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Satbayev University

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ИЗВЕСТИЯ

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Satbayev University

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RESEARCH ON THE QUALITY OF NATURAL WATER OF ZHONGAR-ALATAU AND ALTYNEMEL NATIONAL NATURAL PARKS OF THE ALMATY REGION, REPUBLIC OF KAZAKHSTAN

Abstract. The relevance of this research is connected with strengthening of anthropogenic and technogenic impact of pollutants on the biosphere in the Republic of Kazakhstan and in the world. The greatest influence of ecotoxicity is experienced by the water environment, being the final reservoir of the most pollutants. Over the past 25-30 years, the structure of water use has changed, which is expressed in a sharp increase in the social component of water use. The share of household and drinking water supply increased from 11% in 1980 up to 28% in 2018. In this connection, there is a real problem of drinking water quality, which is determined by contamination of natural water, unsatisfactory water treatment at water supply stations, secondary pollution in spreading networks. The article presents the results of physico-chemical indicators of the quality of natural water and experimental studies in Zhongar-Alatau and Altynemel National Natural Parks. Quality control of natural water was carried out by the basic laboratory of the Testing Center of Taldykorgan branch of Joint Stock Company "National Center of Expertise and Certification". The laboratory was certified by the State Standard of the Republic of Kazakhstan for the right to carry out analyses of water sources and drinking water in all respects according to state standards. Experimental conditions: air temperature - 20ºC, relative humidity - 71%.

Key words: comparative analysis, monitoring, groundwater, water quality, national parks.

Introduction. The geological-structural and climatic conditions of the territory of Zhongar-Alatau National Natural Park (hereinafter, NNP) promote formation and spread fissure and fissure-veined type underground water in Palaeozoic strata sediments, pore and pore-layers type in Meso-Cenozoic sediments. Waters are joined with various aquifers and complexes.

The water-bearing complex of Paleozoic effusive-sedimentary deposits is associated with effusive rocks, tuffs, conglomerates, less often with sandstones and limestones.

Good exposure and fissure of rocks with a significant amount of precipitation, presence of snowfields and glaciers favor formation of fresh groundwater. The capacity of the most flooded fissure zone is 100-150 m, underground water depth is up to 5 m in the valleys of thalwegs, up to 100 m on the slopes and watersheds. Fissured water obtains the main nourishment in the spring from melting snow and during autumn-summer rains.

Water-inflow feature of Paleozoic rocks naturally increases from the root of mountains to its peaks and from higher mountain massifs to low mountain spurs. Discharge of the most wellsprings in effusive and metamorphic rocks varies from 0.5 to 2 l/s, in granites, conglomerates, sandstones it is 2-3 l/s. Areas of tectonic disturbances are especially watery, where the discharge of wellsprings reaches 5-10 l/s.

The water-bearing complex of Pre-Paleozoic and Paleozoic metamorphosed rocks is connected with fissured gneisses, shales, sandstones, siltstones, conglomerates and it is developed in upstreams of the Aksu, Lepsi rivers.

The depth is 50-60 m, water-inflow is different and depends on nourishment conditions, location, lithological composition and fissuring degree.

Wellsprings joined to the fissured zone have a discharge from 0.5 to 10 l/s. Water is fresh, mainly contains bicarbonate calcium.

A groundwater regime is closely related to climatic factors. In the late spring and summer, due to intensive snow melting, the discharges of wellsprings increase and reach a maximum value, whereas in winter they decrease reaching a minimum value.

Intermountain areas, located among the mountain ranges, are characterized by a great variety of shapes, sizes, altitude position, geological structure, and conditions of underground run-off. The capacity of sediments in basins varies from ten to several hundred meters. Their geological structure is different. Large basins are made of Neogene-Quaternary sediments, smaller ones (Pokatilovskaya, Kolpakovskaya basins) only of Quaternary sediments.

The groundwater depth in Quaternary sediments predominantly of gravel and pebble composition varies from 80 m near the mountains up to 1-2 m in the valleys of the basal rivers. The direction of groundwater flow, as a rule, coincides with the slope of the surface and goes out from the outskirts to the centres of basins, in river valleys along their stream flow.

The aquifer of the Upper Quaternary-Modern alluvial sediments widespreads in the valleys of the Baskan, Lepsi, Tentek rivers, it is joined to the sediments of flood plains and first above-floodplain terraces. The lithological composition of the water-bearing strata is various, ranges from boulder and pebble in the upstream of rivers, to sandy, sandy-loamy and loamy in the lower reaches.

The underground water lays at a depth of 0.8-8.0 m. Mineralization varies from 0.1 to 1.4 g/l, composition is calcium carbonate and magnesium, and transferring to plains the composition changes to sulphate-hydrocarbonate calcium-sodium.

In the river valleys, underground water is closely connected with surface water. They feed on river water, atmospheric precipitation and, to a lesser extent, flowing from the mountains. Water-inflow of rocks is high, specific discharges of boreholes at least 1-2 l/s, wellsprings discharges - 2-3 l/s. Water is predominantly fresh hydrocarbonate calcium and calcium-sodium, sometimes magnesium. Regime is unstable. Fluctuations of underground water level are closely related to changes in water discharge in rivers and depend on precipitation. Maximum discharges of wellsprings are observed in spring, Minimum - in January and February.

Depending on the nourishment conditions in different landscapes and climatic zones, a composition and mineralization of underground water changes. In general, fresh water is predominant in the territory of the Zhongar-Alatau NNP, among which are ultra-fresh, slightly mineralized and relatively high mineralized.

Ultra-fresh water (with mineralization up to 0.1 g/l) is common in the fissured Paleozoic sedimentary and igneous rocks of the nival and partly meadow belts.

Composition of water is calcium bicarbonate, less often the chloride-hydrocarbonate, sulphate-hydrocarbonate sodium-calcium. With the decrease in the altitude, mineralization increases, the composition becomes predominantly hydrocarbonate, chloride-hydrocarbonate sodium or magnesium-calcium.

Weakly-mineralized (with mineralization of 0.2-0.5 g/l) fresh water is formed in meadow-forest, forest-steppe and partly steppe landscapes, mainly in the midlands. The water is joined to fissured Paleozoic rocks which expose on peaks and slopes of mountain massifs, as well as to loose sediments that form intermontane basins. The composition of water is calcium bicarbonate with a small amount of sulphates and chlorides.

Fresh underground water with mineralization from 0.5 g/l to 1 g/l is formed within the lower part of the middle altitude, in the steppe belt.

The composition of water is calcium bicarbonate, often sulphate-hydrocarbonate sodium-calcium and hydrocarbonate-sulphate calcium-sodium.

In the low mountain area, brackish water with different degrees of mineralization (from 1g/l to 5 g/l) prevails in certain areas.

Review of scientific literature. In the territory of Zhongar-Alatau NNP underground water with mineralization of 3-5 g/l is joined to saline Neogene sediments. Brackish water both pore and fissured, have a hydrocarbonate-sulfate calcium-sodium or calcium-magnesium-sodium composition [1].

According to the Research Contract of February 4, 2018, under the budget program 055 "Scientific and (or) scientific and technical activities, sub-program 101" on the theme "Comparative analysis and monitoring of air pollution, soil, water in anthropogenically disturbed buffer zone in a protected regime of Zhongar-Alatau, Altynemel National Natural Parks" in these specially protected natural areas, experimental studies were carried out to determine the quality of natural water.

The purpose of the research was to determine the quality and level of pollution of water in Zhongar-Alatau and Altynemel NNP.

The following tasks were solved as a part of researches:

- defining physicochemical indicators of the quality of natural water;
- analysis the pollution level of studied water.

Quality control of natural water was carried out by the basic laboratory of the Testing Center of Taldykorgan branch of Joint Stock Company "National Center of Expertise and Certification". The laboratory was certified by the State Standard of the Republic of Kazakhstan for the right to carry out analyzes of water sources and drinking water in all respects according to state standards [2-6]. Experimental conditions: air temperature - 20ºC, relative humidity - 71%.

Discussion. In Zhongar-Alatau NNP, the researches to define water quality were carried out on April 11, 2018.

Water samples were taken from the rivers Sarkan and Lepsi. The results of the researches are presented in table 1.

According to the results of the research, natural water meets the regulatory requirements of GOST according to the above quality indicators.

The territory of Altynemel National Natural Park (hereinafter, NNP) is a part of Ili semi-desert zone on of Ili-Balkhash-Alakol desert basin. According to hydrogeological zoning in the studied region, the basins of the underground water of the Altyn-Emel, Koyandytau ranges in the north and the Katutau, Atyzhek, Koktas ranges in the east and in the south are allocated, between which there is a small intermontain Basshiy-Konurolen underground water basin opened to the south towards Kopa-Ili artesian basin of the first order.

The south-eastern part of the territory to the south of Katutau mountains is the northern side of the Zharkent artesian basin of the second order [7].

Underground water is non-artesian, in some places sub-artesian. The greatest underground water lay depth (65-100 m) is typical for the nourishment zone in the foothills. In the central part of the basin the water level approaches the surface, the underground water of the water complex is unloaded in the form of wellsprings.

Table 1 – Results of experiments of defining water quality in Zhongar-Alatau NNP

№	Item	Standard indicator	Sarkan river	Lepsi river
1	Hardness, mmol/dm^3	no more than 7	2,1	4,1
2	Alkalinity, mmol/dm^3	0,5-6,5	2,3	3,6
3	Calcium, mg/dm^3	25-130	17	23
4	Magnesium, mg/dm^3	5-65	2,4	10,8
5	Hydrogen index, units, pH	6-9	7,71	7,87
6	Total mineralization (dry residue), mg/dm^3	no more than 1000	100	150
7	Permanganate oxydizability, mg/dm^3	no more than 5	1,26	1,72
8	Iron (total), mg/dm^3	no more than 0,3	not detected	0,3
9	Sulfates, mg/dm^3	no more than 500	40,31	40,1
10	Chlorides, mg/dm^3	no more than 350	44,3	49
11	Hydrocarbonates, mg/dm^3	30-400	140,3	219,6

The water-inflow of the complexes is high. Discharges of wells vary from 30 to 107.1 l/s, with decreases of 0.6-1.5 m, respectively. The average wells discharge is 60 l/s. The specific discharge rates in the Konurolen block are 1.23-5.14 l/s·m, on the average 4.0-5.0 l/s·m. In the transitional zone between blocks, the specific discharge rates are reduced to 0.2-1.0 l/s·m. In the Basshi block the specific discharge rates of wells are 0.1-7.14 l/s·m.

In Altynemel NNP, the researches were carried out to define the quality of underground water on April 29, 2018. Water samples were taken at Mynbulak cordon and in Basshi village, where Altynemel NPP's office is located

Results, shown in table 2, were obtained during the tests.

Table 2 – Results of the researches on defining water quality in Altynemel NNP

№	Item	Standard indicator	Mynbulak cordom	Basshi village
1	Hardness, mmol/dm^3	7 at most	2,4	2,3
2	Alkalinity, mmol/dm^3	0,5-6,5	2,1	1,9
3	Calcium, mg/dm^3	25-130	18	18
4	Magnesium, mg/dm^3	5-65	3,6	3
5	Hydrogen index, units, pH	6-9	7	7
6	Total mineralization (dry residue), mg/dm^3	no more than 1000	200	120
7	Permanganate oxydizability, mg/dm^3	no more than 5	0,64	0,48
8	Iron (total), mg/dm^3	no more than 0,3	0,05	0,3
9	Sulfates, mg/dm^3	no more than 500	49,1	17,9
10	Chlorides, mg/dm^3	no more than 350	24,5	21
11	Hydrocarbonates, mg/dm^3	30-400	126	102

Conclusion. According to the data of Table 2, the following conclusion can be drawn: according to the basic physicochemical indicators of quality, natural water meets the requirements of COST.

Thus, in Zhongar-Alatau and Altynemel National Nature Parks in April 2018, the researches were carried out to determine the quality of natural water, laboratory tests confirmed compliance with the normative requirements for the natural water quality of the Sarkan and Lepsi rivers, water at Mynbulak cordon and in Basshi village.

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ҚАЗАҚСТАН РЕСПУБЛИКАСЫ АЛМАТЫ ОБЛЫСЫНДАҒЫ ЖОҢҒАР-АЛАТАУ ЖӘНЕ АЛТЫНЕМЕЛ ҰЛТТЫҚ ТАБИҒИ ПАРКТЕРІНДЕГІ СУ КӨЗДЕРІНІҢ КҮЙІН ЗЕРТТЕУ

Аннотация. Зерттеудің өзектілігі Қазақстан Республикасы мен дүниежүзінде антропогендік және техногендік ластайтын заттардың биосфераға тигізетін әсерінің күшеюіне байланысты. Көптеген ластаушы заттардың соңғы нәтижесі болып саналатын экотоксикологиялық әсерге сулы орта біршама көп ұшырайды. Соңғы 25-30 жылда суды пайдалану құрылымы біршама өзгеріске ұшырағандықтан, оның әлеуметтік құрамдас бөлігі жедел дамыды. Шаруашылық және ауызсумен қамтамасыз етудің үлесі 1980 жылғы 11%-дан 2018 жылы 28%-ға дейін артты. Табиғи судың ластануына байланысты су құбыры бекеттерінде тазалаудың қазіргі талаптарды қанағаттандырмауына, бөлу тораптарында екінші рет ластануына байланысты ауызсудың сапасы шынайы өзекті мәселеге айналуда. Мақалада Жоңғар-Алатау және Алтынемел ұлттық табиғи парктеріндегі табиғи су сапасының физика-химиялық көрсеткіштерінің нәтижелері және тәжірибелі-эксперименталды зерттеулер берілген. Судың сапасын бақылау «Ұлттық экспертиза және сертификация орталық» акционерлік қоғамының базалық зерттеу зертханасында жасалды. Зертхана мемлекеттік стандарттарға сәйкес барлық көрсеткіштер бойынша су көзінің талдамасын алуға құқығы бар Қазақстан Республикасының мемлекеттік аттестатау комиссиясы сертификаттаған. Зерттеу жүргізу шарттары: температура 20˚С, салыстырмалы ылғалдылық 71 %.

«Жоңғар-Алатау» ұлттық табиғи паркі (бұдан әрі – ҰТП) аумағының геологиялық-құрылымдық және климаттық жағдайлары мезо-кайнозой шөгінділерінде палеозой қабаттары, поролық және поролық-қабаттық шөгінділерде жерасты суларының жарық және жарық-прожилкалық түрінің қалыптасуына және таралуына ықпал етеді. Су түрлі сулы деңгей және кешендермен қосылады.

Палеозойды эффузивті-шөгінді шөгінділердің сулы кешені эффузивті жыныс, туф, конгломерат, сирек құм және әктастармен байланысты.

Жақсы экспозиция және көп мөлшерде жауын-шашын түсетін тау жыныстарының жарылуы, қар алқаптары мен мұздықтардың болуы жерасты тұщы суының пайда болуына қолайлы. Жарықшақтардың су басқан аймағының қуаты 100-150 м, жерасты суларының тереңдігі – тальвег алқаптарында 5 м, беткей мен су бөліністерінде 100 м дейінгі мөлшерді құрайды. Жарылған су көктемде қардың еруінен және күзгі-жазғы жаңбыр кезінде негізгі тамақты алады.

Палеозой жыныстарының сулы-ағындық сипаттамасы тау түбінен шыңына және биік тау массивтерінен төмен тау сілемдеріне дейін заңды түрде ұлғаяды. Эффузивті және метаморфикалық жыныстардағы бұлақтардың көпшілігінің шығыны 0,5-тен 2 л/с, гранит, конгломерат, құмтастарда 2-3 л/с құрайды.

Палеозой және палеозой метаморфизденген жыныстардың сулы кешені жарылған гнейстер, тақтатас, құмтас, алевролит және конгломераттарға байланысты және Ақсу, Лепсі өзендерінің жоғарғы жағында дамиды.

Жатып қалу тереңдігі 50-60 м құрайды, су ағыны түрлі тамақтану, орналасу жағдайына, литологиялық құрамына және жарылу дәрежесіне байланысты. Жарылған аймаққа жанасатын ұңғымалар 0,5-тен 10 л/с-ға дейін шығынға әкеледі.

Жерасты суларының режимі климаттық факторларға тығыз байланысты. Көктем соңында және жазда қар жылдам еритіндіктен ұңғыма көздерінің төгілісі ұлғаяды және ең жоғарғы мәнге, ал қыста азайып, ең төменгі мәнге жетеді.

Тау жоталарының арасында орналасқан тауаралық аудандар нысан, өлшем, биікте орналасуы, геологиялық құрылымы мен жерасты ағын жағдайларының алуан түрлілігі арқылы сипатталады. Бассейндердегі шөгінділердің қуаты оннан бірнеше жүз метрге дейін ауытқиды. Олардың геологиялық құрылымы әртүрлі. Ірі бассейндер неоген-төрттік шөгінділерден, ал ұсақтауы (Покатиловка, Колпаковка шұңқырлары) тек төрттік шөгінділерден тұрады.

Жерасты суларының төрттік шөгіндіде орналасу тереңдігі негізінен гравиялық-галалық құрамның тауға жақын 80 м-ден базалды өзендер алқабында 1-2 м-ге дейін ауытқиды. Жерасты сулар ағынының бағыты, әдетте, үстіңгі қабаттың еңістігімен сәйкес келеді және шетінен бассейндердің орталықтарына, олардың арналық ағысы бойындағы өзен алқаптарына шығады.

Түйін сөздер: салыстырмалы талдау, мониторинг, жерасты сулары, су сапасы, ұлттық парктер.

