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СНИЖЕНИЕ ГЕОЭКОЛОГИЧЕСКИХ ПОСЛЕДСТВИЙ ПРИ СКЛАДИРОВАНИИ ГАЛИТОВЫХ ОТХОДОВ

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Аннотация: представлена актуальность исследований в части снижения геоэкологических последствий при обогащении калийных руд за счет складирования галитовых отходов способом гидронамыва. Даны результаты исследований водно-физических и прочностных свойств галитовых отходов. Изложены параметры устойчивости формируемого гидронамывом солеотвала из галитовых отходов и даны рекомендации по технологии безопасного формирования солеотвала способом гидронамыва.

Ключевые слова: техногенные массивы; калийная промышленность; галитовые отходы; солеотвал; шламохранилище; складирование отходов.

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Reducing the geo-environmental impact of halite waste storage

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Abstract: The article describes the relevance of research on reducing the geo-environmental impact of potash processing by storing halite waste on exhausted slurry pits by hydraulic filling. The results of water-physical and strength properties of halite wastes were obtained in the course of research. The parameters of stability of salt pile formed by hydraulic filling from halite wastes are described and recommendations on the technology of safe formation of the salt pile by hydraulic filling are given.

Key words: technogenic massifs; potash industry; solid halite waste; potash tailing pile; slurry pit; waste storage.

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Introduction

Global demand for potash production leads to an intensification of potash operations, which is increasing every year [1—3]. The main potash companies are based in Canada, Russia and Belarus. Thus, potash production in the latter two countries accounts for more than 35% of global production [4].

Mining operation leads to the withdrawal of agricultural land [5], landscape transformation and surface deformation [6,7], changes the hydrological regime of groundwater and surface water [8,9] and pollution of soils and water basins [10—12]. However, the main problem with this industry is the accumulation of significant amounts of waste, which leads to the formation of technogenic massifs and changes in the geologic medium, which in turn have a detrimental effect on the environment [13—15] and human activities [16].

Reducing the geo-ecological impact in the potash mining area should be considered by developing new methods for the storage of wastes to reduce the increase in the area used to dispose of these wastes.

Halite wastes are stored in tailings piles and slurry pits near industrial sites [17]. The storage of halite waste on the surface in large quantities and over large areas leads to the formation of NaCl-saturated brines as a result of the dissolution of the salt waste by atmospheric precipitation [18].

Analysis of the results of previous geo-environmental assessment research at potash mines shows that a large number of investigations are being carried out to reduce the negative impact of potash waste on the environment [19—22].

The importance of maintaining the production capacities of potash mines when the tailing piles are full of waste requires the search for new systems of waste storage. New methods will reduce the technogenic load on the area by reducing the withdrawal of additional land for tailings piles while using exhausted slurry pits as a base for expanding the tailing pile [23, 24].

Methods and interpretation of research results

The aim of the research is to investigate the storage of waste by hydraulic fill at the exhausted slurry pit, which will reduce the withdrawal of additional land.

The balance reserves of mine is 261.38 million tons and the involved reserves of Darasinsk mine (B+C1+C2 513.03 million tons), the total volume of halite wastes was about 400.00 million tons for 30—40 years. The potential storage volume is about 50.46 million tons in the existing tailing pile contour.

The land area for the tailing pile is 232 ha; the area allocated for storage is 192 ha; the area occupied by the existing tailing pile is 189 ha; the residual area is 2.71 ha. The mass of stored halite waste for six months amounts to 2.97 million tons.

The base of the slurry pit before the hydraulic fill was at the absolute mark of +153.5 m. The storage of halite wastes by hydraulic fill is carried out in tiers up to the absolute mark of +207.5 m. The thickness of one tier is 1.5 m.

The relevant issue for the Soligorsk mining district is to solve the problem of allocation of new areas for storage of halite wastes. Special attention should be paid to the actions on the use of exhausted slurry pits as bases for the expansion of potash tailings piles by hydraulic fill method, contributing to the reduction of the withdrawal of additional agricultural areas for tailings piles, which leads to the reduction of geo-environmental consequences [25].

