Substantiation of Rational Parameters of Rock Salt Extraction in High-Altitude Conditions Using Environmentally Friendly Combined Geotechnologies

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Abstract. The article is devoted to solving the problem of choosing and justifying rational parameters of rock salt extraction in high-altitude conditions. The Chon-Alai rock salt deposit, located at an altitude of 3,200 meters from sea level, was considered as an object of research. The deposit is characterized by complex mining and geological conditions, and its physico-mechanical properties are suitable for obtaining fodder and edible salt. According to the results of the research, the optimal parameters of the dissolution of rock salt were determined. Taking into account the geological and mining conditions of the deposit, resource-saving and environmentally safe methods of integrated phased development of the deposit have been developed. It is recommended to extract salt at the initial stage by evaporation of brine from natural springs that carry salt from the depth of the deposit; at the second stage by the quarry method and at the third stage by underground dissolution using drilling wells. The first and last of them are characterized by minimal environmental consequences for the environment. The results obtained contribute to the enrichment of world experience in the development of high-altitude mineral deposits with environmentally friendly combined geotechnological methods consistent with the principles of sustainable development.

1 Introduction

Table salt (*sodium chloride, NaCl*) is the most important food product for human life. Salt is extracted mainly by mining or quarrying, although sometimes there are self-settling deposits near lakes and sea bays, for the extraction of which the method of natural evaporation is applicable. Sodium chloride is very widely used in the chemical and food industries, it is a raw material for the production of chlorine, caustic and calcined soda. In agriculture, salt is important because it is used as animal feed, as well as to improve soil quality and to increase crop yields.

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Currently, the global production of table salt is about 190 million tons per year. Salt is produced in 110 countries around the world, but the main production (about 90%) is carried out in 21 countries, the leading of which are the USA (19%), China (11%), Germany (9%), India (6%), Canada (5%). There is a growing trend in the consumption of table salt in the world, only in the last 7 years the need for salt has increased by 5% [2].

There are solid reserves of rock salt in the Kyrgyz Republic, according to exploration data, deposits of rock salt with total reserves of about 33 million tons have been explored for the needs of the food and chemical industry. The largest deposits are: Ketmen-Tube (6.6 million tons), Chon-Tuz (3.8 million tons), Chon-Alai (21.5 million tons), Tunuk-Tuz (0.6 million tons) and others. Despite such significant reserves of raw materials, the republic produces only about 20 thousand tons of salt per year. The main need for edible salt is met by imports from Kazakhstan and Russia. The development of its own deposits could ensure that domestic needs are fully met, in particular for the needs of livestock and even establish the export of table salt. Consequently, the rational development of mineral resources and the creation of new jobs in the mining industry is an urgent problem for the Kyrgyz Republic.

The increasing demand for fodder and edible salt, as well as the high cost of imported table salt in the Kyrgyz Republic, necessitates the development of its own deposits of rock salt. Solving this problem requires a thorough study of world experience, taking into account modern requirements for resource conservation and environmental management indicators. The study of literary sources shows that the trend of a constant increase in the depth of development of promising sites and deposits dominates in world practice, the problem of searching for fundamentally new geotechnologies, including convergent ones, which radically solve the problems of safety and completeness of extraction of balance reserves on the basis of alternative methodological approaches and technical means for their implementation becomes more urgent [7,8,13,14]. Many authors note that the key direction of the mining industry development is the introduction of convergent mining technologies, which combine digital technologies and artificial intelligence, as well as bio- and nanotechnology for the development of the subsoil.

The analysis of literary sources shows that the main obstacles to the development of high-altitude deposits are unfavorable terrain, more severe climatic conditions, the presence of permafrost and glaciers, heterogeneous geological structure, increased seismicity, remoteness from infrastructure and inaccessibility [9,10,12].

The construction of mine workings for mining requires reliable information about the physical and mechanical properties of rocks. In [4], the behavior of rock salt in various deformation conditions was studied when they were in cavities formed as a result of mining. Comparing five models from different geographical locations and studying the results of numerous tests, the authors of this work came to the conclusion that it is difficult to give a long-term forecast of the behavior of salt caverns.