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ИЗУЧЕНИЕ СОСТОЯНИЯ ВОДОИСТОЧНИКОВ ЖОНГАР-АЛАТАУСКОГО И АЛТЫНЕМЕЛЬСКОГО НАЦИОНАЛЬНЫХ ПРИРОДНЫХ ПАРКОВ АЛМАТИНСКОЙ ОБЛАСТИ РЕСПУБЛИКИ КАЗАХСТАН

Аннотация. Актуальность настоящего исследования связана с усилением антропогенного и техногенного влияния загрязняющих веществ на биосферу в Республике Казахстана и в мире. Наибольшее влияние экотоксичности испытывает водная среда, являясь конечным резервуаром большинства загрязняющих веществ. За последние 25-30 лет изменилась структура использования воды, что выразилось в резком увеличении социальной составляющей водопользования. Доля хозяйственно-питьевого водоснабжения выросла с 11% в 1980 г. до 28% в 2018 г. В связи с этим реально существует проблема качества питьевой воды, определяемая загрязнением природной воды, неудовлетворительной очисткой ее на водопроводных станциях, вторичным загрязнением в разводящих сетях. В статье даны результаты физико-химических показателей качества природной воды и опытно-экспериментальные исследования в Жонгар-Алатауском и Алтынемельском национальных природных парках. Контроль качества воды осуществлялся базовой лабораторией испытательного центра акционерного общества «Национальный центр экспертизы и сертификации». Лаборатория аттестована государственной комиссией Республики Казахстан на право проведения анализов воды источников по всем показателям согласно государственным стандартам. Условия проведения испытаний: температура 20˚С, относительная влажность 71 %.

Геолого-структурные и климатические условия территории национального природного парка "Жонгар-Алатау" (далее-НПП) способствуют формированию и распространению трещинного и трещинно-прожилкового типа подземных вод в отложениях палеозойских толщ, порового и порово-слоевого типа в мезо-кайнозойских отложениях. Воды соединяются с различными водоносными горизонтами и комплексами.

Водоносный комплекс палеозойских эффузивно-осадочных отложений связан с эффузивными породами, туфами, конгломератами, реже с песчаниками и известняками.

Хорошая экспозиция и трещиноватость горных пород со значительным количеством осадков, наличие снежных полей и ледников благоприятствуют образованию пресных подземных вод. Мощность наиболее затопленной зоны трещин составляет 100-150 м, глубина подземных вод - до 5 м в долинах тальвегов, до 100 м на склонах и водоразделах. Трещиноватая вода получает основное питание весной от таяния снега и во время осенне-летних дождей.

Водно-приточная характеристика палеозойских пород закономерно возрастает от корня горы к ее вершинам и от более высоких горных массивов к низким горным отрогам. Расход большинства родников в эффузивных и метаморфических породах колеблется от 0,5 до 2 л/С, в гранитах, конгломератах, песчаниках он составляет 2-3 л/с. участки тектонических нарушений особенно обводнены, где расход родников достигает 5-10 л / с.

Водоносный комплекс допалеозойских и палеозойских метаморфизованных пород связан с трещиноватыми гнейсами, сланцами, песчаниками, алевролитами, конгломератами и развивается в верховьях рек Аксу, Лепси.

Глубина залегания составляет 50-60 м, приток воды разный и зависит от условий питания, расположения, литологического состава и степени трещиноватости.

Скважины, примыкающие к трещиноватой зоне, имеют расход от 0,5 до 10 л/с. вода пресная, в основном содержит бикарбонат кальция.

Режим подземных вод тесно связан с климатическими факторами. В конце весны и летом из-за интенсивного таяния снега сбросы скважинных источников увеличиваются и достигают максимального значения, тогда как зимой они уменьшаются, достигая минимального значения.

Межгорные районы, расположенные среди горных хребтов, характеризуются большим разнообразием форм, размеров, высотного положения, геологического строения и условий подземного стока. Мощность отложений в бассейнах колеблется от десяти до нескольких сотен метров. Их геологическое строение отличается. Крупные бассейны состоят из неоген-четвертичных отложений, более мелкие (Покатиловская, Колпаковская котловины) – только из четвертичных отложений.

Глубина залегания грунтовых вод в четвертичных отложениях преимущественно гравийно-галечного состава колеблется от 80 м вблизи гор до 1-2 м в долинах базальных рек. Направление стока грунтовых вод, как правило, совпадает с уклоном поверхности и выходит от окраин к центрам бассейнов, в речные долины вдоль их руслового течения.

Ключевые слова: сравнительный анализ, мониторинг, подземные воды, качество воды, национальные парки.

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DOUBLE-CHAMBER ROTARY TYPE DOWNHOLE HYDRAULIC MOTOR FOR DRILLING MULTIBRANCH WELLS

Abstract. Importance of wells drilling method in subsoil use is stated. In general, reliable geological material can be obtained by the method of multibranch wells construction. By technological capabilities, the most effective means -downhole hydraulic motors performing wells drilling without drill string rotation. According to analysis of information sources containing data about downhole motors in the world, among all of them (propeller, turbodrills, rotors), the corresponding to conditions of drilling wells with offshoots are rotor type hydraulic motors, small-size longwise, fitting into the curvature of deviation from the parent well.

Based on the new physical principle, structural layout of double-chamber rotary type downhole hydraulic motor was formed with multilayer reactive force moment that became the subject of research. Methodology of calculating hydraulic motor output parameters was developed, technical characteristics were identified: length –0.80 m, weight – 40 kg with housing diameter 88 mm.

Prototype model was manufactured, test was performed to check reproducibility of calculations and test data. By output parameters and technical characteristics, the prototype model has significant advantage over abroad analogue.

Introduction of hydraulic motor into the execution of drilling operations, scope of application of wells drilling is extended, cost of minerals prospecting and mining is reduced.

Key words: geology, prospecting, drilling, well, multi-hole, hydraulic motor, layout, parameters, characteristics.

In today's subsoil use, detection of mineable mineral depositsis possible at depths only, which raises exclusive standards to methods and means of geological exploration works execution.

The main method of geologic exploration – wells drilling identifying the accuracy of study objectsevaluation, selection of optimum schemes of subsequent development and cost of works.

In the paper [1] it was noted that the solution of task of drilling process optimization is complicated by uncertainty of decision-making situation expressed in multivectorness, multicriteriality, inaccuracy and many-valuedness. In the opinion of authors, to resolve such problems, it is necessary to use respective methods that are based on the results of geological-technical studies. The most remarkable of them is the method of obtaining generally reliable geological information by construction of multibranch wells with drilling of offshoots along the strike of productive strata.

In the area of hydrocarbons, opening of productive series by horizontal offshoots increases the filtering area and flow rate as compared to vertical by 2-4 times more at oil and 3-8 times at gas fields [2].

Comparatively safe and less costly means of drilling offshoots– downhole hydraulic motors fitting into the curvature of deviation from the parent well and performing the drilling process without drill string rotation. Experiments proved by practice showed that capacity losses for blank drill string rotation amount to 65-85% of the total power spent for drilling [3].

Known are hydraulic turbine downhole motors manufactured by Neyrfor (Schlumberger) and TurboPower (Halliburton): their turbodrills 10-15 m long comprise one or two turbine sections [4].

Also abroad the use was made of the driven rotor configurations and specifically designed PDC drill bits manufactured by BakerHughes, Halliburton and Schlumberger, which allow successful drilling of deviant directional and horizontal offshoots. Their disadvantage include the structural complexity and high cost of maintenance, and their price is comparable to rocket-and-space equipment [5].

Interesting technical solution was reflected in a patent of UK "Downhole hydro turbine motor with regulated bend angle" [6]. Its advantage is in the creation of favorable downhole conditions for offshoot kickoff and displacement from parent hole.

US patents [7-10] give schematic diagrams of downhole hydraulic motor components force interaction ensuring life prolongation and reliability of their work while drilling directional wells, especially turbo drills with improved performance characteristics.

Designers of Neftegazotekhnika research and development enterprise (Russia) managed to reduce the turbodrill length for drilling wells with drill bits with diameter of 215.9 mm from 25.7m to 8.8m, which allowed improvement of well and offshoots walls formation conditions [11].

Practice of downhole hydraulic motors operation in drilling of wells around the world [12-17] shows that main ideas for improvement of their design (propeller, turbodrills and rotor type) are aimed at the simplification of structure, extending of elements' functions, ensuring high accuracy of their interaction.

Analysis of known schemes and conditions of various types downhole hydraulic motors usability allowing making a conclusion that by design and technological capabilities, the most suitable for the construction of multibranch wells are hydraulic motors of rotor type, small-size longwise, low-consuming operating fluid.

However, the paper [18] notes that the main disadvantage of rotor type machines – vibration arising due to rotor rotation.

Based on analysis results and with account of the possibility of vibration occurring, on the basis of a new physical principle, design of double-chamber rotor hydraulic motor with multilayer reactive force moment [19,20] was formed. Hydraulic motor comprises internal nonrotating rotor 1 which is interacted with a power unit through bearing boxes, such power unit comprising upper (figure 1) and lower (figure 2) parts, disconnectably-rigidly connected with each other. The upper part of the power unit represents a housing 2, inside of which and with formation of external chamber a shaft 3 is hard-mounted set with hemispheric blades 4 and side ports 5 for feeding operating fluid to internal chamber. In the housing body 2, channels 6 are made for jet exhaust of operating fluid to hole annuity.

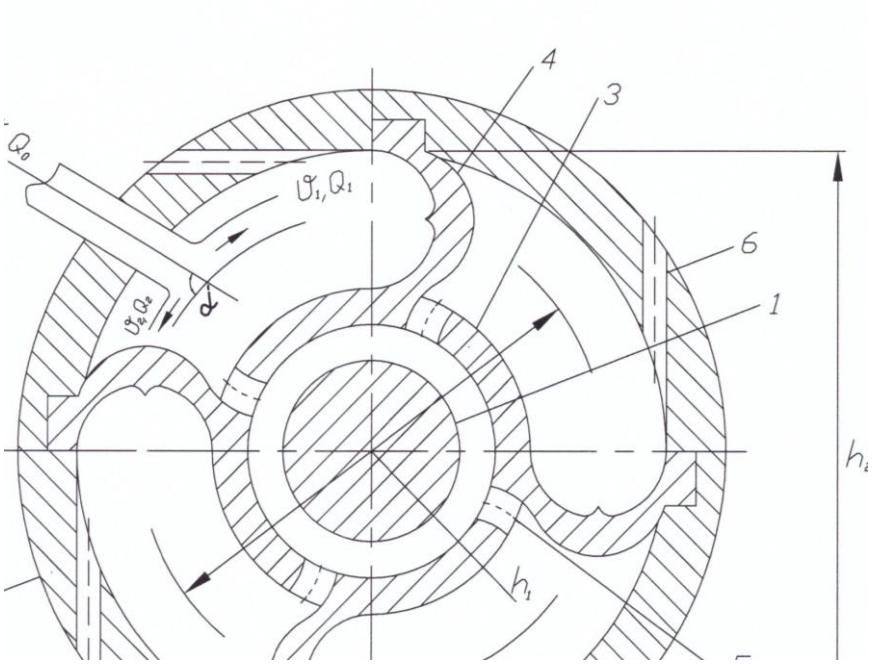

Figure 1 – Power unit upper part

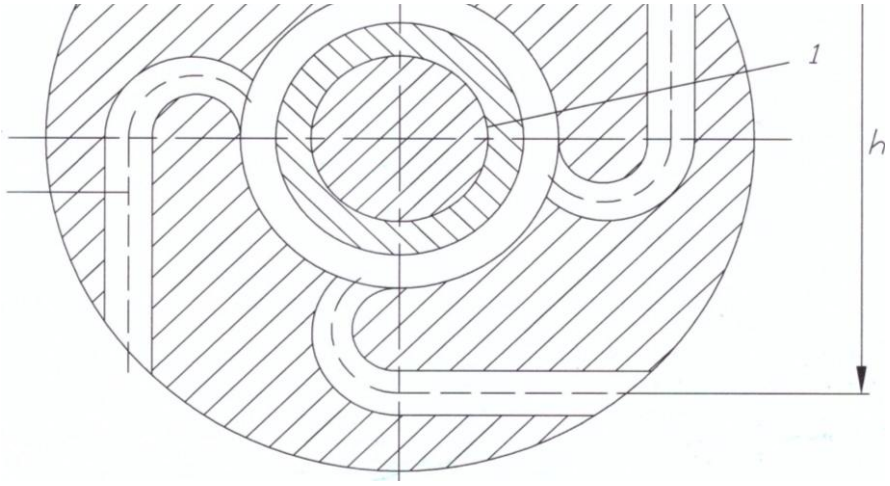

Figure 2 – Power unit lower part

On housing 7 of the power unit lower part, made are horizontal grooves8 departing from the internal chamber and with the turn entering to hole annuity oppositely to corotation of housings 2 and 7.

Principle of operation and calculation of double-chamber downhole rotor type hydraulic motor output parameters. Motor housing with diameter of 88 mm was chosen as an example.

When feeding along inclined channels at an angle αto horizontal,operating fluid downstream falls on the bottom of the external chamber along the direction of housing rotation 2. The apprise flow has a flow of Q_0, velocity ϑ_0, and the flows diverging in opposite directions Q_1, ϑ_1 and Q_2, ϑ_2. to find excess pressure equivalent force Rlet's write down Euler theorem [21] in force projections on coordinate axes OXand OУ:

$$\begin{cases} P_0 * cos \propto = P_1 - P_2 \\ P_0 * sin \propto + R = 0 \end{cases} \quad (1)$$

where $P_0 = \rho * Q_0 * \vartheta_0$; $P_1 = \rho * Q_1 * \vartheta_1$; $P_2 = \rho * Q_2 * \vartheta_2'$

With account to P_0, P_1, P_2 and having assumed that flow velocity does not change, that is $\vartheta_0 = \vartheta_1 = \vartheta_2$:

$$\begin{cases} \rho * Q_0 * \vartheta_0 * cos \propto = \rho * Q_1 * \vartheta_1 - \rho * Q_2 * \vartheta_2 \\ \rho * Q_0 * \vartheta_0 * \sin \propto + R = 0 \end{cases} = \begin{cases} Q_0 * \cos \propto = Q_1 - Q_2 \\ R = -\rho * Q_0 * \vartheta_0 * \sin \propto' \end{cases} \quad (2)$$

where R – reaction of external chamber bottom, oppositely directed, but in value equal to $-P_0$;

It is known that $Q_0 = Q_1 + Q_2$. Let's make and solve system of equations with twounknowns:

$$\begin{cases} Q_0 = Q_1 + Q_2 \\ Q_0 * \cos \propto = Q_1 - Q_2 \end{cases} = \begin{cases} Q_1 = \frac{Q_0}{2} * (1 + \cos \propto) \\ Q_2 = \frac{Q_0}{2} * (1 - \cos \propto) \end{cases} \quad (3)$$

Oncoming fluid flow velocity depending on height Hof fluid feed can be written as follows:

$$\vartheta_0 = \sqrt{2 * q * H} \quad (4)$$

Force of flow impact on the external chamber bottom shall be as follows:

$$P_0 = \rho * Q_0 * \sin \propto \quad (5)$$

Depending on value of angle $\propto$, the major part of flow Q_1impacts a blade with bent surface, symmetrical with relation to line center of the external chamber in a circumferential direction. Form of blades execution in the form of hemisphere condition the turn of operating fluid flow by angle 180℃, thus, doubled dynamic impact can be obtained [22].

$$P_1 = 2 * \rho * Q_1 * \vartheta_1 \quad (6)$$

When the operating fluid flow impacts on a series of alternating hemispheric blades, oncoming fluid flow rate will be

$$\vartheta_1 = \vartheta_0 - \vartheta_л\,, \tag{7}$$

where $\vartheta_л = \frac{\pi * D * n}{1000 * 60}$ – blade speed (D = housing diameter, n – housing rotation frequency, deduced from experiments – 800 *r*/*min*).

With account to (3) and (7), expression (6) will be as follows:

$$P_1 = 2 * \rho * \frac{Q_0}{2} * (1 + \cos \propto) * (\vartheta_0 - \vartheta_л) \tag{8}$$

Moment of force of operating fluid flow impact on the external chamber bottom, subsequently converted into rotation torque:

$$M_0 = P_0 * h_1, \tag{9}$$

where h1 – distance between external chamber median lines in circum ferential direction.

Rotating blade torque:

$$M_1 = P_1 * h_1, \tag{10}$$

Moment of operating fluid jet exhaust through channels 6 in the upper part of the power unit:

$$M_2 = P_1/2 * h_2, \tag{11}$$

where h_2 - distance between opposite channels of the power unit upper part.

The remaining part of the flow enters the internal chamber through side ports 5:

$$P_2 = \rho * Q_2 * \vartheta_2 \text{or } P_2 = \rho * \frac{Q_0}{2} * (1 - \cos \propto) * \vartheta_0 \tag{12}$$

Moment of operating fluid jet exhaust through grooves 8 of the power unit lower part:

$$M_3 = P_2 * h_3 \tag{13}$$

where $h_3 -$ distance between opposite grooves.

Cumulative torque of the housing with account of the number of sections of external and internal chamber and channels of the lower power unit:

$$\sum M = (M_0 + M_1 + M_2 + M_3) * 4 \tag{14}$$

Baseline data for recalculation:

Inclination angle of operating fluid feeding channels, α = *45*^{o}

Operating fluid density (water), ρ [kg/m^3] *1000*

Acceleration of gravity, g [m^2/s] *9,8*

Operating fluid flow rate, [m/s]

with H=100 m *44,27*

with H=300 m *76,68*

with H=500 m *99*

Length force lever, m

h_1 *0,057*

h_2 *0,07*

h_3 *0,064*

Results of calculating values of double-chamber downhole rotary type hydraulic motor output parameters are summarized in table 1.

