h, c*. Taking into account the dynamic shear stress of solution τ_0, the equilibrium condition for a parallelepiped can be written down as follows:

$$mg \sin\varphi = \tau_0 ac$$
$$\rho gahc \sin\varphi = \tau_0 ac \tag{5}$$

From which to determine the thickness of a parallelepiped from the dissolution there is a formula:

$$h = \frac{\tau_0}{\rho g \sin\varphi} \tag{6}$$

However, in such a statement, the problem solution does not consider the flowing pressure of the dissolution at the exit out of the well which significantly influences both layer thickness and dissolution spreading radius. Therefore, the mine opening which is intersected by the well at the depth of H will be considered.

At the same time, on the surface (on the collar of well) the speed of dissolution is almost equal to zero, and at the exit out of the well the dissolution gets the speed v_0. Thus, the dissolution has the flowing pressure of P_d and spreads to the sidewalls of the opening for the distance R. The energy conservation principle at the dissolution development along the well can be written down as follows:

$$\left(mg - 2\pi r \tau_0 H\right)H = \frac{mv^2}{2} \quad (7)$$

where r is the radius of the well, m.

Or on rearrangements the next is obtained:

$$v^2 = 2\left(g - \frac{2\tau_0}{\rho r}\right)H \quad (8)$$

Therefore, the flowing pressure of dissolution equals to:

$$P_\partial = \frac{\rho v_0}{2} = \left(\rho g - \frac{2\tau_0}{r}\right)H \quad (9)$$

The thickness of the mortar bed, taking into account the equilibrium condition of the parallelepiped, is defined from the equation:

$$h = \frac{\tau_0}{\rho g\left(\left(1 - \frac{2\tau_0}{\rho g r}\right)\frac{H}{R} + \sin\varphi\right)}$$

The received formula is correct on the condition of H » h_o. Otherwise, at not deep bedding of the opening, it is necessary to consider its height h_o, then

$$h = \frac{\tau_0}{\rho g\left(\left(1 - \frac{2\tau_0}{\rho g r}\right)\frac{H + ho/\cos\varphi}{R} + \sin\varphi\right)} \quad (11)$$

Thus, the dissolution pumping into the vacant place of the opening in the gravity mode requires the use of the batching technology. At the given spreading of dissolution R, the volume of dissolution batch equals to:

$$V_s = aRh \quad (12)$$

therefore, the quantity of batches is defined from the expression:

$$n = \frac{k\sum_{i=1}^{n} V_{Pi}}{aRh} = \frac{kVo}{aRh} \quad (13)$$

where k is a correction factor on the section of the opening; V_{Pi} is the volume of the i-th batch of solution; V_o – the volume of the abandoned opening.

The above-described technique does not consider the parameters of underground cavities in development that is characteristic, for example, of the period of mining enterprises abandonment, the specification on which is given above.

The formation of filling massif in the hydraulic way is explained in considerable detail in [7, 18]. Here it is shown that the rheological properties of hydraulic stowage mixes are caused by a high content of water and a wide range of granulometric composition in these mixes and it requires the particular mode of manufactured massif formation.

The water filtration rate is in the limits of 100-200 mm/h [14].

The water removal from stowage material characterizes its permeability K (m^2), which is determined by Darcy's law:

$$K = v^{/} L\mu / \left(hS\rho^{2}\right) \tag{14}$$

where $v^{/}$ is the volume flow rate of solution in porous medium, m^3/s;

L is the length of a porous medium in the direction of fluid flow, m;

μ is the fluid dynamic viscosity, Pa·s; h is the static pressure difference within a sample, m; S is the cross-sectional area of the porous medium in the direction, perpendicular to the stream flow, m^2; ρ is the fluid density, kg/m^3.

If we express a flow rate in m/s and to denote by v, then

$$K = vL\mu / \left(h\rho^{2}\right) \tag{15}$$

For separate dissolutions at a constant temperature μ/ρ = const. Therefore, the permeability coefficient

$$K = vL / \left(h\rho^{2}\right) \tag{16}$$

The dimension of permeability coefficient is the same, as for the filtration rate of v_f which is defined from the expression [15]

$$v_f = q/S \tag{17}$$

Three areas are distinguished on the intensity and nature of settlement of binding substance. The first is the central (when pulp supplying through the central well) area of the pulp active movement at the expense of velocity head preventing its layering, and, therefore, cement is placed evenly in sand within the radius R_1.