The work [2] also studied the physico-mechanical properties of rocks for the selection and justification of systems for the development of mineral deposits. However, the authors have not specified which destruction methods are effective for the extraction of rock salt.

Another equally important issue in the development of salt deposits is the environmental safety of mining processes. The environmental impact of rock salt extraction by dissolution manifests itself in different ways: surface and groundwater may be affected by emissions of polluted waters, air may be affected by emissions of solid particles, subsidence of the surrounding area may affect populated areas. The work [6] is devoted to this issue, where the authors, based on the experimental data obtained, note the high potential of using the borehole method for effective large-scale development of salt deposits.

In the open-pit mining method, a drilling and blasting method is also used for salt extraction, with the help of which a quarry is built. But this method, in our opinion, is not effective enough from the point of view of industrial safety and because of the negative

impact on the environment. Based on the results of the study of literary sources, taking into account the gaps and shortcomings in previous work, a research question is posed: is it possible to use combined geotechnology of extraction in the conditions of the same rock salt deposit located in a high-altitude area and under what conditions?

2 Materials and Methods

The purpose of these studies is to substantiate the parameters of combined geotechnology for the development of rock salt deposits located in high-altitude areas and characterized by difficult mining and geological conditions. To achieve this goal, you will need to solve the following tasks:

– The study of typical mining, hydrogeological and engineering-geological conditions of high-altitude rock salt deposits (using the example of the Chon-Alai deposit located in the Kyrgyz Republic).

– Analysis and systematization of factors affecting the main indicators of the development of rock salt deposits.

– Substantiation and selection of optimal, environmentally friendly ways to develop proven (estimated) reserves of mineral raw materials at the lowest cost.

The object of research in the work was the Chon-Alai rock salt deposit, located on the territory of the Osh region of the Kyrgyz Republic, at a distance of 300 km from the city of Osh. The salt deposit is confined to the Sarynamak formation of the Middle and Upper Jurassic, located in the Vakhsh thrust zone and tectonically forms evaporite melange. The salt deposit is located on an area of 750mx800 m, it is not sustained in power and structure. The thickness of the deposit varies from 22 m to 130 m, averaging 42 m. The content of sodium chloride is from 2.9% to 81.8%, on average 62%, insoluble precipitate-34.9%, gypsum-8.2%. The remaining water-soluble salts are contained in small amounts.

The modern relief of the deposit area is a domed hill, elongated in the latitudinal direction with a flattened karst surface and rather steep northern and southern slopes. The steepness of the slopes is from 10-30 to 90° (steep ledges 1-10 m high on the left side of the Tuz-Suu stream). The total area of the deposit, where relatively fresh karst sinkholes are observed directly at the exits of the Cenomanian salt-bearing section, is about 1.0 km2. The sizes of rounded dips range from 5-6 to 60-70 m. The frequency of sinkholes ranges from 1 to 4-6 pieces per hectare. The absolute marks on the developed area within the Tuz-Suu riverbed are 3100-3150 m, and in the aplical part of the dome they reach 3350 m. Proven reserves in categories B+C 1+ C 2 are 48,089,130 tons, with an average sodium chloride content of 58%.

To study the mining conditions of the deposit and select effective development systems, materials from geological reports made in different years and stored in the archives of the Department of Geology of the Kyrgyz Republic and the South Kyrgyz Geological Expedition were used [1,5,11].

The work uses methods of mineralogical and petrographic studies of stone material, analytical studies, including the determination of chemical, mineralogical compositions and technological studies, including the determination of parameters of dissolution of rock salt.

3 Results

The mineral (rock salt) belongs to semi-rocky rocks. The strength coefficient of rock salt on the Protodiakonov scale is f =2-3. Useful thickness and overburden rocks, represented by semi-rocky formations, usually require the use of drilling and blasting operations for development. Rock salt, which is a mineral called halite, is easily soluble (more than 100

g/ml), slightly ripe, viscous and permeable. Laboratory tests of the samples were carried out in the analytical laboratory of the South Kyrgyz Geological Expedition.

In order to study the content of a useful component (sodium chloride) and harmful impurities in salt bodies, as well as the choice of a method for processing rock salt into useful products, laboratory tests of the technological properties of the mineral were carried out.