Table 1 – Values of downhole hydraulic motor output parameters

Output parameters	*H=100m*			*H=300m*			*H=500m*		
	Q_0, l/min			Q_0, l/min			Q_0, l/min		
	40	*60*	*80*	*40*	*60*	*80*	*40*	*60*	*80*
P_0, *H*	19.13	28.70	38.26	34.41	51.61	68.81	44.92	67.38	89.85
P_1	46.19	69.28	92.38	83.07	124.61	166.14	108.46	162.70	216.93
P_2	7.93	11.89	15.86	14.26	21.39	28.52	18.62	27.93	37.23
M_0, *H*m*	1.10	1.65	2.20	1.98	2.97	3.96	2.58	3.87	5.17
M_1	2.66	3.98	5.31	4.78	7.16	9.55	6.24	9.35	12.47
M_2	1.62	2.42	3.23	2.91	4.36	5.81	3.80	5.69	7.59
M_3	0.51	0.76	1.01	0.91	1.37	1.83	1.19	1.79	2.38
ΣM	23.56	35.24	47.0	42.32	63.42	84.60	55.24	82.40	110.44

With the purpose of checking the results of output parameters calculations, a prototype model of double-chamber hydraulic motor was tested on testing drilling bench equipped with twin circulation pump NB 320/63, flow meter PROMASS 40, tachometer IT-371 and pressure gauge MP-2. Obtained was satisfactory reproducibility of calculations and test data.

Table 2 below gives comparative characteristics of the prototype model of double-chamber hydraulic motor with series-produced propeller hydraulic motors Dyna-Drill of Smith Tool.

Table 2 – Comparative characteristics of series produced hydraulic motor prototype model

Motor nominal size	Housing diameter, mm	Fluid flow rate, l/s	Differential pressure, MPa	Rotation frequency, rpm	Force moment, N*m	Length, m	Weight, kg
MS-98 Dyna-drill	98	8,2	3,45	460	47,5	5,85	220
Prototype model	88	6-7	4,0	600-800	110,44	0,80	40

The data given prove that hydraulic motor prototype model with lower weight and length has considerable advantage over series-produced downhole motor.

Be values of output parameters and technical characteristics, a double-chamber downhole rotary type motor may become an effective means for the construction of multibranch wells for oil and gas, underground water, opening of geothermal fields. There are also preconditions that it will give a high-power impulse to the development of hydraulic borehole mining method, making process-oriented mine openings.

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КӨПОҚПАНДЫ ҰҢҒЫЛАР БҰРҒЫЛАУҒА АРНАЛҒАН ҚОСКАМЕРАЛЫ АЙНАЛМАЛЫ ТҮПКІ ГИДРОҚОЗҒАЛТҚЫШ

Аннотация. Жер қойнауын пайдалану шаруасында ұңғы бұрғылау – айрықша маңызды. Көлемді, шынайы геологиялық ақпарат алу, көпоқпанды ұңғы жүргізу әдістемесі арқылы іске асырылады. Технологиялық мүмкіндігіне орай, олардың құрылысын жүргізуге ең тиімді құрал-ұңғыдағы гидроқозғалтқыштар, бұрғы жұмысын құбыр тізбегін айналдырмай іске асырады. Әлемдегі ұңғы қозғалтқыштар туралы мәлімдеме беретін ақпарат көзіне жасалған таңдау бойынша олардың ішіндегі (винтті, турбина және ротор) көпоқпанды ұңғылар жүргізу шартына сай келетіні – ротор түріндегісі ұзындығы қысқа, негізгі ұңғыдан бұралатын бүйірлі оқпанның радиусына енеді.

Жаңа физикалық заңдылықтар негізінде қоскамералы, ұңғыдағы гидроқозғалтқыштың айналмалы түрінің көпдеңгейлі кері тебу күші бар сызбасы анықталды, зерттеу нысаны болып белгіленді. Оның жұмыс көрсеткішін, құрылымын есептейтін әдістеме дайындалды: ұзындығы – 0,80 м, салмағы 40 кг, сыртқы бел сызығы 88 мм болатын тәжірибе үлгісіндегі гидроқозғалтқыш жасалды.

Теориялық есептеу нәтижесі, зертханадағы сынақ көрсеткіштері арқылы дәлелденді. Негізгі жұмыс көрсеткіштері жағынан үлгідегі гидроқозғалтқыш әлемдегі жаппай қолданыстағы өзі теңдес гидроқозғалтқыштардан әлдеқайда басым, тиімді.

Үлгідегі гидроқозғалтқыштарды бұрғы жұмысына енгізу арқылы ұңғы бұрғылау аясын кеңейтіп, барлау жұмыстарының пайдалы қазба байлықтарды өндірудің шығынын азайтады.

Түйін сөздер: геология, барлау, бұрғы, ұңғы, көпоқпанды, гидроқозғалтқыш, сызба, көрсеткіштер, мінездеме.

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ДВУХКАМЕРНЫЙ ЗАБОЙНЫЙ ГИДРОДВИГАТЕЛЬ РОТОРНОГО ТИПА ДЛЯ БУРЕНИЯ МНОГОЗАБОЙНЫХ СКВАЖИН

Аннотация. Изложена значимость способа бурения скважин в сфере недропользования. Объемный, достоверный геологический материал можно получить посредством метода сооружения многозабойных скважин. По технологическим возможностям наиболее эффективное средство-забойные гидродвигатели осуществляющие бурения скважин без вращения бурильной колонны. По анализу источников информации, содержащих сведения о забойных двигателях в мире, из всех них (винтовые, турбобуры, роторы), соответствующими условиями проведения скважин с боковыми стволами являются гидродвигатели роторного типа, малогабаритные по длине, вписывающиеся в радиус кривизны отхода от основной скважины.

На основе нового физического принципа сформирована конструктивная схема двухкамерного забойного гидродвигателя роторного типа, с многоуровневым моментом реактивных сил, ставшая объектом исследований. Разработана методика расчета выходных параметров гидродвигателя, определены технические характеристики: длина – 0,80 м, масса 40 кг при диаметре корпуса 88 мм.

Изготовлен опытный образец, проведены эксперименты с целью проверки сходимости результатов расчета и данных эксперимента. По выходным параметрам и техническим характеристикам опытный образец имеет значительное преимущество над зарубежным аналогом.

Внедрением гидродвигателя в производство буровых работ, расширяется сфера применения бурения скважин, снижается стоимость разведки и добычи полезных ископаемых.

Ключевые слова: геология, разведка, бурение, скважина, многозабойное, гидродвигатель, схема, параметры, характеристики.

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3D MODELING FOR ESTIMATION OF ENGINEERING-GEOLOGICAL CONDITIONS OF OPERATING MINERAL DEPOSITS

Abstract. The article is devoted to the nowadays actual problem - ensuring the safe and rational operations of mineral deposits in the underground working conditions of existing mining production. In recent years, progressive technologies have introduced actively to the mining industries with using the latest high-performance mining equipment, automation and complex mechanization of mining drift and stope. Their introduction was not sufficiently substantiated by specially conducted engineering-geological studies. As a result of such approaches, in areas operated with new technology using self-propelled equipment, were formed the vast zones of exposure of the roof and huge voids of the worked-out space with a large number of supporting interchamber pillars. On formalization of pillars were designed without taking into account the engineering and geological conditions of the underground excavation field, there were cases of their mass destruction, which led to the rock massifs collapse, shifting the overlying roof stratum under the built-up territory and environmental disasters.

As purpose to solve this problem, on researching works were made to quantify the engineering and geological conditions of thin-vein gold ore deposits using three-dimensional modeling on platform of modern computer technologies. The research used the results of the latest theoretical and methodological work in the field of engineering geology, as well as the results of a comprehensive survey of the state of the rock mass during exploration and operation on the example of the existing Beskempir gold deposit.

Key words: Engineering-geological conditions, 3D modeling, database, gold ore deposit, rock massif, stability of mine workings.

Introduction. The success of the development and exploitation at this level of the country's mineral resource base requires a modern and integrated approach to the operation of mineral deposits. In this regard safety, rationality, and the efficiency of mining ore bodies in the bowels play an important role. It is determined by the degree of knowledge and assessment of engineering and geological conditions of deposits, which in turn is also of great importance during mining operations in mining productions. This will let maximize the volume of ore mining and reduce dilution of the rock mass.

The main point of engineering and geological research conducted to address the assessment of the sustainability of the mine workings is determined by the principle and purpose of the work.

The fullness and self-sufficiency of studying and forecasting the engineering and geological conditions (hereinafter as EGC) of mineral deposits is achieved if these studies are synchronized with geological exploration at the stages of exploration and operation of the deposit. It should be borne in mind that the content, volume, accuracy and confidence level of the received data on EGC should be sufficient to solve the tasks. In the future, the obtained data will be used in the construction and operation of a mining production, its underground mine workings.

Engineering and geological studies were carried out at the Beskempir thin-vein gold ore deposit. The selection of the fundamental teaching methods and research methods, the combination of which will allow

us to implement a rational set of field, laboratory and cameral studies of EGC. They are dictated by the need to solve the following problems:

– The study of EGC on the basis of special field geological studies and purposeful processing of the entire known information of geological database;

– Assessment of forecast parameters for the development of geotechnical conditions and processes during field operation. Achieving this goal will be based on 3D modeling of the geological environment, with the help of which the tasks of assessing the quantitative parameters of the EGC deposit will be successively solved.

Analysis and discussion of research results. An objective assessment of all the components that make up the Engineering and geological conditions of the Beskempir gold ore deposit makes it possible to make the most reliable and objective forecast of the stability of the rock massif. The main engineering and geological components of the selected ore bodies and host rocks are due to their petrographic composition, the presence of structural and tectonic elements, crushing zones with varying degrees of crushing of the rocks and the development of joint systems that form weakening zones, and physical-mechanical properties [1,6,7].

Geological and structural structure of the deposit. The Beskempir deposit is localized within the Akbakai ore field, located 3 km northeast of the Jambyl fault, one of the regional faults of the Jalair-Naiman geostucture [2-4]. It is clearly limited in space by the Kashkimbai Fault from the southwest, Kengir Fault from the northeast, Kyzyljartas Fault from the north and South-Kengir Fault from the south. The length of the Fault along the strike is 15 km with a width of 3.5-4 km. From the north-west, the ore field is overlapped by Devonian volcanics filling the Kyzyljartas graben-syncline.

The Beskempir deposit is essentially the eastern flank of the Akbakai field, shifted 1800 meters eastward along the Beskempir post-ore fault and 300 m higher relative to Akbakai.The fault falls southward at an angle of 75-85° and borders the field at a depth of about 400-500 m (Porechin et all., 1986). The deposit area is composed of rocks of the Kyzyljartas (earlier-middle Devonian) gabbro-diorite complex, which is represented by several intrusive phases.

To the first phase of introduce includes sub-consonants with stratification, less often cutting small bodies, composed of diabases, diabase porphyrites, diabases and diorite porphyrites. A detailed study of these intrusives on the Olympic field showed that diabase porphyrites have a quenching zone in contact with diorite porphyrites of biotite and biotite-hornblende composition, i.e. the formation of these small-sized intrusions occurred in two stages.

They clearly differ in natural radioactivity. The second phase of introduce includes gabbro-diorites of intrusive appearance, which components of the Kengir stock. Actually, the Kyzyljartas intrusives completes the formation of the complex. It is composed of rocks that vary in composition from gabbro-diorites through quartz diorites and granodiorites to adamellites and granites. The main part of the intrusives is composed of granodiorites, on which siliceous-potassium metasomatism is imposed under the influence of Jeltau granites. According to previous studies, Kyzyljartas granodiorites are characterized by a higher potassium content in comparison with standard ones.

A dyke series of rocks consisted with the composition of microdiorites, diorite porphyrites and quartz diorite porphyrites is associated with the Kyzyljartas complex. Single dykes of this composition are known in the Kyzyljartas and Kengir stocks; their difference from later dykes is hornfelsification under the influence of Jeltau granites.

Two main and two secondary ore veins are known at the deposit. Main veins: Beskempir (acclivous dip), Surprise (steep dip). One of the secondary veins of Surprise-2 (steep dip) is controlled by dykes, and the other Berezitovaya (acclivous dip) is not connected with dykes and is distinguished by poor gold grade.

Engineering and geological particular qualities of the rock massif. Ore bodies are represented by veins of a quartz-berezite or substantially berezite composition, occurring in the contacts of diorite porphyrite dykes, less often in the dykes and ore-quartzed, chloritized dykes. A variety of ores is singled out that control sections of the rocker entry of ore-controlling dykes. In this case, the ore body is metasomatically quartz granodiorites, which have acquired a porphyritic appearance, dissected thin quartz veins with highly gold grade.

The contacts of quartz veins with berezites and berezites with host granodiorites or dykes are clear and often represented by tectonic seams with mirrors sliding. Ore bodies with steep (70-80^{o}) and acclivous (40-55^{o}) dip angles.

The host rocks and ores are characterized by high predictive indicators, that is, they are highly stable, with the exception of areas with weakened contacts of ore bodies with rocks. Almost all of the underground mine workings were completed without supporting of rock massif. Only in some rare cases, in areas of local increase in the thickness of the fracture crushing zone, rock stability was low. In such areas, was required continuous underground supporting of individual intervals of mine workings. Minor tectonic faults do not have a significant negative effect on rock stability [1,8-15].

Strength values coefficients of rock massif in deposit according the table prof. M.M. Protodyakonov are: for quartz ores – 16-18; berezites – 11-14; lamprophyre dykes – 11-12; granodiorites – 14-16; terrigenous rocks – 11-12. The weakest are the areas of interfacing of quartz veins, as well as their contacts with ore-controlling dykes.

Ores are not prone to caking, soaking, swelling, spontaneous combustion.

The natural radioactivity of the rocks is within the background values, mcR/h: diorite porphyrites – 10-15; granodiorites – 25-31; ore bodies – 20-30.

The volume mass of ores and host rocks varies from 2.69 to 2.83 t/m^3, the loosening coefficients are the same and is 1.6. The natural moisture content of ores and rocks does not exceed 1.5%. More detailed information about the physical-mechanical properties presented in table.

Characterization of the physical-mechanical properties of the Beskempir deposit rocks

Lithological type of rocks	Identified by laboratory tests			
	Density (volume mass), g/cm^3	Water absorption, %	The limit of compressive strength (in dry condition), MPa	Strength coefficient from-to
Loam with inclusion of gravel and crushed stone up to 15%	Density (volume mass) 2.73 t/m^3, coefficient of loosening 1.4-1.6			
Granodiorites	2,7	1,5	138	14-16
Hornfelsific sandstones	2,7	1,5	162,9	11-12
Quartz ore	2,73	1,5	170	16-18
Berezites	2,73	1,5	127,8	11-14
Lamprophyres	2,73	1,5	91,8	11-12

Estimation of jointing. The study of jointing is of great practical importance in the development of deposits since joints violate the continuity of rocks and reduce their strength in the massif. Under the conditions of the Beskempir deposit, the study of rock mass joints both in ore bodies and in host rocks in underground mines was carried out by visual inspection and using special tools (measuring tape, surveyor's compass, special laser equipment, etc.). In addition, such work was carried out on cores of geotechnical and production exploration holes. When performing work, special attention was paid to the following components of the engineering geological conditions: rock type, blocks of massif, number of joint systems, distance between joints, frequency, extent, thickness, filling and macro-roughness of joints, etc.

On the whole, the massif of rocks is moderately jointed, in some places there are crushing intervals, composed of rocks with rigid structural bonds belonging to the class of very strong and strong rocks. The regime of spatial variability of the properties of the massif can be attributed to stable both in strike and in dip. Tectonic structures control the degree of fragmentation of the massif and the intensity of fracturing, as well as the development of jointing systems in the rock massif. It should be noted that ore bodies are characterized by varying degrees of intensity, rock jointing, and ore-bearing granodiorites are mainly characterized by the lowest intensity of jointing. The main aspects that determine the formation of jointing and the development of their intensity, as well as the orientation of joints in the rock mass within the entire deposit, are ore-forming processes and tectonic faults, developed almost across the strike of ore bodies. This is evidenced by the existence of three main systems of jointing according to the fall and strike of ore bodies, and across their strike. In areas of discontinuous faults, joints are developed more intensely.

Joints breaking the massif of rocks, mostly oblique, chipped with mirrors and slip strokes. Joint fillers are: friction clay, vermiculite, chlorite, kaolinite. As a rule, processes of carbonatization, berezitization, sulfidization, and sericitization are developed along joints. Jointing system leads to anisotropy of the properties of the massif and block structure, for example joints of different orientations in the rock mass

intersecting mutually add up different separate shapes (rectangular, prismatic, tiled, etc.) and sizes. The greatest joint voids are confined to the areas of development of tectonically disturbed rocks. The presence of weakened zones is the result of unloading of rock masses. A decrease in the average values of rock strength in weakened zones and zones of increased jointing is noted.

The database – fundamental basis of 3D modeling in assessing the engineering and geological conditions of deposits (the necessary source data for the formation of the database). The fundamental basis for creating a three-dimensional model of the geological environment, then using it to assess the engineering and geological conditions of the deposits, is the geological database and the database of engineering and geological conditions, which should be constantly updated on maintenance of mining operations. The formation of databases is carried out as a result of exploration and operational exploration work with data collection. These data reflect the actual state of the rock mass in accordance with specific systems. On documentation of core from hole, the aforementioned types of databases are created in one spatial coordinate field and their required tables collar (coordinate file) and survey (inclinometry file) should be the same.

A geological database is needed to build a 3D model of ore bodies and host rocks of the hanging and bedding walls in three-dimensional space. There are additional interval tables in this database such as assay (sample data file) and lithology (lithology data file) [10-15].

The database of engineering and geological conditions is designed to visualize the results of documentation and research on engineering and geological study of rock mass and their use in the interpolation of quantitative parameters into a block model (evaluation in a three-dimensional environment) with using modern computer technologies. This type of database is compiled in two forms, the first one is for documentation of underground mining workings (geotech_drive), and the other is for documentation of core samples frome hole (geotech_drillhole). To generate the geotech_drive and geotech_drillhole files, data are needed on the following important components of the engineering-geological conditions, which are used to interpolate (estimate) by the value of the Burton rating (figure 1):

– *Lithological code (ROCK).*

– *Water cut of the rock (Jw)*: 1 – no water inflow, dry rocks; 0.66 – wet rocks; 0.5 – casing, wet rocks; 0.33 – light water inflow; 0 – noticeable water inflow.