The authors' research on the safe storage of halite waste is based on the evaluation and practical experience of many years of implementing a potash tailing pile formation project by means of the hydraulic fill of the exhausted slurry pit (Fig. 1).

The carried out researches allowed to establish new water-physical and strength properties of halite wastes, engineering and geological processes in the enrichment wastes from the moment of storing to their consolidation, features of obtaining by halite wastes new physical and mechanical properties during high-altitude storage and their prognostic indicators which are used for the safe design of salt pile formed by the hydraulic fill on the exhausted slurry pit. Thus, the weakening of bonding forces at the contacts between halite waste grains is a consequence of increased mineralization, enclosed in the stable range 340—375g/l, increased viscosity the brine of NaCl. The viscosity decreases as the temperature rises and, when the temperature drops to -21.2 °C the brine of NaCl freezes completely, turning into a mixture of ice crystals and hydrogalite.

Most important is research into the stability of downstream and upstream slopes of dams with stability classes II and III, the impervious blanket of upstream slopes of dams for normal and special operating conditions of the slurry pit. Assessment of structural stability makes it possible to present the technological parameters of the process of hydraulic fill of the slurry pit and ensure the geo-environmental safety of tailing pile formation.

The analysis of geomechanical models and their corresponding numerical schemes made it possible to study the stress-strain state of the «tailing pile-slurry pit» system [26]. As criteria for assessing the strength of the geosystem, the Coulomb-Mohr strength criterion and the energy strength criterion were used, which in the main normal stresses have the form:

$$\sigma_1 - (2\lambda + 1)\sigma_3 = \sigma_{\text{press}}, \tag{1}$$

$$\sigma_{\text{экв}} = \sqrt{\frac{1}{2}\left[\left(\sigma_1 - \sigma_3\right)^2 + \left(\sigma_2 - \sigma_3\right)^2 + \left(\sigma_3 - \sigma_1\right)^2\right]} \leq \sigma_{\text{press}}, \tag{2}$$

where σ_1, σ_2 and σ_3 are maximum, average and minimum main normal stresses, respectively; λ is the lateral spreading coefficient (tabular value); σ_{press} is rock's ultimate strength in uniaxial compression.

The geometric dimensions of the geosystem were limited by the contour of

a

b

Fig. 1. General view of the storage of halite waste by the hydraulic fill on the exhausted slurry pit: a — August 2015; *b* — June 2021

the slurry pit in the form of a system of dams of stability classes II and III.

The boundary conditions for assessing the construction are limited by the contour of the slurry pit in the form of a system of dams of stability classes II and III.

Since the considered technological processes proceed in a long time interval, the mechanical-mathematical (geomechanical) model problem was solved in a non-linear (taking into account the Mohr-Coulomb property) quasi-static formulation. When building the computational models, the objects (elements) of the general geosystem under study, including the dam system (classes II and III), the slurry pit bed, the slurry pit structure, the impervious blanket, and other system elements, were considered as linearly deformable uniform isotropic bodies.

According to research carried out by the authors, the process of intensive squeezing of the liquid phase of halite waste with simultaneous compaction lasts for no longer than 18 hours under conditions of predicted development of waste storage. To ensure reliable storage of the reclaimed surface, at least 48 hours are required for its consolidation, and the reclamation of the halite wastes should be carried out in layers (Fig. 2).

Hydraulic fill by the highly concentrated slurry allows:

– form a slope with any slope angle;

– use any area for the basis;

– increase the mass of deposited halite wastes per unit area due to the higher density of the filled massif.

The research was carried out an analysis of halite waste properties such as total strain modulus, porosity, density, angle of internal friction, moisture content along the body of the exhausted slurry pit are illustrated in the graphs shown in Fig. 3.