To study the solubility of rock salt, two technological samples were selected: TP-1, which is rock salt in solid form, and TP-2, which is brine from salt sources available on the territory of the deposit. Studies have shown the following results. In the temperature range of the solvent (water), the behavior of the salt differs from that in the range of negative temperatures from 0 °C to -20 °C. At this temperature, sodium chloride dihydrate hydrate (NACLX2H2O) crystallizes at solution concentrations from 24.4 to 26.3%. Thus, the study of salt solubility makes it possible to choose two main ways to obtain sodium chloride crystals: by evaporation of a solvent (water) to obtain crystals of anhydrous sodium chloride or by freezing it to obtain a dihydrate crystallohydrate. The crystallohydrate already loses water at room temperature, and additional drying makes it possible to remove two water molecules to obtain anhydrous crystals of edible salt. Good results in the dissolution of rock salt are obtained by crushing the material to 5 mm or less.

It is recommended to use cellulose (cotton) as a filter to separate the insoluble residue from the mother liquor. Quartz sand and glass wool give slightly worse results, but when using them, the brine is slightly contaminated with silicic acid. The best results are obtained by gravitational settling (simple settling). At the height of the brine column of 50 cm, the complete settling of the insoluble residue occurs in 24 hours. According to the chemical composition of rock salt from the TP-1 sample and brine from salt sources from the TP-2 sample, it follows that in the first case, the main undesirable impurities are sulfate ion (5.03%), bicarbonate ion (0.12%), calcium ion (2.00%) and magnesium ion (0.06%). In the second case (TP-2): sulfate ion (4.01%), bicarbonate ion (0.02%), calcium ion (0.15%), magnesium ion (0.03%). However, according to the TP-1 sample, the sulfate ion is associated with calcite to form anhydrite (5.67%), and according to the TP-2 sample, with sodium to form tenardite (5.28%). The remaining salts (except sodium chloride) in both cases are less than one percent.

Salt cleaning from the above-mentioned impurities was carried out in two stages: without chemical reagents (mechanical purification) and chemical cleaning, and ordinary drinking water was used to dissolve rock salt.

During mechanical cleaning, rock salt after dissolution and settling for 24 hours, and brine from springs after filtration, were evaporated using electricity. When 97% of the solvent (water) is removed, evaporation stops, and further dehydration of the salt was carried out on a centrifuge.

As a result, 2 kg 445 g of salt from 4 kg of the initial sample of rock salt and 500 g from 2 kg of brine from springs were obtained according to the TP-1. The salt yield was 61.2% and 25.3%, respectively.

Then, the obtained salt was subjected to chemical analysis separately for two samples, and after secondary dissolution in water, introduction of corrective additives (calcined soda) and filtration, it was re-evaporated to remove the solvent by 90%. In all cases, filtration was carried out at a boiling point of the salt solution equal to 106 °C. The results of the analysis are shown in Table 1.

Table 1. Salt composition of rock salt and brine from springs before cleaning, after mechanical and chemical cleaning

Sample No. .	$Ca(HCO_3)_2$	$NaHCO_3$	$CaSO_4$	$MgSO_4$	K_2SO_4	Na_2SO_4	NaCl	Sum of salts .

1.Before cleaning (feedstock) .								
TP-1	0.16	0.00	6.67	0.30	0.04	0.08	68.97	76.23
TP-2	0.03	0.00	0.47	0.13	0.00	5.28	29.34	35.25
2.After mechanical cleaning .								
TP-1	0.24	0.00	1.63	0.00	0.02	0.25	97.03	99.18
TP-2	0.16	0.00	1.70	0.00	0.00	0.17	96.44	98.47
3. After chemical cleaning .								
TP-1	0.00	0.10	0.00	0.00	0.02	0.05	99.37	99.54
TP-2	0.00	0.17	0.00	0.00	0.00	0.01	98.78	98.96

As can be seen from the table, after the first stage of cleaning (mechanical), the sodium chloride content was 97.03% (TP-1) and 96.44% (TP-2) and the resulting salt can be used for technical purposes. The decrease in calcium sulfate (anhydrite) to 1.63% according to TP-1 compared with the initial content (6.67%) is explained by the fact that the solubility of the latter at the boiling point of a saturated salt solution (106 °C) is significantly lower than at room temperature and it precipitates in the form of gypsum, and is separated during filtration from the mother liquor. Bicarbonate ions contained in tap water react with magnesium ions and form calcium carbonate (limestone), completely precipitate the ions of the latter. Potassium sulfate is precipitated by half due to its relatively low solubility. There is a slight increase in the content of calcium bicarbonate and sodium sulfate (tenardite) within the analytical tolerance.