– *Water cut of the rock (Jw), Rat*, the value is determined depending on Jw: when Jw = 1 (Jw), Rat = "10", Jw = 0.66 (Jw), Rat = "7", Jw = 0.5 (Jw), Rat = "4", Jw = 0.33 (Jw), Rat = "0".

– *Rock strength (UCS),* MPa, set by the device.

– *Strength category, the value is determined depending on the UCS*: within 1-5 MPa, the value is "R1" (very weak); 5-25 MPa value of "R2" (weak); 25-50 MPa value of "R3" (medium strength); 50-100 MPa value "R4" (durable); 100-250 MPa value "R5" (very strong); greater than 250 MPa, the value of "R6" (extremely durable).

– *Rock Quality Designation (RQD)* in m, the sum of the lengths of whole pieces over 10 cm in the documented interval.

– *RQD (Rat),* the value is determined depending on (RQD), %: at (RQD), % 90-100 the value is "20", 75-90 the value is "17", the 50-75 value is "13", 25-50 value of "8", less than 25 value of "3".

– *Number of jointing systems (Jn):* 0.5 – no joint, 1 – random joints, 2 – one jointing system, 3 – one jointing system + random joints, 4 – two jointing systems, 6 – two jointing systems + random joints, 9 – three jointing systems, 12 – three jointing systems + random joints, 15 – four or more jointing systems, 20 – crushing zone.

– *Number of joints (NJ)* for a specific interval.

– *The distance between the joints (SD).*

– *The distance between joints (SD00) Rat,* the value is determined depending on (SD): with a smaller 0.06 value of "5", 0.06-0.2 value of "8", 0.2-0.6 a value of "10", 0.6-2 a value of "15", greater than 2 a value of "20".

– *Roughness of the walls of the joints (Jr):* 0.5 – polished flat, 1 – smooth flat, 1.5 – flat rough, 2 – smooth wavy, 3 – wavy rough.

– *Joint wall friction (Ja).*

– *Burton Rating Index (Q).*

– *Class category according to the Barton system*, the value is determined depending on Q: when Q is less than 1 – the value is "V", 1-4 – the value is "IV", 4-10 – the value is "III", 10 – 40 – the value of "II", 40-1000 – the value of "I".

– *Characterization of the massif* according to the Barton rating index (Q): when Q is less than 1, the value is "very unstable", 1-4 values are "unstable", 4-10 values are "medium-stable", 10-40 values – "stable", 40-1000 values – "very stable".

№ holes	From, m	To, m	length, m	Lithological code (ROCK)	Water cut of the rock (Jw)	Water cut of the rock (Jw), Rat	Strength category	Rock strength (UCS), MPa	UCS(Rat)	Rock Quality Designation (RQD), m	Rock Quality Designation (RQD), %	RQD(Rat)	Number of jointing systems (Jn)	Number of joints (NJ)	The distance between the joints (SD)	The distance between joints (SD00) Rat	Roughness of the walls of the joints (Jr)	Joint wall friction (Ja)	Burton Rating Index (Q)	Class category according to the Barton system	The characteristics of the array according to the rating index of Barton (Q)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
S_Bes_M37_GT_010	0	1	1	GRD	1	10	R4	86	7	0	0	3	12	4	0,02	5	1,5	2	0	V	very unstable
	1	2,5	1,5	GRD	1	10	R4	85	7	0,26	17	3	3	6	0,02	5	1,5	2	4,333	III	medium-stable
	2,5	2,9	0,4	LPH	1	10	R4	84	7	0	0	3	3	3	0,02	5	1,5	2	0	V	very unstable
	2,9	3,7	0,8	GRD	1	10	R4	75	7	0,28	35	8	9	8	0,15	8	1,5	2	2,917	IV	unstable
	3,7	8,4	4,7	GRD	1	10	R2	22,1	5	0,37	8	3	9	8	0,15	8	1,5	2	0,656	V	very unstable
	8,4	9,1	0,7	GRD	1	10	R3	40	4	0	0	3	20	3	0,02	5	3	2	0	V	very unstable
	9,1	10	0,9	GRD	1	10	R4	55	7	0,4	44	8	3	2	0,4	10	3	2	22,22	II	stable

Figure 1 – An example of a geotech_drillhole filled file

After the database was formed in the conditions of the Beskempir field it was checked for integrity, systematical errors, etc. in the mining and geological information system Micromine. Further, all possible errors are eliminated using the software. As a result of the work performed, we obtained a reliable database, which, in turn, was used in modeling and interpolation of quantitative parameters in three-dimensional space.

3D modeling and with its help an estimate the engineering and geological conditions of the Beskempir gold ore deposit. When three-dimensional modeling was taken into account the features of the geological and structural structure of the deposit, its knowledge degree and geological exploration methods. Then, in the Micromine software were used standard 3D modeling methods and techniques of ore mineralization within the deposit. The order of execution of the work consisted of the following steps:

– Loading the geological database. Successfully implemented the creation 3D models of ore bodies and host rocks of the hanging and bedding walls.

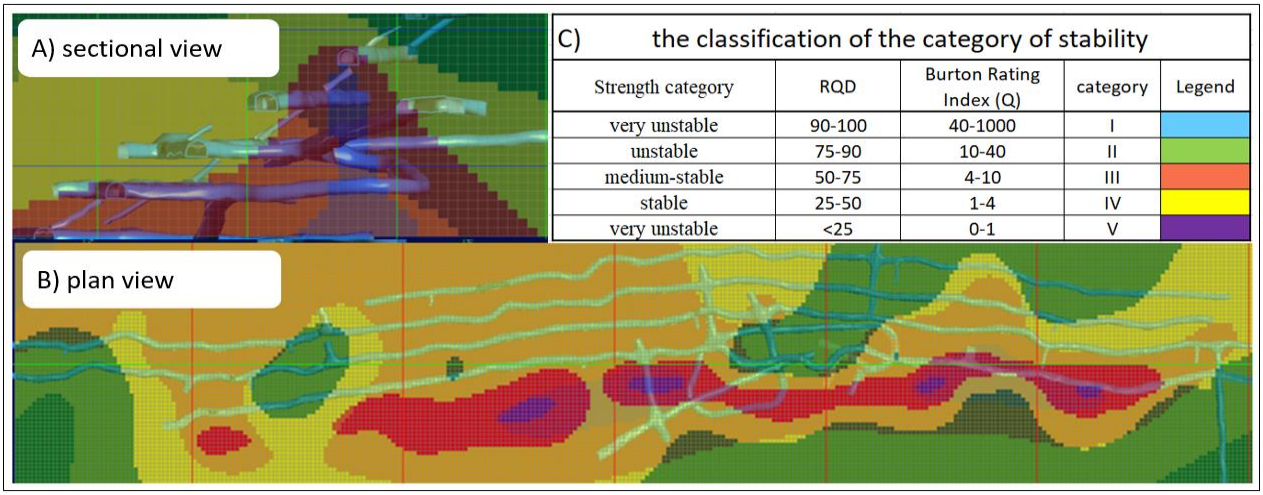
– Visualization of the results of engineering geological mapping. Constructed 3D models of discontinuous faults in three-dimensional space;

– Block modeling. At this stage, realized the creation of a blank block model within the boundaries of the deposit and coding of the block model with structural domains (ore bodies, enclosing rocks, discontinuous violations);

– Import a database of engineering and geological conditions. The data was visualized and verified in three-dimensional space in order to verify the readiness of the base for interpolating the quantitative parameters of the components of the engineering and geological conditions of the field into a block model.

– Estimation of engineering and geological conditions of the deposit. To carry out the estimate, was used inverse distance weighting – IDW interpolation method, beacause this method is most suitable for the Beskempir deposit. There is a clear structural control of mineralization, and the breakdown into structural domains was carried out only according to geological criteria. For this, of course is used the IDW-method (inverse distance weighting). Difference from other methods, here the weighting coefficient is calculated not only to the nearest indicator, but also to all neighboring indicators. In this case, the weighting coefficient is inversely proportional to the distance raised to a power from a point to a neighboring indicator. Naturally, the nearby indicator will have the high weight, the influence of other indicators is also taken into accounting.

As results, we obtained an experimental 3D block model of the deposit, which clearly shows the engineering and geological conditions of the geological environment in real time in three-dimensional space (figure 2).



C) the classification of the category of stability

Strength category	RQD	Burton Rating Index (Q)	category	Legend
very unstable	90-100	40-1000	I	
unstable	75-90	10-40	II	
medium-stable	50-75	4-10	III	
stable	25-50	1-4	IV	
very unstable	<25	0-1	V	

Figure 2 – Fragment of a 3D block model: A) sectional view; B) plan view;
C) the classification of the category of stability according to the Barton system with certain colors

Conclusion. In mine workings, engineering-geological phenomena include the following: deformation of rocks in the walls and at the bottom of mine shafts, swelling (blowing, extrusion) of rocks in the soil of workings, displacement and various types of rock collapse in the roof (inrushing, creating domes, collapsing of the false roof), emissions of rocks and minerals, inrushing and caving in zones of low stability and at the borders of changing stability classes, etc.

To prevent the occurrence of hazardous processes, it is necessary to use effective methods that ensure the safe and rational conduct of underground mining. In general, predicting the development of engineering-geological processes during field development under certain geological conditions, with a limited amount of information available, is a very difficult task due to the ambiguity and versatility of mutually affecting factors.

Nowadays, to solve the above problems, an estimation of the engineering and geological conditions of the Beskempir deposit has been implemented based on 3D modeling of the geological environment. During the work, data were collected on real criteria formulated according to the results of a comprehensive analysis of the geological, structural-tectonic, engineering-geological features of the deposit. A 3D model of the engineering and geological conditions of the deposit at the mine will serve as valuable material in the way of achieving the maximum safe, rational and efficient mining of ore bodies in the bowels.

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ӨНДІРІСТЕГІ КЕН ОРНЫНЫҢ ИНЖЕНЕРЛІК-ГЕОЛОГИЯЛЫҚ ЖАҒДАЙЫН БАҒАЛАУҒА АРНАЛҒАН 3D МОДЕЛДЕУ

Аннотация. Ғылыми жұмыс бүгінде өзекті мәселеге – пайдалы қазба кен орындарын қауіпсіз және ұтымды өндіру және жұмыс істеп тұрған кен өндірісі саласындағы өнеркәсіптің жерасты кен үңгімелері тұрақтылығын қамтамасыз етуге арналған. Әсіресе, соңғы жылдары кен өндірісі саласына жаңа жоғары өнімді кен техникаларын қолдану арқылы прогрессивті технологиялар белсенді енгізілді, жерасты кен үңгімелерін қазу және тазалау жұмыстары кешенді механикаландырылды және автоматтандырылды. Жаңа технологиялардың өндіріске енгізілуі инженерлік геологиялық зерттеулер негізінде жеткілікті негізделмеді.

Нәтижесінде жаңа технологияларды қолдану арқылы жер қойнауының бөлікшелерінде тау жыныс массиві жабынының ауқымды аймақта ашылуы және өндіру жұмыстарынан кейін көптеген камерааралық тіреуіш кентіректері бар үлкен бос кеңістігі қалыптасты. Өндіріс алаңының инженерлік-геологиялық жағдайын есепке алмай камерааралық тіреуіш кентіректердің дайындалуы олардың жаппай бұзылуына негіз болды, ал оның салдары тау жыныс массивінің опырылып құлауына, жоғарғы қабатының жердің беткі қабатына жылжуына және экологиялық апаттарға әкелді.

Белгілі бір уақыт аралығында жетекші әлемдік компаниялар геологиялық барлау және кен өндірісі салаларында үшөлшемді модельдеуді қолдану арқылы өндіру жұмыстарының тиімділігін көтеруге, аналитикалық және статистикалық есептерге кететін уақыттың үнемделуіне, геологиялық және өндірістік барлау жұмыстары бойынша дерекқордың дұрыс қалыптасуына және толығуына, сонымен қатар зерттелетін аймақтың инженерлік-геологиялық жағдайын толығырақ бағалауға қол жеткізді.

Соңғы жылдары кен-геология саласында компьютерлік технологиялардың қолданылуы елімізде де кеңінен орын алып келеді. Кен орындарын ашық және жерасты тәсілдермен өндіру барысында кен денелерін 3D модельдеу сәтті жүзеге асырылуда. Дегенмен, бүгінгі күні кен орындарын максималды қауіпсіз және ұтымды игеру жолында үлкен практикалық мәнге ие 3D модельдеу арқылы геологиялық ортаның инженерлік-геологиялық жағдайларын бағалауға толығымен қол жеткізілмеді.

Үшөлшемді ортада қазіргі компьютерлік технологияларды қолдану арқылы кен орындарының инженерлік-геологиялық жағдайларын бағалау бойынша шетелдік мамандардың тәжірибесі зерделенді. Біз осындай жұмыстарды Бескемпір алтын кен орнында жүргіздік және мақсатымыз геологиялық ортаның (кен денелері, сыйыстырушы тау жыныстар, тектоникалық жарылымдар және т.б.) 3D моделін қолдану арқылы осы кен орнының инженерлік-геологиялық жағдайларын бағаладық.

Атқарылған жұмыстар кен-геологиялық ақпараттық жүйеде үшөлшемді модельдер тұрғызуда және кен орнының инженерлік-геологиялық жағдайларын бағалау кезінде үлкен маңызға ие төмендегідей зерттеу сатыларын қамтиды: жұмыс ауданының геологиялық-тектоникалық құрылысы кен орнының геологиялық ерекшеліктерін зерттеу; кен үңгімелеріндегі құрылымдық тектоникалық элементтерді; тау жыныс массивінің инженерлік-геологиялық ерекшеліктері; кен және сыйыстырушы тау жыныстардың заттық құрамы және олардың физикалық-механикалық қасиеттері жайлы деректерді жүйелеу және жинақтау; тау жыныс массивінің кернеулік күйін тексеру; жарықшақты бағалау; жерасты кен үңгімелерінде тау жыныс массивінің опырылу, бұзылу жағдайын бағалау; жарықшақ жүйесінің тау жыныс массивінің тұрақтылығына әсері және оны есепке алу; деректер қоры – кен орындарының инженерлік-геологиялық жағдайларын бағалаудағы 3D модельдеудің іргелі негізі (деректер қорын құру үшін қажетті мәліметтер); жерасты кен үңгімелерін және геотехникалық, өндірістік барлау ұңғымаларының кернін инженерлік-геологиялық құжаттау; Бартон жүйесі бойынша тау жыныс массиві жіктеліміндегі класты анықтау; талдау және модельдеуге деректер дайындау – геологиялық және инженерлік-геологиялық деректер қорын құру.

Бескемпір кен орнының жерасты үңгімелерінде жүргізілген ғылыми-зерттеу жұмыстары нәтижесінде геологиялық ортаны 3D модельдеу арқылы кен орнының инженерлік-геологиялық жағдайларын бағалауға қол жеткізілді. Кен өндіру өнеркәсібінде осы модель кен орнын максималды қауіпсіз, ұтымды және тиімді игеру жолында құнды материал ретіде қызмет етеді, сонымен қатар басқа ұқсас кен орындары үшін дайын тәжірибе түрінде қолдануға ұсынылады.

Түйін сөздер: инженерлік-геологиялық жағдай, 3D модельдеу, мәліметтер базасы, алтын кен орны, тау жыныс массиві, тау-кен қазбаларының тұрақтылығы.

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3D МОДЕЛИРОВАНИЕ ДЛЯ ОЦЕНКИ ИНЖЕНЕРНО-ГЕОЛОГИЧЕСКИХ УСЛОВИЙ РАЗРАБАТЫВАЕМЫХ МЕСТОРОЖДЕНИЙ

Аннотация. Работа посвящена актуальной на сегодняшний день проблеме – обеспечению безопасной и рациональной разработки месторождений полезных ископаемых и устойчивости подземных горных выработок действующих горнодобывающих предприятий. Особенно в последние годы в горные отрасли были активно внедрены прогрессивные технологии с применением новейшей высокопроизводительной горной техники, автоматизация и комплексная механизация горнопроходческих и очистных работ. Внедре-

ние их не было достаточно обосновано специально проведенными инженерно-геологическими исследованиями. В результате таких подходов на участках, отработанных по новой технологии с применением самоходного оборудования, образовались обширные площади обнажения кровли и огромные пустоты выработанного пространства с большим количеством поддерживающих целиков. При оформлении междукамерных целиков без учета инженерно-геологических условий выемочного поля происходили случаи их массового разрушения, что привело к обрушению горной массы породного массива, сдвижению налегающей толщи до выхода на дневную поверхность и экологических катастроф.

На протяжении определенного времени ведущие мировые компании геологоразведочной и горнодобывающей сфер деятельности с применением объемного трехмерного моделирования достигли существенного повышения эффективности добычных работ и экономии времени на аналитические и статистические расчеты, корректности формирования и пополнения базы данных по геологоразведочным и эксплуатационно-разведочным работам, в том числе подробной оценки инженерно-геологических условий на изучаемом участке.

В последние годы компьютерная технология в горно-геологической сфере все шире применяется и в нашей стране. Успешно осуществляется применение 3D моделирования рудных тел при добычных работах как открытом, так и подземном способах разработки месторождений. На сегодняшний день пока полностью не реализована оценка инженерно-геологических условий геологической среды с помощью 3D моделирования. Моделирование в свою очередь имеет большое практическое значение для достижения максимально безопасной и рациональной разработки месторождений как открытым, так и подземным способом.