The second (Δr_2) is the site of irregular cement settlement, gradually decreasing from the central area to the periphery. The particles suspended in water under the influence of gravitational forces flocculate slowly and are placed between sand grains. The area of slow cement settlement makes 8-10 m.

The falling velocity of particles in water v (m/s)

$$v = \frac{20}{9} g r^{2} \frac{\rho_p - \rho_w}{\mu} \tag{18}$$

where r is the radius of particle, mm; ρ_p and ρ_w are the densities of solid particles and water, accordingly, g/cm^3.

The third (Δr_3) is the area of clarified water, which practically does not contain binding substance.

The dimension of the zone of cement sufficient distribution in the filler is limited by the efficient radius

$$R_e = R_1 + 0{,}5\Delta r_2 \quad (19)$$

which averages 17-20 m.

For the construction of a monolithic massif of high quality on the large area, more solution feeding sites are placed, the water velocity in openings is increased by means of drainage devices, etc.

3. RESULTS

At the present time, there is no information available on the hydrodynamics of hydraulic fluid fluctuation in karst cavities. Back in the 1970s, the experiments were made on studying of the physical mechanism of hydraulic fluid fluctuation [19, 20]. The results show the following fundamentals of its fluctuation and solid particles settlement.

At the first phase of the hydraulic fluid pumping at the bottom, a cone from granular material is formed. The cone is increased up until the stream velocity becomes critical. Then there comes the second phase of fluctuation. The hydraulic fluid flow direction at the top of the cone changes from descending to horizontal; there is an advancing of the side surface of the cone, whereas alongside the roof of vesicle a free scissure is left. At the exit of a scissure, the velocity sharply decreases, as a result of which solid particles flocculate. At first, the large particles fall out, they are stored in the upper side of the slope, then more and more minor particles. Thereby the distribution of particles in section by particle-sizes turns out reverse: in the upper side, the particles are large, in lower – minor ones, at the bottom layer – they are argillous. Due to the difference in the internal friction angle for the deposit with different sizes of particles, the slope obtains a concave form – cragged in the upper side and flat in the lower part.

As the cone extends the length of the free scissure increases, with the result that hydraulic resistance increases, and the hydraulic fluid discharge decreases. At some minimum discharge, the layering of hydraulic fluid in the wellbore happens, resulting in the formation of sand seal, and hydraulic fluid absorption completely stops.

The analysis of the physical mechanism of hydraulic fluid fluctuation in karst cavities is based on the postulate on the constancy of the hydraulic fluid fluctuation velocity in the free scissure between the roof and washed body and on equality of this velocity to its critical value, at which there is a settlement of particles [20]. Indeed, if the velocity is less than critical, then particles would settle and would not be carried out from the scissure. If the velocity exceeds critical, then there would be a washout of already deposited micronite, the contour interval of the scissure would increase until the velocity decreases to critical.

It is known that the fluctuation velocity is connected to a pressure gradient dependence:

$$v = ki^n \quad (20)$$

where k is the coefficient, constant for this environment, i is a pressure gradient,

n is the index depending on the mode of fluctuation.

It is apparent that if $v=const$, then the pressure gradient is also constant. From this, it follows that the piezometric level at hydraulic fluid pumping has the form of the regular cone within a scissure. It should be also noted that hydraulic fluid fluctuation does not depend on the height of a karst cavity and on the form of its lower bound. Besides, this reasoning is fair both for radial and for the linear nature of hydraulic fluid fluctuation.

Proceeding from the explained working hypothesis on the physical mechanism of hydraulic fluid fluctuation, the mathematical description of process for the elementary conditions might be given, namely assuming that the height of cavity is constant, and its roof is horizontal [15].

For the point, corresponding to crossing of the well with a cavity roof, the following equilibrium equation is true:

$$H_L + \gamma_c \Delta H_H - k_1 Q^2 = H_E \gamma_E + S_W \gamma_E + iR \tag{21}$$

where H_L is the pressure in long-distance pipeline from which hydraulic fluid is taken away, γ_c is the relative density of hydraulic fluid, ΔH_H is the difference of heights between the point of hydraulic fluid intake and the considered point, k is coefficient of hydraulic resistance of feed pipelines and the wellbore, Q is the discharge of hydraulic fluid, H_E is the head elevation of the edge waters, S_W is an increase in the level due to water pumping to the seam, i is a hydraulic slope of hydraulic fluid at its fluctuation in the scissure, R is the radius of the top of the washed cone.

As the coefficient of transmissibility of the seams, containing karst cavities, is extremely high, it is possible to neglect the increase in a piezometric pressure head of edge waters S_W.