Brines from springs (TP-2) behave somewhat differently. The decrease in the content of tenardite from 5.25% to 017% occurs due to its increased solubility in water (up to 42.3 g / 100g at t = 100 °C) and its bulk remains in the under-filled (10%) part of the solution.

After establishing the chemical equilibrium described above, which occurs during boiling and evaporation of the salt solution, the required amount of a corrective additive (calcined soda) for the chemical deposition of calcium ions was calculated. Calcined soda binds and deposits excess calcium ions in the form of calcium carbonate (limestone), while freeing the salt solution from calcium bicarbonate and gypsum. The sulfate ions released from gypsum in the form of brines are most likely bound to the hydrogen ion of water to form a small amount of sulfate acid and remain in the composition of an under-evaporated amount of the solvent.

Upon completion of the stage of chemical cleaning of salt, it was found that the resulting table salt contains 99.37% sodium chloride (TP-1) and 98.78% (TP-2), which, according to current standards, corresponds to the highest and first grade.

The further task of the research was to develop methods of extracting minerals for the purpose of industrial development of the deposit. As is known, open-pit and underground mining methods are currently widespread in the world, and the choice of the development method depends on the mining and technical conditions of the deposit and the physical and mechanical properties of rocks. The results of the study of the physico-mechanical properties of the rock salt of the Chon-Alai deposit, which are of crucial importance for development, are presented below (Table 2).

Table 2. Characteristics of the physico-mechanical properties of rock salt from the Chon-Alai deposit

Indicator	**Unit of measurement**	**Value**
Rock category by drillability	according to the VITR classification	IV-VII
The pressure at which the destruction of the rock occurs	n/cm^2	800-2100

Loosening coefficient	-	1.25 -1.45
The coefficient of excavation	-	0.6-0.7
Average density (bulk weight)	g/cm^3 (t/m^3)	2.02
Temporary resistance to uniaxial compression	Pa	50x10^5
Bulk mass (true density) of rock salt	g/cm ^{3}	2.02

There are about a dozen springs on the area of the deposit and near its borders. During the research, water samples for hydrochemical analysis were taken from springs numbered 1-6 located directly on the field area (sample numbers correspond to the numbers of the springs). Springs numbered 1-5 correspond to sodium chloride-saturated brines, and spring 6, located in the north of the deposit area, is fresh.

The results of processing hydrochemical analysis of water samples revealed an interesting picture about the possibility of salt extraction directly in natural springs. The flow rate and the degree of salinity of the springs are shown in Table 3.

Table 3. Flow rate and degree of salinity of natural springs

Springs No.	**. .**	**Flow rate of springs, l/min**	**Salt content, %**	**Volumes of withdrawal, l/min**	**Note**
1	2	3	4	5	6
1	1	3.35	31.50	105.33	Southern group of salt springs
2	2	1.55	31.62	49.01	
3	3	0.97	31.45	30.51	
4	4	3.66	31.21	114.23	
Total 9.53					
5	5	11.17	20.93	233.79	Northern salt spring
TOTAL:		**20.7**	**146.71**	**533.07**	
Arithmetic mean:			29.34		Sample TP-2 (weighted average of 5 springs)
Weighted average:			25.75		Sample TP-2 (weighted average of 5 springs)
6	6	98.6	0.25	-	Northern fresh spring

As can be seen from the table, the total flow rate of five springs is 20.7 l/min, if we recalculate the possible production volumes at different time intervals:

Hourly: 20.7:1000 x 60 = 1.242 m3/hour
Daily: 1.242 x 24 = 29.808 m3/day
Monthly: 29.808 x 30 = 894.24 m3/month
Annual: 894.24 x 12 = 10730.88 m3/year