Изучен теоретический и практический опыт зарубежных специалистов по оценке инженерно-геологических условий месторождений в трехмерной среде с использованием современных компьютерных технологий. Нами такие исследования проведены на золоторудном месторождении Бескемпир. Цель работ заключалась в оценке инженерно-геологических условий месторождения с применением 3D модели геологической среды (рудных тел, вмещающих пород висячего и лежачего боков, тектонических нарушений и зон дробления и др.). Выполненные работы состояли из следующих важных этапов работ: Геолого-структурное строение района работ: изучение геологических особенностей месторождения; изучение структурно-тектонических элементов в пределах горных выработок. Инженерно-геологические особенности массива горных пород: обобщение, систематизация данных о вещественном составе руд и вмещающих пород и их физико-механических свойствах; обследование напряженного состояния массива горных пород (рудные тела, массивы в лежачем и висячем боках); Оценка трещиноватости: оценка обрушаемости, нарушенности горных пород в подземных горных выработках; учет и влияние систем трещиноватости на устойчивость массива горных пород; инженерно-геологическая документация подземных горных выработок и керна геотехнических и эксплуатационно-разведочных скважин; классификация и определение класса массива горных пород по системе Бартона; анализ и подготовка данных к моделированию, формирование баз геологических и инженерно-геологических данных; 3D моделирование и с его помощью оценка инженерно-геологических условий месторождений на примере золоторудного месторождения Бескемпир.

В результате научно-исследовательских работ, проведенных в горных выработках золоторудного месторождения Бескемпир, достигнута оценка его инженерно-геологических условий с применением 3D моделирования геологической среды. На горнодобывающем предприятии данная модель будет служить ценным материалом для достижения максимально безопасной, рациональной и эффективной отработки рудных тел, а также хорошим опытом для аналогичных месторождений.

Ключевые слова: инженерно-геологические условия, 3D моделирование, база данных, золоторудное месторождение, горный массив, устойчивость горных выработок.

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FORMATION OF STRENGTH AND PHASES OF SEQUENCE OF DESTRUCTION OF ARBOLITE COMPOSITES AT VARIOUS LONG LOADS

Annotation. The article discusses the study of the strength and deformation characteristics of sulfur-containing arbolite composites using secondary resources, which is relevant in regions with a hot and sharply continental climate. This is one of the lightest building materials with low thermal conductivity and good sound insulation ability. The aim of this study is to determine the mechanism of strength formation and the destruction of sulfur-containing arbolite composites under various long-term loads and to substantiate the effectiveness of their use in housing construction. The methodological basis of the study was the current provisions of the theory and practice of creating, developing high-strength concrete concrete based on composite sulfur-containing binders. When conducting scientific research, standard measuring instruments and methods for analyzing the physicomechanical characteristics of arbolite composites obtained using modern methods of X-ray diffraction, differential thermal, microscopic analysis and testing equipment were used.

The properties of sulfur-containing arbolite samples were studied at 7, 28, and 90 days old under various conditions and loads. The study of the effect of the resulting deformations on the compression strength of the sulfur-containing arbolyte was based on certain models of concrete structure. The sulfur-containing arbolyte was considered as a two-component system consisting of a fibre of crushed cane and a sulfur-containing solute component, the strength of the solute being variable. Four series of samples from sulfur-containing arbolyte were produced for the study, and a fifth series, for comparison, from sulfur-containing ceramic concrete. Each series consisted of six samples of prisms measuring 150x150x600 mm, three of which (model I) consisted only of a sulfur-containing solute (sulfur-to-pyrite fire ratio of 1:3), and in three other prisms (model II), milled cane fibers of about 18-20 mm diameter were placed in the middle. The prism samples were tested in stages corresponding to a voltage increment of 0.1 to 0.15 MPa, after each load stage the samples were held for five minutes. Readings by indicators (with measurement accuracy of 0.01mm) were taken after application of each load stage and before application of new load. Such a test technique allowed extracting elastic instantaneous deformations and determining the value of the initial modulus of elasticity of sulfur-containing light concrete.

It was established that the destruction of sulfur-containing arbolite occurs sequentially, first the destruction of the solution component occurs, and then the organic aggregate. The results can be used in the manufacture of effective wall material for civil buildings, including seismic areas.

Key words: Sulfur-containing arbolite composites, strength, hardening phase, long-term load, deformation modulus, mortar component, fracture.

Introduction. Due to the rapid development of the construction industry and the expansion of industrial and civil construction in the regions of Kazakhstan, the demand for building materials and structures is increasing every day, which is the creation of structural and heat-insulating materials using

secondary resources. Arbolite concrete occupies a special place in the production of building materials in regions with a hot climate, which combines lightness, environmental friendliness, high heat-insulating qualities and may contain plant agricultural waste, which is rich in steppe regions. Also in the regions of Kazakhstan there are also huge raw materials in the form of large-tonnage industrial wastes, their disposal as part of building materials is the first decision of the national economy. However, the increased requirements for the quality of arbolite pose a task to further increase its construction and operational, technological and strength indicators. The aim of the study is the development of highly effective concrete concrete based on composite sulfur-containing binders, the development of scientific foundations for the formation of their structure, composition and properties when used as wall material for housing construction. To achieve the goal, the influence of additives of sulfur-containing waste from the petrochemical industry on the structure formation and physicochemical properties of composite binders, the influence of their main components on the physicomechanical properties of sulfur-containing wood concrete using chopped reed fiber, the mechanism of strength formation and destruction of sulfur-containing wood concrete, depending on the type and method, were studied. loading, analysis of the use of wood concrete in building structures.

Studies have established that it is possible to improve properties, simplify manufacturing technology and increase the efficiency of arbolite production by purposefully changing its properties and structure with various additives of industrial and plant wastes in the composition [1-17]. An analysis of numerous data [18-27] shows that, in contrast to conventional wood crushed wood concrete, where organic cellulose aggregate is most often the least strong component, sulfur-containing components of the mortar part have a significant effect on its strength and deformation characteristics.

Materials: the object of the study is the industrial waste of enterprises in the region of Kazakhstan in the form of sludges and solids.

1. Portland cement grade 400 Chimkent cement plant.

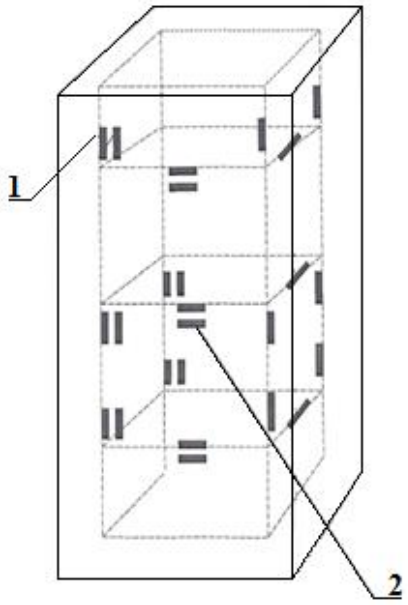
2. As an additional additive, pyrite cinders of the former JSC “Phosphorhim” were used, consisting mainly of a mixture of iron oxides (II, III) Fe3O4 (Fe2O3), calculated on the iron content of 40–63%, and sulfur impurities of 1-2%. The rest is non-ferrous metal oxides.

3. As a modifying additive, technical sulfur was used - a secondary product of the processing of high sulfur oil from deposits of the Republic of Kazakhstan. Sulfur is a granular product that meets the requirements of GOST 127.1-93.

Shredded reed fibers were used as initial porous aggregates for the production of sulfur-containing arbolites. The physicochemical properties of reed, its chemical and fractional composition were established empirically in accordance with the requirements of GOST 19222, GOST 25820-2000, as well as on the basis of reference and published data [1-20].

Methods. The characteristics of the initial and activated binder were determined in accordance with GOST 30515-97, GOST 31108-2003 and GOST 7473-2010. The tensile strength and bending strength of sulfur-containing binders were determined on beam samples 40x40x160 mm in size using an IP 2710 instrument. Using the X-ray phase analysis, the phase composition of the activated sulfur-containing binder was determined. Radiographic imaging was performed on a DR-ON-3 diffractometer. During the survey, the interval of diffraction angles from 2 to 32º was chosen. The radiographs were decoded on the basis of reference radiographs of the constituent minerals. Differential thermal analysis of hydrated sulfur-containing cement powders was carried out on a MOM Budapest photo-recording derivatograph (Hungary) according to a standard method. The nature of the strength formation and the reasons for the destruction of sulfur-containing arbolite were studied using tensometric equipment and depth strain gauges with a base of 10-50 mm glued to the reed fibers using the “Moment” quick-hardening adhesive, oriented along and perpendicular to the applied load to the prisms installed before concreting. The task of the tests was that deep strain gauge sensors were installed both on the fibers of the chopped reed and in the sulfur-containing mortar component of the material, which made it possible to determine the root cause of the destruction sequence of the individual components of the sulfur-containing material (figure).

Studies were carried out on samples of sulfur-containing arbolite at 7, 28 and 90 days old. The study of the effect of deformations on the compressive strength of sulfur-containing arbolite was based on certain models of concrete structure. Sulfur-containing arbolite was considered as a two-component system consisting of chopped reed fiber and a sulfur-containing mortar component, while the strength of the mortar part was a variable. For the study, four series of samples were made from sulfur-containing



Installation diagram of deep strain gauges. 1- sensor on reed fibers; 2- sensor in the mortar component

arbolite, and the fifth series, for comparison, from sulfur-containing expanded clay concrete. Each series consisted of six samples of prisms 150x150x600 mm in size, three of which (model I) consisted only of a sulfur-containing mortar part (the ratio of sulfur to pyrite cinder was 1: 3), and in three other prisms (model II) fibers of crushed reed were placed in the middle with a diameter of about 18-20 mm. All samples after heat treatment before testing were stored in vivo laboratory. The interval of the maximum load on the test samples varied from 60 to 120 kN, which was determined by the limiting level of loading of the samples, equal to 0.75 Rpr (Rpr is the primary strength of sulfur-containing arbolite). It is known [12–27] that the creep of sulfur-containing expanded clay concrete is mainly determined by the creep of the gel, which is part of the cement stone, therefore, it was suggested that these patterns apply to sulfur-containing arbolite. The compositions of sulfur-containing arbolite and sulfur-containing expanded clay concrete for the manufacture of prototypes are given in table 1 and 2.

Table 1 – Composition of sulfur-containing arbolite prism samples

No. of series of samples	The composition of concrete (by weight),%	Water-cement ratio, W / C	Cement consumption per 1m3 of concrete, kg
1	Cement 33.3%: crushed reed fibers 22.4%: additives in the form of industrial sulfur and pyrite cinder 10.8%: water 33.5%	1,34	321
2	Cement 34.4%: crushed reed fibers 21.4%: additives in the form of industrial sulfur and pyrite cinder 10.8%: water 33.4%	1,37	335
3	Cement 34.9%: ground cane fiber 20.6%: additives in the form of industrial sulfur and pyrite cinder 10.94%: water 33.56%	1,4	345

Table 2 – The Composition of sulfur-containing expanded clay prism samples

No. of series of samples	The composition of concrete (by weight),%	Water-cement ratio, W / C	Cement consumption per 1m3 of concrete, kg
1	Cement 37.8%: expanded clay 20.9%: additives in the form of industrial sulfur and pyrite cinder 10.8%: water 30.5%	0,97	390
2	Cement 38.2%: expanded clay 21.8%: additives in the form of industrial sulfur and pyrite cinder 10.8%: water 29.2%	1,2	400
3	Cement 38.6%: expanded clay 22.7%: additives in the form of industrial sulfur and pyrite cinder 10.8%: water 27.9%	1,1	410

Results. Our studies have shown the following results:

1. Depth strain gauges located in the sulfur-containing mortar component of the material, record the moment of its destruction and the achievement of ultimate tensile sulfur-containing arbolite in prisms perpendicular to the current load of the press. In this case, the arrow of the press gauge falls, that is, the initial destruction of the sulfur-containing material is always observed. At the same time, strain gauge sensors mounted on the fibers of the chopped reed and oriented along and across the current load continue to show an increase in deformations, and the pressure gauge needle of the press continues to show an increase in stresses. These effects are not detected in a sulfur-containing arbolite of a porous or large-pore structure of low density of less than 500 kg / m3.

2. When testing a sulfur-containing arbolite of a dense structure, no simultaneous destruction of the sulfur-containing solution component and organic aggregate occurred. Usually, sequential failure was observed associated with the aggregate, then with the sulfur-containing solution component, but only in the second phase of hardening. The destruction of the sulfur-containing material along the solution component occurred only in the first phase of hardening.

When testing a sulfur-containing arbolite of a dense, porous and coarse-porous structure, the adhesion surface of the fiber of crushed reeds with a sulfur-containing solution component is of significant importance, while for a material of a dense structure, the adhesion strength of the solution component is less than the strength of the organic aggregate. For a porous and porous material, the adhesion strength of the mortar component is greater than that of the organic aggregate.

Discussions. The conducted studies provide the basis for clarifying the hypotheses of strength formation and the causes of the destruction of sulfur-containing arbolite. The strength theory of A. I. Vaganov [7, 25] is acceptable for explaining the process of increasing the strength of a sulfur-containing material during hardening, when the deformability of the sulfur-containing mortar component is less than the deformability of the clogged fibers of shredded reed. To explain the increase in the strength of sulfur-containing arbolite of dense structure in the second phase of hardening, this hardening theory requires additional refinement, since the simultaneous destruction of the organic aggregate and the solution component is not observed. The destruction of sulfur-containing material in the second phase of hardening occurs in steps, first an organic aggregate, then a sulfur-containing solution. The final strength of the sulfur-containing arbolite of a dense structure in all tested samples was determined by the strength of the mortar component. So, with a lower strength of the sulfur-containing solution compared to the strength of the aggregate, single-phase hardening and single-stage destruction occur along the solution. With the high strength of the sulfur-containing solution compared with the strength of the organic aggregate, two-phase hardening and two-stage destruction occur. The strength of the sulfur-containing arbolite of the porous structure is formed in one phase, the destruction occurs in a one-stage process - according to the clogged organic aggregate, the strength of which determines mainly the strength of the material.

Conclusions. The conducted studies allow one to plan to obtain sulfur-containing arbolite of various strengths depending on the grain fraction or fiber length of the organic aggregate. The research results can be widely used in the manufacture of wall materials and structures for all types of public and civil buildings, including areas of high seismicity.

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ӘРТҮРЛІ ҰЗАҚ МЕРЗІМДІ САЛМАҚ ӘСЕРІНЕН АРБОЛИТ КОМПОЗИТТЕРІНІҢ БЕРІКТІГІ МЕН БҰЗЫЛУ БІРІЗДІЛІГІНІҢ ҚАЛЫПТАСУЫ

Аннотация. Мақалада ыстық және күрт айнымалы климатты өңірлерге ыңғайлы және қалдық материалдарды қолдану арқылы жасалатын күкіртті құрамалы арболит композиттерінің беріктік және деформативті қасиеттері қарастырылған. Арболит – жылу өткізгіштігі төмен және дыбыс ұстағыштығы жоғары жеңіл құрылыс материалдарға жатады. Зерттеудің негізгі мақсаты – күкіртті құрамалы арболит композиттерінің әртүрлі ұзақ мерзімді салмаққа шыдас беріп, беріктік қасиетін күшейту механизмін және бұзылысының бірізділігін анықтай отырып, тұрғын үй құрылысында қолдану тиімділігін анықтау болып саналады. Зерттеудің әдіснамалық негізіне күкіртті құрамалы композитті байланыстырғыштар негізінде жасалған, жоғары беріктік қасиеті мығым арболитбетондар жөніндегі қазіргі заманғы теориялар мен оларды жасап шығару технологиялары негіз болды. Зерттеу жұмыстарын жүргізу барысында арболит композиттерінің физика-механикалық қаситтерін анықтау үшін қазіргі заманғы әдістегі рентгенфазды, дифферациалды-термиялық, микроскопты әдістегі стандартты өлшеу және сынау құралдары қолданылды. Күкіртті құрамалы арболит композиттері үлгілерінің қаситтерін зерттеп үйренуде оларды 7, 28, және 90 тәулік ашық ауада және жылуда ұстап кептіргеннен кейін түрлі салмақ түсіріп сынап көрдік. Күкіртті құрамалы арболиттердің сығылғандағы беріктік шегіне түрлі күштерден пайда болатын деформациялар әсерін үйрену барысында нақты бір құрамдағы бетон моделін жасау қажеттігі туды. Мұнда күкіртті құрамалы арболит ұсақталған қамыс фибрасынан және күкіртті құрамалы ертіндіден тұратын екі компонентті жүйе ретінде қарастырылған және ертінді беріктігі өзгермелі болып келеді. Зерттеу жұмыстарын жүргізу барысында күкіртті құрамалы арболиттен даярланған төрт үлгі және жұмыстарды салыстыру үшін күкіртті құрамалы керамзитті бетоннан жасалған бесінші үлгі сериялары даярланды. Әрбір серия өлшемдері 150х150х600 мм болған алты призма үлгіден тұрады, яғни олардың үшеуі (модель I) күкіртті құрамалы ертіндіден (күкірттің пирит тотығына қатынасы 1:3) жасалса, ал қалған үш призма үлгілердің арасына (модель II) диаметрлері 18-20 мм болған ұсақталған қамыс фибралары орналастырылған. Призма үлгілерді сынау кернеуі 0,1-ден 0,15-ке МПа дейін көбейетін этаптар арқылы жүргізіледі және әрбір салмақ басқышында үлгілерді бес минут ұстап тұрады. Индикаторлардағы есептер (0,01мм дәлдікке дейін) үлгілерге жаңа салмақ түскенге дейін және салмақ түсірілгенннен кейін өлшенеді. Зерттеу барысында кеуек түрдегі күкіртті құрамалы арболиттар беріктігі бір фазалық болып, олардың қирауы бір сатылық, яғни арболит құрамындағы колльматацияланған органикалық толықтырғыш түріне қатыстылығы анықталды. Тығыз түрдегі күкіртті құрамалы арболиттер беріктігін әртүрлі салмақ түсіріп сынағанда олардағы бұзылу бірізділігі түрінде болатынығы, яғни бірінші фазада байланыстырғыш ерітінді қирап, соңынан екінші фазада органикалық толықтырғыштың үзіліп сынатындығы анықталды. Күкіртті құрамалы арболит композиттерін зерттеу арқалы алынған нәтижелерді тұрғын үй құрылысына, соның ішінде сейсмикалық аудандарға арнап шығарылатын қабырғалық материалдарды даярлау барысында толық қолдануға болады.