It is denoted

$$H_L + \gamma_c \Delta H_H = H_1 \tag{22}$$

Besides, $iR=S$, moreover, $i=const$. Then

$$S = H_1 - k_1 Q^2 \qquad Q = \sqrt{\frac{H_1 - S}{k_1}} \tag{23}$$

The values of Q and S change in the time t.

To find this dependence it is assumed that the body of solid deposit has the form of a truncated cone with the volume

$$W_B = \frac{\pi m^2}{3tg\alpha}\left(2R - \frac{m}{tg\alpha}\right) \tag{24}$$

from here

$$R = \frac{3W_B tg\alpha}{2\pi m^2} - \frac{m}{3tg\alpha} \tag{25}$$

At $\alpha \approx 300$ and $m << R$, the second member of equation can be neglected, then

$$R \approx k_2 \frac{W_B}{m^2}; \quad k_2 = \frac{3tg\alpha}{2\pi} = 0{,}27 \tag{26}$$

The volume of the cone can be expressed through the volume of the pumped hydraulic fluid W:

$$W_B = Wc$$

where c is the ratio of the deposit volume to hydraulic fluid volume.

Taking into account these ratios

$$S = iR = \frac{k_2 iWc}{m^2} \quad (27)$$

Having differentiated this equation on time, it is received

$$\frac{dS}{dt} = \frac{k_2 icQ}{m^2}, \quad Q = \frac{dW}{dt} \quad (28)$$

Substituting the value Q from the formula (23), it is found:

$$\frac{dS}{dt} = A\sqrt{H_1 - S}, \quad A = \frac{k_2 ic}{m^2 \sqrt{k_1}} \quad (29)$$

The integration of this equation leads to the expression

$$-2\sqrt{H_1 - S} = At + c_1 \quad (30)$$

The constant c_1 can be found from the condition: t=0; S=0, that is

$$c_1 = -2\sqrt{H_1} \quad (31)$$

as a result

$$\sqrt{H_1} - \sqrt{H_1 - S} = \frac{At}{2} \quad (32)$$

considering (23)

$$Q = \sqrt{H_1/k_1} - \frac{A}{2\sqrt{k_1}}t \quad (33)$$

At the invariable composition of hydraulic fluid, only *t* is variable in this equation, that is, the discharge decreases in time under the rectilinear law. The maximum intake capacity of well corresponds to the beginning of pumping and is equal to

$$Q_{\max} = \sqrt{H_1/k_1} \quad (34)$$

and under the condition

$$\sqrt{H_1} = \frac{At}{2} \quad (35)$$

the discharge goes to zero.

4. DISCUSSION

Using the given dependences, the influence of some factors on process parameters will be analyzed. First of all, it should be noted that under the accepted conditions the pressure gradient of hydraulic fluid is the constant value depending only on the structure of the hydraulic fluid (concentration and sizes of particles). With a knowledge of pressure gradient value, it is possible to determine the radius of the top of cone at any time if *S* is known as *R = S/i*.

The radius of the wash cone does not depend on the height of karst cavity, and depends (at this composition of hydraulic fluid) only on pressure:

$$R_{max} = \frac{H_1}{i} \tag{36}$$

At the known R, it is easy to define the volume of the washed cone by the formula (24). The maximum volume is defined by the height of cavity and the angle of depositional gradient of the stowage material.

The duration of the hydraulic fluid pumping is defined from the formula (35):

$$t_{max} = \frac{2\sqrt{H_1}}{A} = \frac{2H_1 m^2}{Q_{max} ic} \tag{37}$$

The offered model, apparently, is fair in that case when the height of scissure on which hydraulic fluid moves is less than the height of the karst cavity. It is necessary to estimate these values.

$$h = \frac{Q}{2\pi v_{\kappa r} R_1} \tag{39}$$

$$v_{kr} = 1.4\sqrt{dg(5 + 2/d)} \tag{40}$$

Table 2 The scissure height variation with the distance from the well

R, m	1	2	5	10	20	30
h, mm	37	18	7	3.7	1.8	1.2

From these estimates, it is visible that the height of a scissure is small.

As the discharge, as it was shown above, decreases in time, the height of the scissure also decreases in the course of pumping. Eventually, it can become commensurable with the diameter of particles. It is apparent that in this case the delay of large particles will start, i.e. the stowing of cavity comes to an end with filling of a scissure with solid precipitation.