According to the TP-2 technological sample, which is made up of five springs (a combined sample from samples No. 1-5 in equal amounts of 0.5 liters each), the sodium chloride content was 29.34%. The weighted average content of sodium chloride by debit is 25.75%. The salt withdrawal by springs is:

29.808 x 0.2575 = 7.68 tons of salt per day
894.284 x 0.2575 = 230.27 tons of salt per month
10730.88 x 0.2575 = 2763.20 tons of salt per year

Thus, 2,763 tons of salt (in terms of 100% sodium chloride) are leached and withdrawn from the deposit (and irretrievably lost) at the deposit annually by natural springs. In order to make rational use of the reserves of the deposit, it is proposed to start development from

natural springs. Salt evaporation can be carried out using electric boilers or in metal tanks heated with coal. In any case, the cost of production will be low, since there are no costs for the construction of mining workings.

In the process of designing the development, the area of the Chon-Alai rock salt deposit is divided into two sections based on the features of the geological structure and mining conditions. The southwestern part of the field is recognized as site 1 of the next mining, since the overburden capacity is the lowest in this area and there is a test pit. According to the results of our surveys, it was found that the mining and geological conditions and mining technical features of this section of the Chon-Alai deposit are favorable for open-pit mining. We have prepared a mining development plan and a front-end and detailed design for open-pit mining in the south of the western flank to meet the needs of the region for fodder salt (Fig.1).

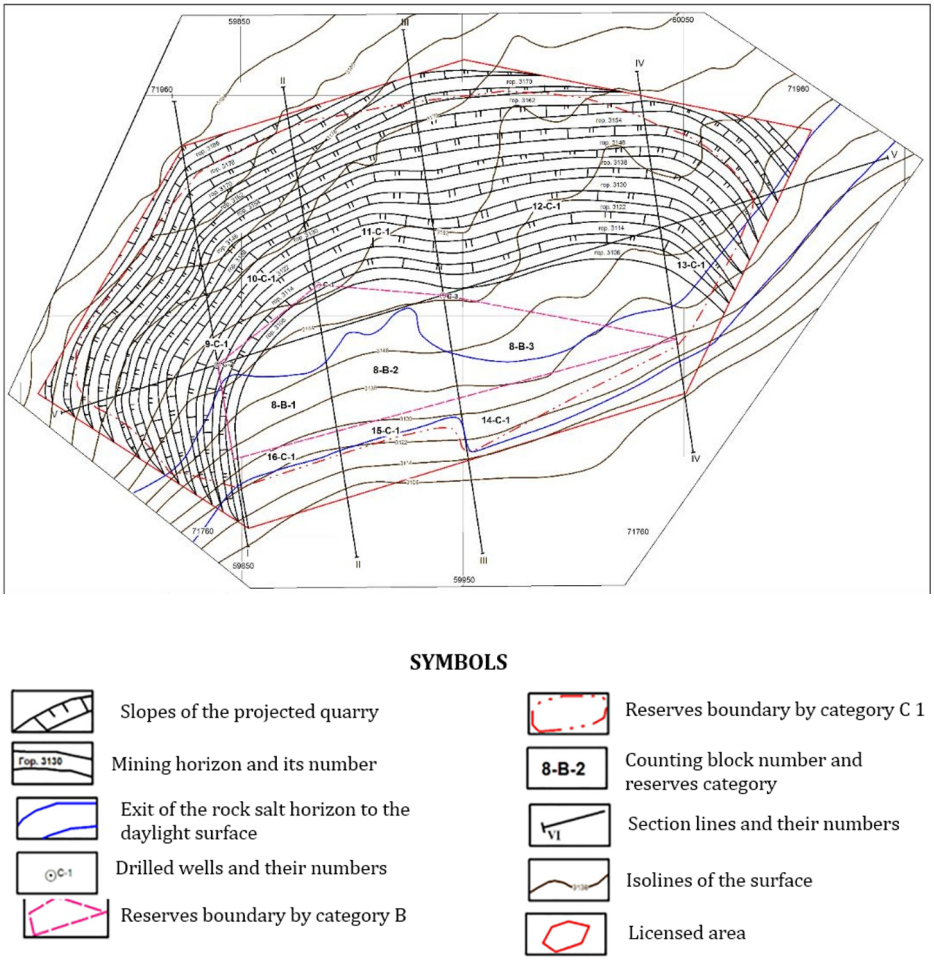

Fig. 1. Mining development plan on the southwestern flank of the Chon-Alai rock salt deposit (scale 1:10000)