Түйін сөздер: күкіртті құрамалы арболит композиттері, беріктік, қатаю фазасы, ұзақ уақыт әсер етуші салмақ, деформация модулі, ертінді құрамасы, қирау.

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ФОРМИРОВАНИЕ ПРОЧНОСТИ И ПОСЛЕДОВАТЕЛЬНОСТИ РАЗРУШЕНИЯ АРБОЛИТОВЫХ КОМПОЗИТОВ ПРИ РАЗЛИЧНЫХ ДЛИТЕЛЬНЫХ НАГРУЗКАХ

Аннотация. В статье рассматриваются вопросы по исследованию прочностных и деформативных характеристик серосодержащих арболитовых композитов с использованием вторичных ресурсов, что является актуальным в регионах с жарким и резкоконтинентальным климатом. Это один из самых легких строительных материалов, обладающих низкой теплопроводностью и хорошей звукоизоляционной способ-

ностью. Целью данного исследования является определение механизма формирования прочности и разрушение серосодержащих арболитовых композитов при различных длительных нагрузках и обоснование эффективности их использования в жилищном строительстве. Методологической основой исследования послужили современные положения теории и практики создания, разработки высокопрочных арболитобетонов на основе композиционных серосодержащих вяжущих. При проведении научных исследований использовались стандартные средства измерений и методы анализа физико-механических характеристик арболитовых композитов, полученных с применением современных методов рентгенофазового, дифференциально-термического, микроскопического анализа и испытательного оборудования. Свойства серосодержащих арболитовых образцов изучали в 7-ми, 28-ми, и 90 суточном возрасте в различных условиях и нагрузках.

Изучение влияния возникающих деформаций на предел прочности при сжатии серосодержащего арболита основывалось на определенных моделях структуры бетона. Серосодержащей арболит рассматривался как двухкомпонентная система, состоящая из фибры измельченного тростника и серосодержащей растворной составляющей, при этом прочность растворной части была величиной переменной. Для проведения исследования были изготовлены четыре серии образцов из серосодержащего арболита, а пятая серия, для сравнения – из серосодержащего керамзитобетона. Каждая серия состояла из шести образцов призм размером 150х150х600 мм, три из которых (модель I) состояли только из серосодержащей растворной части (отношение серы к пиритному огарку 1:3), а в трех других призмах (модель II) в середину помещались фибры измельченного тростника диаметром около 18-20 мм. Испытание призм-образцов производилось этапами, соответствующими приращению напряжения от 0,1 до 0,15 МПа, после каждой ступени нагрузки образцы выдерживали в течение пяти минут. Отсчеты по индикаторам (с точностью измерения 0,01 мм) брались после приложения каждой ступени нагрузки и перед приложением новой нагрузки. Такая методика испытаний позволяла выделить упругие мгновенные деформации и определить величину начального модуля упругости серосодержащих легких бетонов.

Установлено, что разрушение серосодержащего арболита происходит последовательно, сначала происходит разрушение растворной составляющей, а затем – органического заполнителя. Полученные результаты можно использовать при изготовлении эффективного стенового материала для зданий гражданского назначения, в том числе для сейсмических районов.

Ключевые слова: серосодержащие арболитовые композиты, прочность, фаза твердения, длительная нагрузка, модуль деформации, растворная составляющая, разрушения.

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COMPUTER SIMULATION OF FIRE TEST PARAMETERS FAÇADE HEAT INSULATING SYSTEM FOR FIRE SPREAD IN FIRE DYNAMICS SIMULATOR (FDS)

Abstract. This paper considers issues related to fire hazard of constructions of external walls fit with façade heat insulation and finished with rendering which is dependent on constructive solution of the heat insulating system and type of heat insulating material. Appropriate works aimed at use of "Fire Dynamics Simulator" (FDS) software for the computer simulation of fire spread across façade system surfaces and comparison of experimental and calculated data were analyzed.

A number of full-scale fire tests were conducted of the external wall constructions fit with façade heat insulation and finished with rendering for fire spread while using 150 mm wide slabs fabricated of expanded polystyrene of "PSB-S-25" type as heat insulating material. Computer simulation of fire dynamics using FDS numeric tool was implemented and results obtained were compared with experimental data in order to check possibility of use of appropriate software for the reproduction of real conditions of fires at dwelling houses.

Key words: expanded polystyrene, heat insulation, façade heat insulating system, construction fit with façade heat insulation and finished with rendering, standard temperature/time curve, external fire, computer simulation, fire spread across façade, FDS, PyroSim.

Introduction. Arrangement of constructions of external walls fit with façade heat insulation and finished with rendering is rather a widespread measure not only at our state but abroad as well. Work purposed at heat insulation can be performed during new construction as well as while conducting reconstruction or general overhaul of existing buildings. State-of-the art heat insulating materials have wide range of application and heat insulation of roofs, external, internal and basement walls as well as that of ceilings and floors are performed using them. One of the most common uses of heat insulating materials is heat insulation of façades of the buildings and, hence, issues related to their fire hazard require appropriate attention and studying in order to lower risk of fire occurrence and its negative consequences. Examples of fires accompanied with fire spread across façade systems of the buildings denote their special fire hazard [1]. This hazard is related directly with constructional specific features of the specific building, type of heat insulating material used and parameters of the fire itself [2]. The most frequent cause of ignition of constructions of external walls fit with façade heat insulation and finished with rendering is spread of fire from the window opening due to intensive fire inside the room. Convection heat flows are able to ignite combustible finishing of external walls under these conditions. A number of factors influences process of fire spread across façade systems. The following ones can be specified amongst them: external conditions (heat flows coming from the window opening, temperature regimes of burning of the heat insulating material), fire hazard indices of the heat insulating material (ignition temperature, fire spread velocity across the material, self-ignition temperature etc.), and architectural and space-and-planning characteristics of the building.

Problem definition. Based on the results of analyzing thermal and physical characteristics of heat insulating materials we can affirm that not all of them meet fire safety requirements. In particular, expanded polystyrene demanded in the construction sphere at present has significant drawbacks related to fire hazard indices: it is a combustible material, a number of toxic substances are evolved from it during fire and, moreover, it increases a great deal fire hazard of buildings fit with façade heat insulation [3]. Burning of polymers is complicated physical and chemical phenomenon; it includes processes of heat and mass transfer, chemical kinetics of reactions taking place both in condensed and gas phases as well as a number of other factors. Wide assortment of polymer materials characterized by their chemical composition and structure, availability of a number of components within them, and their combination with other construction materials and wide application in the construction sphere make for special conditions of occurrence, development and extinguishing of fires involving facades of the buildings [4].

Constructions of external walls fit with façade heat insulation and finished with rendering using heat insulating materials and finishing layer belonging to "non-combustible" combustibility group can be used for buildings and constructions of 47 m conditional height without any limitations [5]. Adherence to fire safety requirements standardized for external envelopes is met in full in such the façade systems and fire spread across the surface has virtually no place. Fire occurrence and development can take place as result of violation of fire safety requirements while arranging façade systems using some layer of combustible heat insulation and finishing layer composed of some combustible materials because of non-adherence to or otherwise violation of the general rules of arrangement and use of buildings with façade heat insulating systems of external walls.

Hence, issues related to ensuring fire safety of constructions of external walls fit with façade heat insulation and finished with rendering as well as development of organizational and technical measures aimed at increasing fire safety of such objects gain significant actuality.

Analysis of the recent studies and publications. A number of domestic and foreign researches were engaged in studying issues of fire safety of façade systems. It becomes rather widespread recently not only to conduct full-scale tests of façade systems for fire spread as specified by appropriate international standards but to use Fire Dynamics Simulator (FDS) [6] special software for the computer simulation [7,8] of fire spread across the surfaces of heat insulating and finishing systems and to compare experimental and calculated data [9-19].

Paper [9] contains description of the results of a number of studies derived using FDS software (Fire Dynamics Simulator, version 4.0) being compared with experimental data. Purpose of the work was check-up of FDS software capabilities for the simulation of flame spread as well as determination of optimum values of the combustible load material for the engineers' use of FDS. Experimental studies included both conduction of tests as specified in [10] and full-scale tests for fire spread according to [11].

R.Jansson and J.Anderson in their papers [12, 13] studied fire resistance of façade constructions by experimental and computational methods. The test installation simulated three-floor building fit with external heat insulating and finishing system. Numeric model was created in FDS CFD software with similar geometry and instruments. The authors managed to reproduce in due manner real test conditions in their model, but temperatures nearby the fire source could not be have been taken into account duly.

Authors of papers [14,15] compare results of full-scale fire tests of façade systems conducted as specified by Swedish (SP Fire 105) and British (BS 8414-1) methods. Results of experimental studies and computer simulation represented by them take into account some variations of fire impact, fire load and type of fuel. CFD (Computational Fluid Dynamics) simulation in FDS allowed reproduction of the temperature values determined experimentally both qualitatively and quantitatively.

Test of façade system was conducted in [16] as specified by the method demanded by French technical specification (IT 249) for labour safety regulations. It is aimed at limitation of fire risks of fire spread across facades to the upper levels. Simulation of fire dynamics was conducted using FDS for the two full-scale experiments having been performed by "Efectis France" testing laboratory. Principal purpose of the mentioned study was estimation of the ability of the computational model to reproduce quantitative results of measuring gas temperatures and heat release rate at test façade for further evaluation of characteristics of fire impact upon the façade. Satisfactory results for temperature and heat release rate (HRR) were derived when comparing experimental data with those obtained by numeric calculations.

In papers [17-19] the authors studied experimentally impact of horizontal separating elements installed at various heights between exposed openings at the building façade upon external fire spread and compared derived data using Fire Dynamics Simulator (FDS) numeric tool. Numeric study was subdivided into that for validation and comparative analysis. Validation study was conducted for the estimation of FDS as instrument used for the calculation in order to simulate external fire spread; it was fulfilled using experimental data for large-scale fire test having been conducted using SP FIRE 105 test bench in the town of Buros (Sweden). SP FIRE 105 test bench is used for façade systems testing which simulates impact of fire involving ground floor of a three-floor dwelling house upon the upper façade. Conclusion was made that FDC version 6.2.0 could reproduce experimental results with high degree of detailing.

Principal purpose of this work was determination of the parameters of fire test of the construction of external wall fit with façade heat insulation and finished with rendering for fire spread using computer simulation, reproduction of the conditions of fire tests in due manner and check-up of the model developed by comparison of the derived data and results of the experimental studies.

Methods. Tests for fire spread were conducted on an external wall construction fit with façade heat insulation and finished with rendering using slabs fabricated from expanded polystyrene as heat insulating material.

The tests were conducted as specified by [20]. Essence of the test method lied in the determination of the sizes of the damaged section of the façade heat insulating system and temperature rise inside the heat insulating and finishing system having been applied to a fragment of two-floor building (figure 2) of 5.6 m total height at ground floor of which (fire chamber) temperature-time curve was being created close to standard temperature/time curve standardized by [21].

Type K thermocouples with 1.5 mm wires were used for measuring temperature inside the fire chamber; these ones were suitable for measuring temperature in the range of 0 °C to 1300 °C. Temperature inside the fire chamber was measured at least at nine point. Measuring junctions of the thermocouples were installed 190 mm to 210 mm from the surfaces of the walls. Layout of the thermocouples (T1 to T8) positioning in the fire chamber is shown on figure 1.

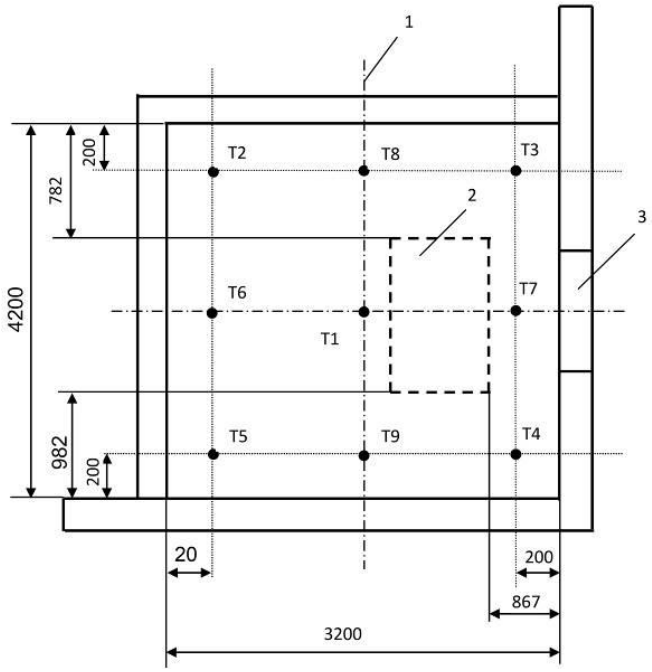


Figure 1 – Layout of the thermocouples positioning within the fire chamber:
1 – symmetry axis of the fire chamber; 2 – crib fabricated from wood bars; 3 – window opening;
T1 to T5 – thermocouples located at a distance of 200 mm from the ceiling surface;
T6 and T7 are thermocouples located at a distance of 850 mm from the ceiling surface;
T8 and T9 are thermocouples located at a distance of 1,500 mm from the ceiling surface [20]

Numeric simulation of the fire development and spread dynamics across the surface of heat insulating and finishing system was implemented using PyroSim instrument which is widely used software for fast and accurate operation of Fire Dynamics Simulator (FDS). PyroSim is graphical interface to FDS and it allows quick and convenient creation, editing and analyzing of complicated fire development models. Fire Dynamics Simulator (FDS) package of software was developed for the simulation of the processes of ignition and spread of fire [22,23]. The algorithms laid in its base are grounded upon physical laws of hydro dynamics and heat transfer. Smokeview software [24] was used for the two- and three-dimensional visualization of the fire dynamics simulation.

Fire Dynamics Simulator (FDS) realizes computational fluid dynamics model (CFD) of heat and mass transfer during combustion. Heat release rate is being calculated by finite elements method within three-dimensional mesh (simulation area). This software helps to reproduce real fire conditions in dwelling and commercial premises. Principal FDS purpose is solution of applied tasks in the sphere of fire safety and provision of the instrument necessary for the studying of fundamental processes during combustion.

Results. Measuring and recording of the temperature inside the building fragment was conducted at intervals not exceeding 1 min. Supervision of the test specimen was conducted as well and chronological description of its changes was compiled specifying, in particular, deformations, crippling, flame occurrence, cracks, smoke, softening, melting, materials charring and so on.

Figure 2 shows photos of the building fragments during the full-scale test at various moments.

a b c d

Figure 2 – Appearance of the building fragment at the time of testing at the following moments from the commencement: a – 5 min.; b – 20 min.; c – 30 min; d – upon removal of finishing and protective layer of façade heat insulation

Visual examination of the specimen was conducted following the test and dimensions of the damaged sections were determined which appeared within the specimen as result of fire impact. We considered damage to be charring and burning-out of the façade heat insulation materials as well as their melting. In order to determine sizes of the damaged sections of the internal heat insulation layer we removed external finishing and protective layer and made photographic survey of the specimen before and following the opening (figure 2 d).

Discussion. Maximum temperature rise values at the reference points within the heat insulating material (expanded poly styrene) layer compared with initial temperature at these points were 347 °C (T34) at 2.7 m height, 215 °C (T37) at 3.5 m height, 186 °C (T40) at 4.3 m height and 84 °C (T43) at 5.1 m height.

Dependency of the heat output of fire on time and appearance of the building fragment during computer simulation at various moments of time are shown on figure 3.

It was determined as result of computer simulation that maximum heat output of fire is reached at approximately 1,200 s (20 minutes) point of time and it is equal to 4600 kW. Local temperature values corresponding to maximum heat output reach 660 °C to 960 °C. Average temperature value within the burning area (fire chamber) at 20th minute equals to 760 °C to 780 °C.