Density and porosity, which, as a rule, are closely connected with the time of existence of halite wastes, depth and degree of their lithification, may not show clear traceable patterns in terms of density increase and porosity decrease with depth. This is explained by the regime (rate, periodicity) of halite waste storage, as well as by the condition of the environment (massif) in which they are stored (cracks, surface subsidence, salt brine occurrences), the stochastic influence of atmospheric conditions (rains, snowmelt, fog).

a *b*

Fig. 2. Technology for storage of halite waste using hydraulic filling: a — June 2020; *b* — June 2021.

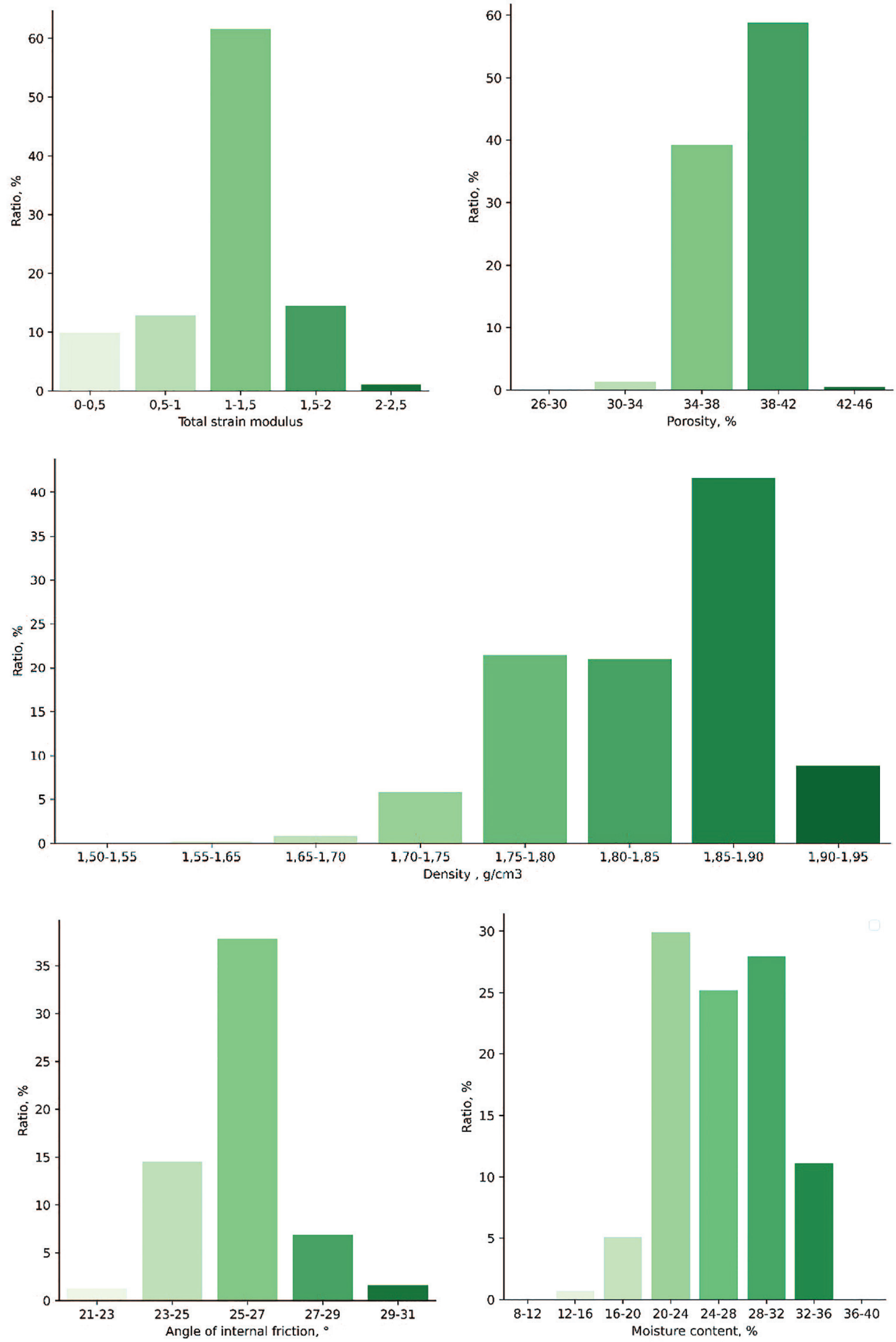

Fig. 3. Properties of halite waste

The high susceptibility of halite wastes to disturbance of their structure is related to the peculiarities of structural bonds caused by the crystallisation of NaCl salt brines contained in the primary brine. The moisture limit of hygroscopicity for halite wastes corresponds to relative air humidity of 75—78%.

The total amount of moisture generated by thermal condensation, hydrosorption processes, and accompanying salt dissolution processes is about 110 mm/year, which at condensation brine salinity of 0.325 t/m^3 is about 400 t/year from 1 ha.

For the current storage of halite wastes by hydraulic fill method from the tailing pile mark of +240.00 m, the overall design of the slurry pit as a geosystem has a safety factor of 1.3 (with a minimum allowance of 1.15).

The process of hydraulic fill of halite wastes must ensure uniform filling of the layer (area, territory, zone) during the whole hydraulic fill period, which requires surveying of the layers. After hydraulic fill of the formed layer for consolidation of the hydraulic fill surface, a technological break of at least 2 days is required, determined by the amount of atmospheric precipitation, humidity, and period of the year. Under dry weather conditions, the duration of the technological break shall be at least 4 hours.

It is necessary to have at least two working hydraulic fill sites. Formation of the salt pile using hydraulic fill within one section can be performed for about 8 hours. It is recommended that the hydraulic fill contour should be erected using bund walls of about 2.5 m in height no later than 12 hours after hydraulic fill. The contour is to be erected after 24 hours after hydraulic fill with a bulldozer ripper.