The annual productivity of the quarry is 5,000 tons of fodder salt. The subsurface user is Altyn-Dara LLC, which has a license to develop this site. Extraction of fodder salt does not require additional processing costs. Due to difficult mining and geological conditions, the northeastern part of the deposit is subject to 2nd stage mining, in this area the overburden

capacity reaches 70-150 meters, the terrain is quite complex (Fig.2). Based on mining and hydrogeological conditions, we recommend mining rock salt in this area by underground dissolution.

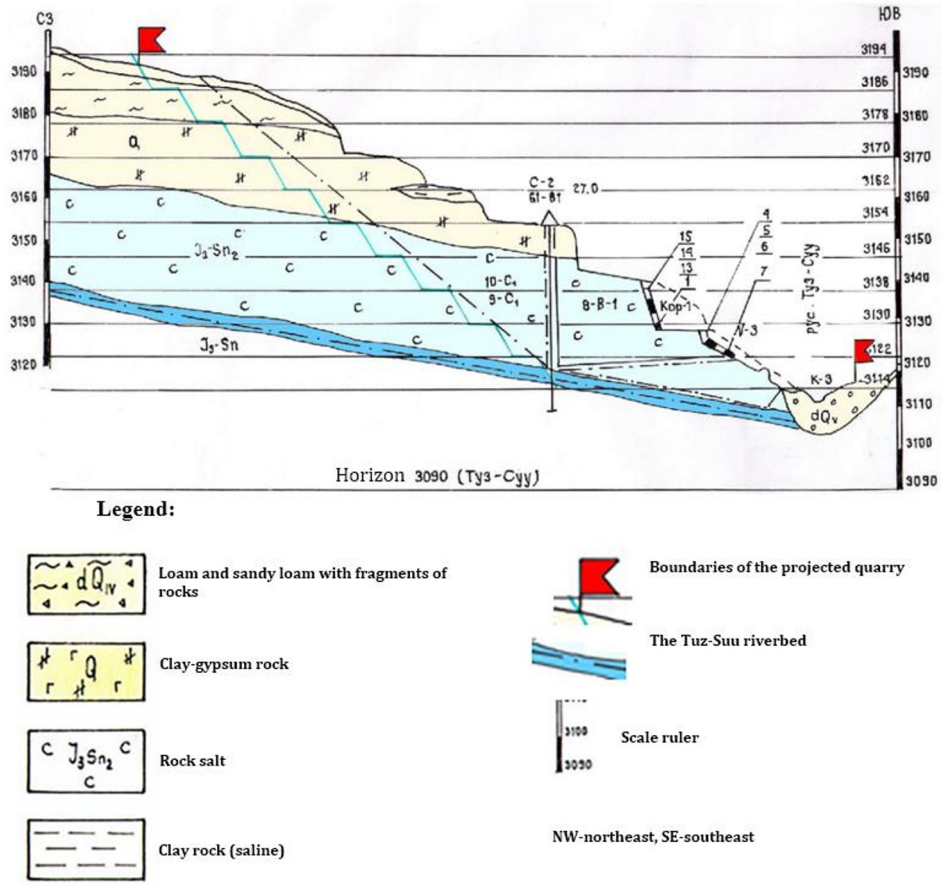

Fig 2. Geological section along the I-I line, characterizing the relief of the deposit (scale 1:1000)

The essence of the proposed method of underground dissolution is as follows: a well is drilled to the roof of a productive salt reservoir and lined with a column of casing pipes with a diameter of 150-250 mm. A pipe of a smaller diameter (75-100 mm) descends into the casing and water is pumped through it at a pressure of 15-25 atm. The water dissolves the salt and, in the form of a saturated brine, is squeezed onto the surface through the annular space between the casing and inner pipes. There is also a reverse, counterflow method, when water is supplied through the casing pipe, and brine is obtained through the inner pipe. Usually, both methods are used alternately in order to evenly wash out the walls of the leaching chamber at the bottom of the well. As the depth of the leaching chamber increases: relative to the lower mark of the casing, the inner pipe is extended to the bottom of the chamber and the process continues. With significant mineral capacities (over 80-100 m), the casing is also increased.