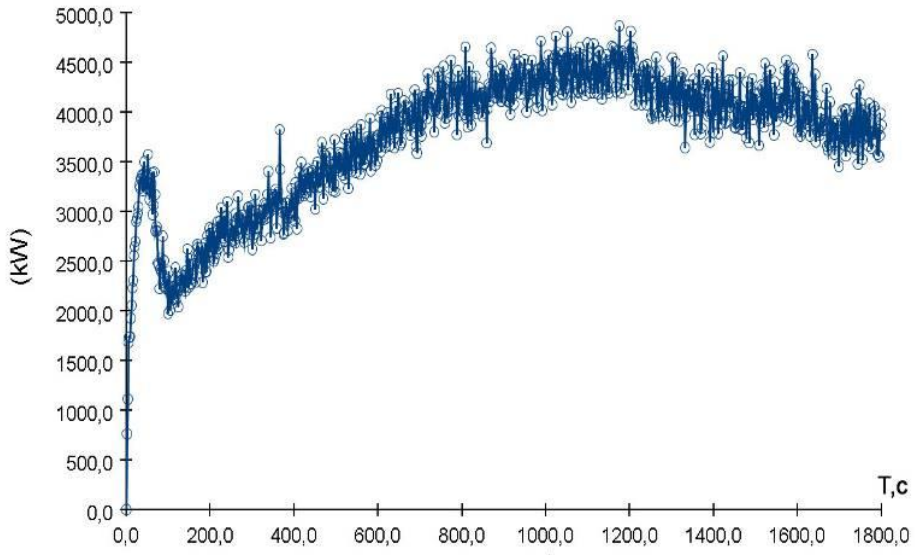
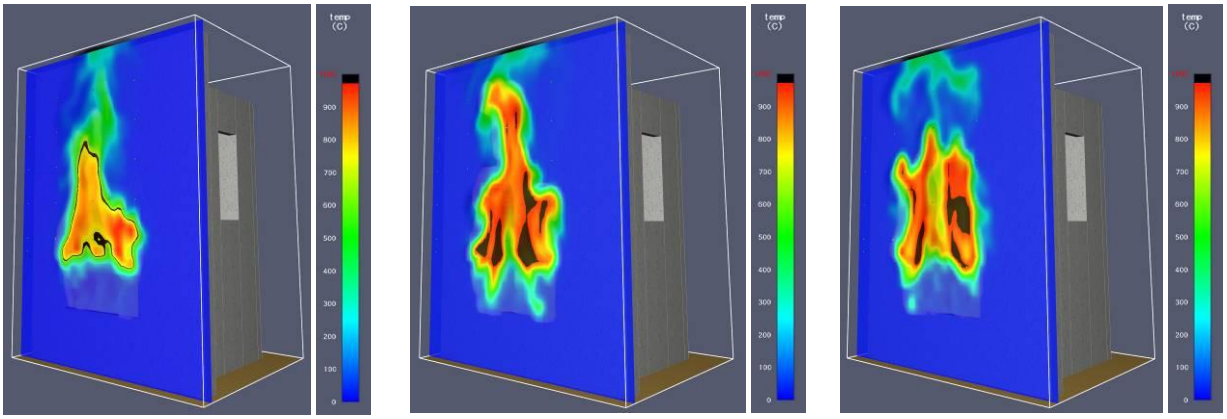


Figure 3 – Heat release rate versus time plot

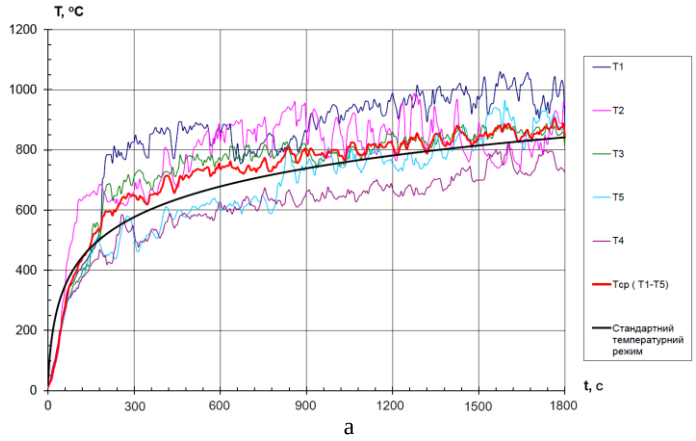
We fulfilled prognostication of dynamics of development and spread of dangerous factors of fire (smoke, heat, carbon monoxide etc.) using computer simulation; moreover, we derived numeric values and graphic representations of temperature of combustion products and heat release rate, temperature distribution within the fire chamber, inside the façade heat insulation system as well as at its surface (figure 4), and heat release rate (figure 3). Derived results of computer simulation of the dynamics of fire development and spread across the surface of the heat insulating and finishing system conform rather well with the results derived by foreign authors.



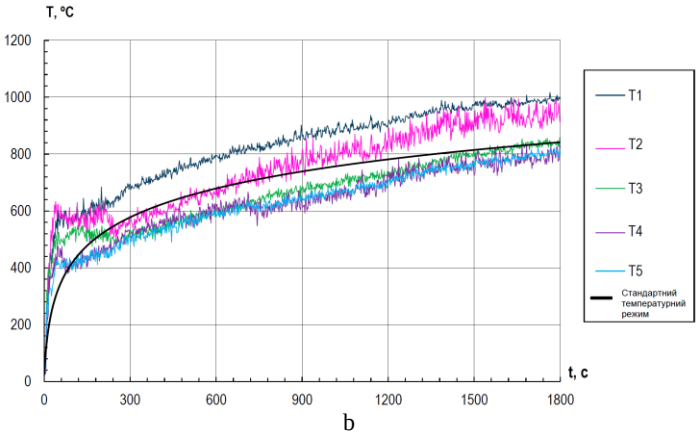
a b c

Figure 4 – Temperature distribution on the surface of the building wall at the time of simulation at the following moments from the commencement: a – 5 min.; b – 20 min.; c – 30 min

Results of FDS simulation are used for numeric evaluation of the temperature values within the fire chamber, inside and nearby the surface of the construction of the façade heat insulation and their comparison with the data derived empirically (figures 5-7).

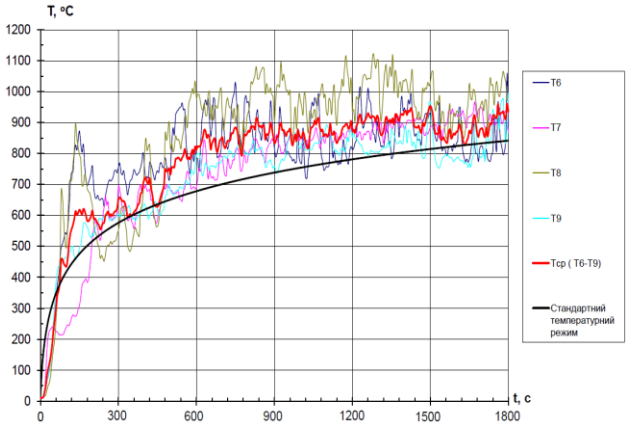


a

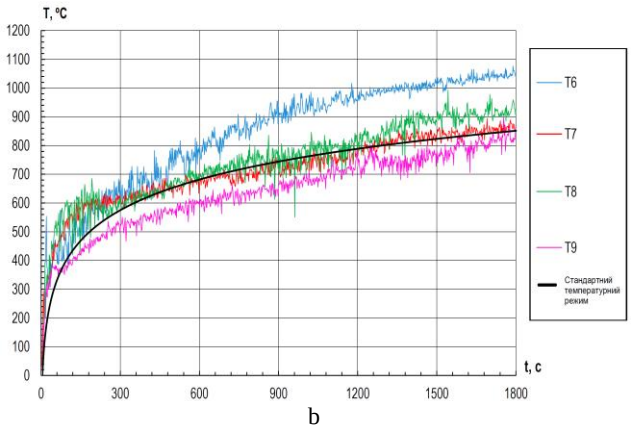


b

Figure 5 – Temperature evolution within the fire chamber (thermocouples T1 to T5): experimental results (a), FDS simulation results (b)



a



b

Figure 6 – Temperature evolution within the fire chamber (thermocouples T6 to T9): experimental results (a), FDS simulation results (b)

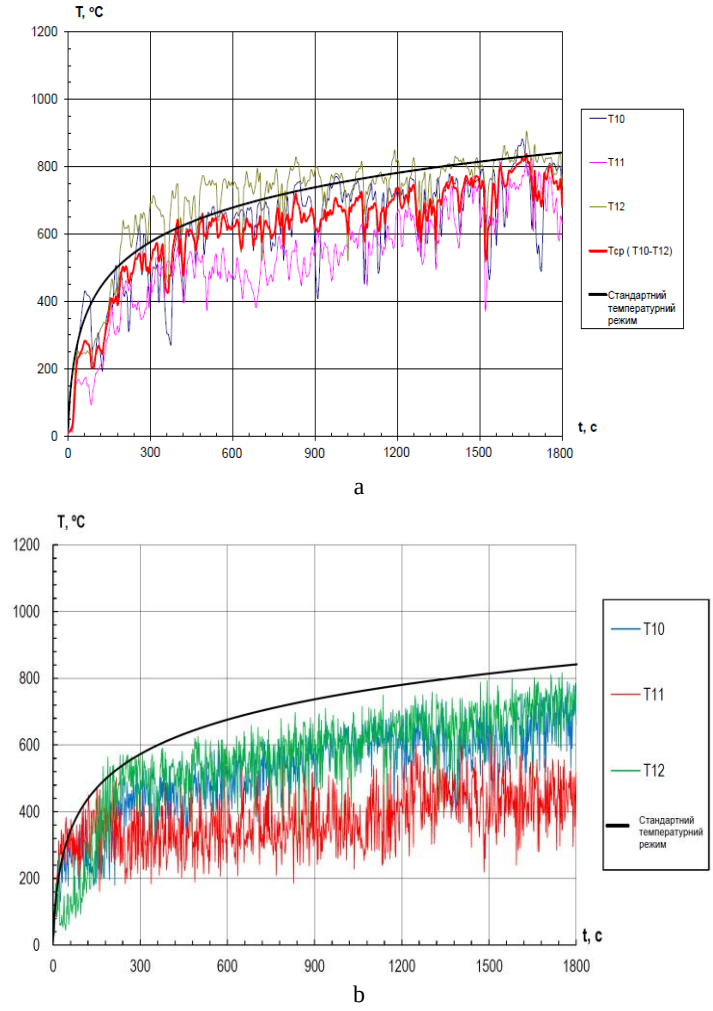


Figure 7 – Temperature evolution within the fire chamber (thermocouples T10 to T12): experimental results (a), FDS simulation results (b)

Conclusion. 1. Using computer simulation of the fire test parameters of the system of façade heat insulation for fire spread in FDS environment numeric and graphic performance were derived which characterize processes of occurrence, spread and development of fire across the surface of the system of façade heat insulation of a building. Simulation results derived allowed reproduction in due manner real conditions of testing, and when comparing experimental data and numeric calculations satisfactory results were obtained.

2. It was revealed as result of full-scale fire tests of a construction of external wall fit with façade heat insulation and finished with rendering and heat insulating material fabricated from expanded poly styrene slabs for fire spread that fire spread across the surface of the façade heat insulation did not take place beyond the boundaries of its direct contacting with flame generated inside the fire chamber.

3. Maximum values of temperature rise at the reference points within the heat insulating material layer (expanded poly styrene) compared with initial temperatures in these points are 347 °C (T34) at 2.7 m height, 215 °C (T37) at 3.5 m height, 186 °C (T40) at 4.3 m height, and 84 °C (T43) at 5.1 m height; these values do not exceed boundary one.

4. Results of the numeric simulation of fire test parameters of façade heat insulating system for fire spread in the FDS environment showed that general deviation within the theoretical calculations was not higher than that derived as result of the experimental researches. General temperature values within the fire chamber derived experimentally and numerically were different by 12 % to 16 %, value of the temperature in the window opening was underestimated by 16 % to 24 %, and temperature nearby the surface of the heat insulating and finishing system within the model was both overestimated by 22 % (T16 and T20) and underestimated by 18 % (T17, T21 and T19). Temperature values inside the façade heat insulating system did not exceed experimental data and deviation of average temperature values was equal to 16 %.

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ӨРТ ДИНАМИКАСЫ СИМУЛЯТОРЫНДА (FIRE DYNAMICS SIMULATOR (FDS) ОТ ТАРАТУ ҮШІН ҚАСБЕТТІК ЖЫЛУ ОҚШАУЛАҒЫШ ЖҮЙЕСІНІҢ ОТТЫ СЫНАУ ПАРАМЕТРЛЕРІН КОМПЬЮТЕРЛІК МОДЕЛЬДЕУ

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КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ ПАРАМЕТРОВ ОГНЕВОГО ИСПЫТАНИЯ СИСТЕМЫ ФАСАДНОЙ ТЕПЛОИЗОЛЯЦИИ НА РАСПРОСТРАНЕНИЕ ОГНЯ В FIRE DYNAMICS SIMULATOR (FDS)

Аннотация. Особенность пожарной опасности теплоизоляционно-отделочных систем фасадов зданий, где в качестве теплоизоляционного материала используется пенополистирол, заключается в возможности распространения огня на выше и ниже расположенные этажи здания. Во время пожара происходит разрушение слоя декоративно-защитной отделки и возгорания большой площади горючего утеплителя обуславливает образование высоких температур и значительного задымления.

Угроза распространения пожара по теплоизоляционно-отделочной системе обусловлена не только пожарной опасностью материала, который в ней используется, но зависит также и от конструктивных особенностей конкретного здания и параметров самого пожара. Частыми причинами возгорания теплоизоляционно-отделочных систем наружных стен является опрокидывания огня из оконного проема здания в результате интенсивной пожара в помещении. В таких условиях конвективные потоки тепла способны занять горюче облицовки наружных стен.

На процесс распространения огня фасадными системами влияет ряд факторов. Среди них можно выделить следующие: внешние условия (тепловые потоки из оконного проема, температурные режимы горения теплоизоляционного материала) пожарно-технические характеристики материала теплоизоляции (температура воспламенения, скорость распространения огня по материалу, температура самовоспламенения и др.) архитектурные и объемно-планировочные характеристики здания.

В данной работе рассмотрены проблемы, связанные с пожарной опасностью конструкций наружных стен с фасадной теплоизоляции с отделкой штукатуркой, которая зависит от конструктивного решения системы теплоизоляции и вида теплоизоляционно материала. Проанализированы работы, направленные на использование программного обеспечения Fire Dynamics Simulator (FDS) для компьютерного моделирования распространения огня поверхностью фасадных систем и сравнения экспериментальных и численных данных.

Проведены натурные огневые испытания конструкции наружной стены с фасадной теплоизоляцией с отделкой штукатуркой на распространение огня, где в качестве теплоизоляционного материала использовали пенополистирол марки «ПСБ-С-25», средней толщиной 150 мм. Исследованием подлежала скрепленная фасадная теплоизоляция с отделкой штукатуркой и утеплителем из пенополистирольных плит. Сущность метода испытаний заключалась в определении размеров повреждения теплоизоляционно-отделочной системы и значение повышения температуры внутри теплоизоляционно-отделочной системы, нанесенная на фрагмент двухэтажного дома общей высотой 5,6 м, на первом этаже которого создавали в течение 30 минут температурный режим, близкий к стандартному температурного режима.

Численное моделирование динамики развития и распространения пожара поверхностью теплоизоляционно-отделочной системы выполняли с помощью инструмента PyroSim, который является популярным программным обеспечением для быстрой и точной работы с Fire Dynamics Simulator (FDS). PyroSim является графическим интерфейсом для FDS и позволяет быстро и удобно создавать, редактировать и анализировать сложные модели развития пожара. Пакет компьютерных программ FDS (Fire Dynamic Simulator) разработан для моделирования процессов воспламенения и распространения пожаров. Алгоритмы, которые вошли в его основу, основанные на физических законах гидродинамики и теплопередачи. Для трехмерной и двухмерной визуализации результатов моделирования динамики пожаров применяли программу Smokeview.

Основной целью данного исследования было получение числовых показателей, характеризующих процесс возникновения, распространения и развития пожара теплоизоляционно-отделочной системы внешней стене дома. Полученные результаты компьютерного моделирования позволили воссоздать должным образом реальные условия испытания, а при сравнении экспериментальных данных с многочисленными расчетами было получено удовлетворительные результаты температуры и теплового потока.

В результате численного моделирования было определено, что максимальная мощность пожара достигается на 1200-й секунде (20-я минута) и составляет 4,6 МВт. При максимальном значении мощности выделения тепла при пожаре локальные значения температуры достигают 660-960 °С. Среднее значение температура в зоне горения (огненная камера) на 20-ю минуту составляет 760-780 °С.

С помощью компьютерного моделирования было выполнено прогнозирование динамики развития и распространения опасных факторов пожара (дыма, температуры, угарного газа и т.п.), а также получено многочисленные и графические значения температуры продуктов горения и теплового потока, температурного распределения в огневой камере, внутри и на поверхности системы фасадной теплоизоляции, мощности выделения тепла (HRR). Полученные результаты численного моделирования динамики развития и расспространения пожара поверхностью теплоизоляционно-отделочной системы достаточно хорошо согласуются с результатами исследований зарубежных авторов.

Результаты FDS моделирования использовались для численной оценки значений температуры в огневой камере, внутри и у поверхности конструкции фасадной теплоизоляции для сравнения их с данными, полученными экспериментальным путем.

Ключевые слова: пенополистирол, теплоизоляция, система фасадной теплоизоляции, конструкция с фасадной теплоизоляцией с отделкой штукатуркой, стандартный температурный режим, пожар, компьютерное моделирование, распространения пламени по фасаду, FDS, PyroSim.

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COMPUTER MODELING OF RODS AND WIRES PRESSING ON THE RADIAL SHIFT MILL OF THE NEW DESIGN

Abstract. In this article the Radial-shift mill (RSM) of a new design is proposed, which allows by combining of rolling and pressing to obtain high-quality rods and wires. The analysis of the stress-strain state (SSS) computer modeling results and heavily loaded elements vibration of the new mill stand using the finite element method and deformational model of the metal strength is presented. The influence of changes in the construction of frame parts on the elastic deformation of heavily loaded elements of the RSM stand is determined. It is shown that the new mill has a sufficiently high rigidity of the stand structure and satisfies the strength condition. It is noted that the pressing of small rods or wires on the proposed mill will lead to the obtaining of finished rolling with precise geometric dimensions. As a result of modeling the heavily loaded elements of the new mill stands elastic deformation, measures for their modernization were developed. The SSS of billets during pressing rods and wires on the RSM was also investigated in this work. By the method of finite elements and MSC. SuperForge program, quantitative data were obtained and the basic patterns of the distribution of SSS, temperature during the pressing of rods and wires on RSM with various single compressions were established. It is shown that pressing on a new designed RSM allows getting the optimal distribution of SSS, which leads to formation of a fine-grained structure in rods and wires.

Key words: radial-shift mill, frame, rolls, stands, matrix, bearings, elastic deformation, rod, wire.