5. CONCLUSION

The complex of technical actions aimed at the elimination of ecological backlash has to be provided by the projects of mines and transverse sections abandonment. The priority directions of ensuring ecological safety are the following:

Environmental monitoring maintaining to the fullest extent from the beginning of abandonment works to the elimination of all negative consequences of the closing-down mines and activities of transverse sections;

Construction and expansion of pump discharge complexes on the closing-down and operating mines having close hydraulic connection for the purpose of ensuring the safe operation of the latter;

Protection of the land surface, industrial and civil facilities located in flooding areas with mine waters;

- implementation of the actions providing prevention of drinking sources pollution which are located in the impact areas of flooded mines;
- Extinction of the burning waste heaps, spontaneous fires in mines and freely burning fires at the coal outbreaks.
- It is necessary for the improvement of the ecological situation in the impact areas of the closing-down mines:
- to increase the effectiveness of environmental monitoring due to enhancement of its organization and carrying out;
- to continue the system establishment of observation wells and monitoring observations over the condition of underground waters;
- to study the need of the construction of new and additions to existing pump discharge complexes associated with possible water flows of the closing-down mines to operating mines;
- to provide with drinking water the inhabitants of the settlements, the water supply sources of which are polluted by mine waters;
- to accelerate construction of treatment facilities in the mines which are carrying out disposal of acid and ferriferous mine waters into water bodies;
- to provide measures for protection of the land surface against submergence in cases of pump dischargers stop in the closing-down mines.
- At the final stage, it is necessary to refer to the core measures for scientific ensuring of coal sector restructuring:
- complete overhaul on a new scientific basis of the sector regulatory and procedural framework in the sphere of ecology taking into account the modern requirements and provisions of the federal nature protection legislation, including the development of new documents as a matter of priority;
- the quantitative assessment of the decrease in the negative environmental effect and the ecological situation improvement in coal regions and the sector in general due to abandonment of unprofitable mines and transverse sections;
- development of design and engineering solutions on the treatment of mine waters of the operating and closed-down enterprises from the sulfates and heavy metals down to regulatory requirements;
- inventory check and certification of waste heaps and other products waste ponds, carrying out of integrated assessment of their environmental effect, development of efficient ways on negative impact neutralization on the basis of eco-economic indexes taking into account the natural environment and climatic and socio-economic factors.

The implementation of this action plan will allow lowering the environmental pressure on the environment in the coal production sphere, will promote its preservation, careful attitude to natural resources, improvement of the population accommodation conditions in coal-mining regions of the country.

The goaf stowing experience at the mines "Falun" and "Kristeneberg" (Sweden) shows that at layer mining from top downward, timber stringers are put to the bedrock of split, then the metal gauze is laid (5 mm) and the stowage mix is filled. In an upper side of a layer, a plastic pipe for air is laid, on the bedrock – the catchwater drain with a diameter of 76 mm which is wrapped up by gunny sack [12].

At the mine "Mount Isa" (Australia), primordial chambers are filled with a mix with 10-12% of cement, the chamberlets – with 6%. The original water content in stowing is of 31%, residual – 22%. The waste water is unwatered with the pump, lowered into the chamber 2 hours later after mix cutting-off. The unit discharge of cement for the chambers of 50 kg, working from bottom up of 100 kg, with the downward mining of 120 kg. The stowing material is given immediately on the bedrock of a layer; the pipeline with a diameter of 50 mm is used, and the hose pipe with a length of 15 m is placed in the layer.

It is difficult to receive the homogeneous distribution of cement in filler. The addition of flocculants (polyacrylamide) in the amount of 10-20 g/t of solid components reduces the losses of small fractions and increases the stowing density.

As it is seen from the above-stated analysis, at the present time a wide experience of carrying out the stowing works during mining enterprises operation is gained and the techniques of creating artificial grouting and stowing massifs are developed.

In view of the results of the studies, it is obviously possible to summarize the main conclusions:

1. The model, describing the hydraulic fluid fluctuation in flooded horizontal cavities, unbounded in area, is proposed. The basis of the model is the postulate on the constancy of the hydraulic fluid fluctuation velocity on the radius and its equality to the critical speed.
2. Under the given conditions, the maximum radius of the cone washed in cavity depends only on the hydraulic fluid composition and pressure.
3. The hydraulic fluid discharge at a constant pressure in the supply pipeline decreases linearly in time.
4. The piezometric level in the field of hydraulic fluid fluctuation has the cone shape with a rectilinear generator.

The proposed model can be used for the parameters calculation of the hydraulic stowing of flooded underground cavities, as well as for the processing of the experimental findings obtained in the course of stowing.

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