Our calculations have shown that when using water from a fresh spring as a solvent, where the average seasonal flow rate is about 100 liters/minute, it is possible to extract salt in the amount of almost one well of underground leaching:

monthly productivity: 100 x 60 x 24 x 30:1000 x 0.35=1512 tons;

annual productivity: 1512 x 12=18144 tons, expressed as 100% sodium chloride. In the case of parallel use of brine from natural salty sources for this purpose, about 20 thousand tons of salt can be obtained annually, that is, to completely cover the shortage of edible salt in the south of Kyrgyzstan.

4 Discussion

The results obtained show that even a small deposit in terms of reserves can be exploited with economic benefit. The object of research we are considering is located in a remote area and is characterized by difficult mining and geological conditions, which required the search for resource-saving technologies for its development. Based on the comparison of the world experience in the development of such deposits, our proposed combined geotechnological development option can be considered effective and economical for obtaining edible and industrial salt in high-altitude conditions. Extraction from natural springs and underground dissolution of rock salt does not cause damage to the environment, since at the same time there is no need to construct mining facilities and conduct mining preparation and stripping operations. In addition, the insoluble residue, which makes up to 40% of the total mass of the mineral, remains directly in the leaching chamber, automatically removing the issue of waste disposal.

5 Conclusion

In this work, the features of the geological structure, mining and hydrogeological conditions of the Chon-Alai rock salt deposit located in the highlands of the Kyrgyz Republic are studied. The main patterns of the distribution of the salt deposit along the strike and to the depth have been clarified, the content of a useful component (sodium chloride) and harmful impurities in salt bodies has been determined. Technological laboratory tests have established that the salt content in the composition of the productive formation varies from 2.9% to 81.8%, averages 62%, insoluble sediment-34.9%, gypsum-8.2%. The remaining water-soluble salts are contained in small amounts.

According to the results of the conducted research, it was found that the rock salt of the Chon-Alai deposit in its natural form meets the requirements of the republican standard RTU 625-63 (fodder salt for livestock) and can be used as fodder salt for livestock needs without any preliminary processing. Studies have shown that after appropriate chemical cleaning of the feedstock, edible salt can be obtained.

After mechanical cleaning (dissolution, settling and evaporation), the sodium chloride content becomes 96-98% and the resulting salt can be used for technical purposes to produce caustic, calcined and drinking soda, hydrochloric acid, ammonium chloride and other chemicals. It is also suitable for use in textile, leather, pharmaceutical and other industries.

Based on the results of the analysis of mining, geological and mining conditions, it is recommended to develop the Chon-Alai rock salt deposit using a combined geotechnological method in three stages. By the beginning of capital mining operations, the organization of extraction directly in natural springs located on the territory of the deposit and irrevocably withdrawing a certain amount of salt reserves precedes. Processing the brine of these sources on site will make it possible to obtain edible salt of about 2,700 tons per year with a relatively low cost. At the second stage, on the southwestern flank of the deposit, where the overburden capacity is the lowest, it is recommended to build a quarry with an annual productivity of 5,000 tons. Mining operations will be carried out in an open manner, overburden strong rocks are allowed to be destroyed by drilling and blasting. As a result of the development of this site, the southern region of the Kyrgyz Republic will be fully supplied with fodder salt for

the needs of animal husbandry. The northeastern section of the deposit is characterized by a very difficult mountainous terrain, the depth of mining, taking into account the capacity of overburden rocks and the capacity of the mineral reaches 200-250 meters. In this regard, it is recommended to work out the geotechnological method, the essence of which is that wells are drilled through the deposit and fresh water is pumped, which dissolves rock salt in underground conditions. The dissolved salt is withdrawn through the walls of the well by backwashing through the tubular annulus.

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