The research has shown that hydraulic fill shall be carried out in phases within separate zones bounded by perimeter berms. The condition for the efficiency of the hydraulic filling process is to ensure the slope of the leaching surface at an angle of not less than 1.5°. The higher surfaces are recommended to have an angle of slope no more than 35°.

The study has also proved that is recommended to storage of halite waste along the dams. Along the perimeter of the salt pile formation, it is recommended to maintain a gap of 10—15 m. It is recommended to maintain a height difference of no more than 5 m between the sections.

The presented regularities of engineering-geological processes change from the moment of halite waste storage to its consolidation, obtaining new physical and mechanical properties of halite wastes during storage from the +240,00 m are recommended to continue the works on halite waste storage by means of hydraulic fill.

Conclusion

The conducted research on further storage of wastes by the hydraulic fill on the spent slurry pit allowed to establish the regularities of engineering and geological processes (filtration consolidation by the mass of the halite waste layers stored above; the processes of plastic deformation developing in time; chemical processes occurring in the pore solution) development in halite wastes and their technogenic influence on the slurry pit structures, which allows to recommend technological parameters of wastes storage, compliance with which will ensure the geo-environmental safety.

The main characteristics that ensure technogenic and geoecological safety of the environment include:

– the availability of at least 2 working sections;

– consolidation of the surface at least 48 hours;

– hydraulic filling of one section about 8 hours;

– from waste to the dikes it is required to maintain a discharging trench of 10—15 m;

– the height difference of the sections is not more than 5 m.

Hazardous sedimentation of hydraulic fill wastes up to +240.00 m is not traceable.

The use of exhausted slurry pits as bases for the expansion of tailings piles by the hydraulic fill method contributes to reducing the withdrawal of additional agricultural land for tailings piles.

This is a priority area for technology development in the mineral resource sector, helping to reduce the geo-environmental consequences of halite waste storage.

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