Introduction. Mills of cross-helical and radial-shift rolling (RSR) [1,2,3], and also of radial-shift broaching [4,5,6] became the main equipment for the production of rods and wires. When using mills data, the rolling of the billets is carried out in the deformation zone formed by three working rolls unfolded to the feed and rolling angles and located after 120° around the deformed billet [3,7,8]. In this case, the longitudinal and rotational deformation of the metal is realized, which ensure a "helical" metal flow, which leads to the formation in the metal of the "spiral" microstructure. In this case, shift deformation degree increases significantly due to the development of macro-shift deformation along the section of deformed billet [9-12]. All this increases the quality of manufactured rods and wires [13-17].

According to the author of the work [18], designing of above-mentioned mills is carried out without taking into account the distribution of stresses on the volume of construction elements of the working stand, which leads to high metal consumption and unreasonable high manufacturing costs.

In our opinion, the use of computer technology and numerical methods, especially the finite element method (FEM), makes it possible accurately determine the SSS of heavily loaded elements of the mill stands and reduce metal consumption and manufacturing costs. For this reason, we believe that the calculation of the SSS of mills of complex construction is an actual task.

Rolling equipment designing method development via simulating modeling of complex construction of the mill and calculation the SSS arising when making heavy loads allows to reasonably choose the equipment characteristics taking into account technological, constructional and operational factors.

The target of the work is to develop the constructing algorithm of computer model of the designed mill and then by using a computer model to design and adjust the mill construction.

Materials and research methods. A radial-shift mill (RSM) of a new design is proposed at the present work [19]. By the combination of hot screw rolling and pressing the metallic rods of small diameters or wires with a fine-grained structure are producing at this mill.

The RSM for pressing rods and wires contains the main drive, working stand, roll knot and the press matrix. The three-roll RSM working stand consists of a frame, in the borings of which, after 120°, the knots of the working rolls are mounted. Working rolls are mounted on the pillows. Torque to the rolls is transmitted via spindles from electric motors. The rolls of this mill have wavy-cone-shaped capture and compression sections and a calibrating section. Note that the ledges and hollows of wavy-cone-shaped sections are made along the helical line. Wherein, the geometric dimensions of the ledges and hollows gradually decrease at the direction of rolling.

The working stand of the RSM consists of two continuous square frames. There are the mechanisms for installing the pillows of the upper and lower working rolls in the through holes of the frames. The approach and breeding of the upper and lower rolls are carried out using wedge- type pressing mechanism. Wedge- type pressing mechanism has rotating screws. To rotate the screws, a gear motor mounted on the frame is used.

Devices which allow adjusting the feed angle and the angle to the rolling axis are provided in construction of the RSM stand. The maximum feed angles values are 18 mm, and the angle to the rolling axis can be constructively adjusted based on the possibility of the rolling technology expansion on a new mill.

To eliminate all possible gaps between the rollers and pillows, wedge mechanisms and the frame, each pillow mounting mechanism was equipped with spring-loaded rods or hydraulic cylinders.

The design of the RSM was carried out by using the accumulated experience in the design of such equipment [20]. At the same time, we developed the frame design, constructed the drive and calculated the strength and rigidity of the heavily loaded elements and the drive power of the new mill, selected electric motors and developed working drawings of this mill.

It should be noted that existing methods for calculating the elastic deformations and vibrations of heavily loaded elements of the mill frames do not allow to take into account all the constructive and technological features of rods and wires hot pressing process. In this regard, the strength and vibration of the heavily loaded elements of the new mill were investigated by computer modeling. The original data for the calculation is the solid-state geometric shape of the RSM, the forces applied to them and the fixing conditions.

For calculating SSS, we applied the Patran Nastran [21] finite element analysis program and developed a computer model of RSM. The computer modeling system Patran Nastran allows to research the kinematics, the dynamics of the mechanisms with the ability to calculate the flexure, vibration, SSS and thermal state of both individual sections and the mill as whole.

When constructing a new mill in the MSC Nastran environment, the above indicators were calculated according to the following algorithm. In the KOMPAS program according to the working drawings, we created a three-dimensional geometric model of each detail and assembled the sections of the working stand. Further we imported the model into the Nastran Patran preprocessor with accepted kinematic connections. We chose the materials of the details, their mechanical and physical properties. Formed kinematic and static boundary conditions, simulated an estimated mechanical scheme, including the load distribution on the surface of the rolled billet. We brought the torque to the rolls (the torque was modeled by using RBE2 type MPC elements). Using the Mesh Seed options, we applied 6 and 8-node volumetric finite element mesh and determined the vibration and SSS.

When developing the calculation scheme, thickened finite element meshes were used in places of the expected stress concentration. Elastic bonds between the stand nodes were modeled by the spring - damper element CBUSH.

For automatic correction of the mill model geometry, the method of geometric sizes construction parameterization was used. This method allows making the corresponding changes in the construction of the new RSM frames, according to the results of heavily loaded parts of the RSM estimated strength, their movement and vibration.

As the material of the rolls and matrix was adopted Steel 9X1, for the frame stands - steel grade 40XC. And the material of other parts of the mill was adopted steel 45.

The software complex MSC.SuperForge was used for calculating the effort and SSS of the pressed rods [22]. A three-dimensional geometric model of the billet, rolls and matrix was built in the CAD Inventor program and imported into the CAE the MSC.SuperForge program. When creating the finite element model of the billet, rolls and matrix the three-dimensional volumetric element CTETRA (four-node tetrahedron), which is applying for modeling three-dimensional bodies was used.

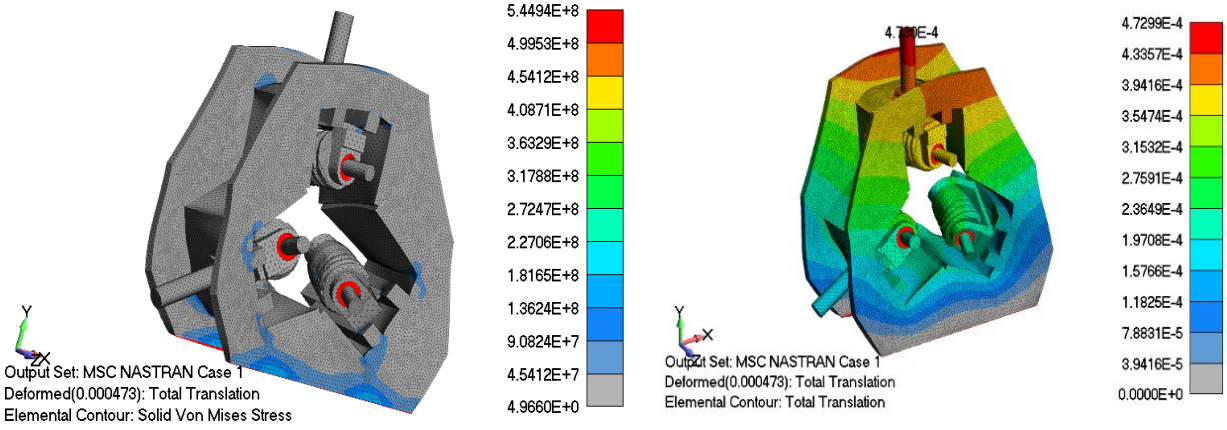
To search the pressing process in continuous RSM, a round billet of M1 copper alloy with a size of Ø40 × 150 mm was used. The billets pressing have been at a temperature of 300 °C up to Ø9 mm. For modeling the plasticity of the billet material, the Johnson-Cook elastoplastic model was chosen. From the database of the software complex "MSC.SuperForge" we set the rheological properties.

To calculate the SSS and normal pressure forces, the technical characteristics of the proposed RSM were used. The electric motor power is 15 kW, and the rotation frequency of the rolls is 70 rpm. Rolling was performed with a feed angle equal to $\beta = 15°$ and a rolling angle of $\alpha = 8°$. The contact between the tool and the rod was modeled by the Coulomb friction law; the coefficient of friction was adopted as 0.3.

We launched the MSC.SuperForge program, and by the step-by-step method calculated the contact pressure, contact area, SSS, and temperature distribution over the volume of the pressed billet.

To calculate the SSS of RSM heavily loaded parts by simulation modeling, we carried out a series of experiments on the pressing of the M1 copper alloy with different geometric sizes of the matrix. Based on the calculation results, the force acting in the contact zone was taken equal to 320 kN per roll and 280 kN to the matrix.

Obtained results and their discussion. As a result of a computer modeling of the M1 copper alloy pressing process at the RSM, were obtained the data that can be used to correct the construction of the mill at the designing stage. From figure *a*, it can be seen that the maximum equivalent stresses occur on the necks of the roll and amount 499.5 MPa. The calculated maximum values of equivalent stresses in heavily loaded roll and matrix do not exceed the maximum allowable value of the tensile strength of steel 9X1 (880 MPa). Stresses in the stand frame amounted 45.412 MPa, which is also significantly less than the tensile strength of steel St40XC (981 MPa).



a) *b*)

The distribution of equivalent stresses (a) and displacement fields (b) on a new design RSM

The greatest displacement under the load is 0.000434 mm and occurs in the necks of the rolls (figure, *b*). This value is within the tolerance limit on the diametrical sizes of the rods, with a diameter up to 20 mm. For the frame, the greatest displacement under a load is 0.000315 mm and occurs in its upper part, and for the RSM matrix this displacement is 0.000093 mm.

The calculation of the components of the stress tensor showed that during the rolling on a new mill the tensile principal stresses arise mainly in the necks of the rolls. The value of the main maximum, average and minimum stresses arising in the necks of the working rolls does not exceed 631.9, 263.8 and 69.95 MPa, respectively. The main maximum stresses arising in the frame stand are tensile and do not exceed 26.84 MPa. It should be noted that the main average and minimum stresses occurring in the frame stand are, in most cases, compressive and do not exceed 7.12 and - 43.97 MPa, respectively.

The results of computer modeling indicate that the RSM stand has a sufficient margin of safety. The estimated rigidity of the mill construction provides the production of rods with high accuracy diametric sizes.

The obtained data showed that the roll units of the designed mill have low rigidity in the horizontal plane. This is connected with the lack of supports in the mill stands, excluding the movement of the working rolls in the horizontal plane, and also the non-horizontal arrangement of the spindles of the mill drive. As a result, even small gaps between bearings, pillows and frame windows caused by fit tolerances and wear lead to horizontal dislocation of the vertical axial plane of the working rolls, i.e. working rolls are in an unstable position, and their axes can warp. This leads to negative consequences: High axial forces occur in the roll unit, and the size of the inter-roll gap is subject to unpredictable oscillations, which reduces the accuracy of rolling.

The calculation found that the pillows are elastically deforming in the vertical and horizontal plane and rotate for a small angle relative to the rolling axis. The elastic displacement in the direction of the load effect for pillows located on the roll' drive side is 1.41 times greater than for pillows located on the opposite side of the roll.

It should be noted that the use of spring-loaded traction to reduce gaps has insignificant effect on the elastic deformation of the bearings. Elastic deformation of bearings varies from 0.0028 to 0.0032 mm. However, the use of hydraulic cylinders to reduce the gaps leads to a significant reduction in value and square of elastic deformation of the bearings. In this case, the elastic deformation of the bearings varies from 0.0008 to 0.0009 mm. The external rings of the bearing have maximum deformation, while with a decrease of the rolls diameter, the area of highest elastic deformation of the bearing is shifted to the internal sides of roll neck. This is connected with a change in the load application scheme in the RSM roll unit.

In accordance with the conducted research, the RSM stand modernization activities were developed in the work. The research showed that it is necessary to install a hydraulic hold-down device in the stand in order to regulate the inter-roll gap of the working rolls. To ensure uniform load distribution and increase service life, it was proposed to replace the bearings. It was offered to use an angular- contact conic double-row roller bearing with a higher load capacity instead of a double row spherical roller bearing in the pillows of stand. To increase the rigidity of the RSM frame, stiffening ribs were attached to its plates. That is, inside the through apertures and around the perimeter of the plates, solid plates with thickness 30 mm were attached. These plates will be used as guides for the installation mechanism of the rolls pillows and wedges of the hold-down mechanism. The proposed design solutions will allow reducing the level of deformation of the mill main elements and getting 5-10 times the safety factor of heavily loaded parts of the mill stand.

It is known that during RSM operation, resonance oscillations that occur when matching the frequency of the construction and the frequency of external forces are especially dangerous. Therefore, it is important to determine the frequency of external forces. One of the main exciters of resonant frequencies in the design of rolling mills is the working rotation frequency of the working rolls drive, which spread the vibration to the mill.

During the amplitude estimating, the oscillations of the mill frame complete with a roll unit and a matrix, the following results were obtained:

- the highest oscillation amplitude gains the RSM matrix;

- at a natural oscillation frequency of the mill equal to 96.6 Hz, 121.08 Hz, 170.63 Hz, 173.01 Hz, 268.47 Hz and 277.73 Hz, the maximum amplitude value of the matrix oscillation is 0.26 mm, 0.199 mm, 0.00695 mm, 0.0168 mm, 0.0203 mm, 0.0763 mm, accordingly.

It should be noted that the RSM frame stand acquires average oscillation amplitude. Their value, at the natural frequency of the mill oscillation, is 96.6 Hz, 121.08 Hz, 170.63 Hz, 173.01 Hz, 268.47 Hz and 277.73 Hz equal to 0.0233 mm, 0.0166 mm, 0, 0556 mm, 0.00586 mm, 0.0218 mm, 0.12 mm, respectively. The least oscillation amplitudes the roll units of the designed RSM had.

The reason for the appearance of a relatively small resonant vibration in the matrix, frame and roll units of the proposed mill is the location of the RSM drive spindles at an angle to the axis of rolling, as well as the lack of a sufficiently high matrix and roll units rigidity in the vertical and horizontal plane.

It should be noted that hydraulic dampers were introduced into the design of the new mill to clamp the matrix and the roll assembly. The hydraulic damper consists of an elastic element, i.e. frame, and

hydraulic cylinder. These elements are connected in parallel. In this case, under the action of rolling forces to the stand frame and its elastic deformation, exceeding the permissible value, a compression pressure is created in the damping hydraulic cylinder, which allows fully or partially damping the vibration.

In our opinion, the use of hydraulic dampers for clamping the matrix and the roll unit will eliminate horizontal and vertical displacement of the matrix and working rolls. In this case, the RSM drive will allow to transmit torques to the working rolls of the mill stands with a large reserve up to resonant vibration. It is expected that all this will contribute to the production of rods and wires with precise geometric dimensions and without surface defects.

Based on the MSC.SuperForge program, from the obtained results of numerical modeling of the M1 copper alloy pressing process the following conclusions can be made. On the surface of the billet, small tensile principal stresses σ_{11} arise, while in the outer layer, compressive principal stresses σ_{22} and σ_{33}effect on each element. During the deformation in helical rolls and matrix of the proposed design, in the deformation zone, the metal flows along a helical path with different speeds of external and internal layers. The movement of metal flows at different speeds causes intense shear displacements in the volume of the billet, which leads to a significant increase of the deformation intensity, and this contributes to a significant grinding of grains and obtaining an ultrafine-grained structure.

Large shear deformations are accompanied by heating of the metal. The temperature effect of heating is up to 100-150 °C. This heating allows reducing the heating temperature before pressing, and significantly optimizes the temperature interval of the processing.

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Conclusions. 1. By the dynamic modeling were obtained quantitative data and established the basic regularities of the SSS distribution and strength characteristics of heavily loaded elements when pressing rods and wires on the RSM.

2. Through the application of information technology, the rational design of the RSM was determined and methodology for selection the technological modes of deformation when pressing rods and wires on this mill was developed.

3. It is proved that when pressing rods and wires on the RSM, dangerous vibrations do not fall into the working range of acting external loads.

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ЖАҢА ҚҰРЫЛЫМДЫ РАДИАЛДЫ ЫҒЫСТЫРУ ОРНАҒЫНДА ШЫБЫҚТАР МЕН СЫМДАРДЫ СЫҒЫМДАУДЫ КОМПЬЮТЕРЛІК МОДЕЛЬДЕУ

Аннотация. Мақалада біріктірілген илемдеу және баспақтау арқылы жоғары сапалы шыбықтар мен сымдар алуға мүмкіндік беретін жаңа құрылымның радиалды-ығыстыру орнағы ұсынылған. Металл беріктігінің деформациялы моделін және шеткі элементтер әдісін қолдана отырып, жаңа орнақ қапастарының ауыр жүктелген элементтерінің дірілін және кернеу-деформациялы күйін компьютерлік модельдеу нәтижелеріне талдаулар берілген. Ралиалды-ығыстыру орнағындағы қапастардың ауыр жүктелген элементтерінің серпімді деформациясына, орнақтың құрылымдық бөлшектері өзгерісінің әсері анықталды. Жаңа орнақтың, қапастар құрылымының айтарлықтай қатты және беріктік жағдайын қанағаттандырарлық екендігі көрсетілген. Ұсынылып отырған орнақта кіші өлшемді шыбықтар мен сымдарды баспақтау нақты геометриялық өлшемі бар дайын жаймалауға әкелетіні көрсетілген. Жаңа орнақ қапастарының ауыр жүктелген элементтерінің серпімді деформациялануын модельдеу нәтижесінде оларды модернизациялау шаралары жасалып шығарылды. Жұмыста, сонымен қатар, радиалды-ығыстыру орнағында шыбықтар мен сымдарды баспақтау кезінде дайындамалардың кернеу-деформациялы күйі зерттелді. Шеткі элементтер әдісі және MSC.SuperForge бағдарламасы арқылы сандық мәліметтер алынды және әртүрлі бірлік жаншумен радиалды-сығымдау орнағында шыбықтар мен сымдарды баспақтау кезіндегі температураның, кернеу-деформациялы

күйдің негізгі таралу заңдылықтары белгілі болды. Жаймалаудың тиімді технологиясы жасалды. Бұрыннан белгілі және алынған мәліметтер негізінде баспақтау режимінің болаттар мен қорытпалар құрылымының қалыптасу әсеріне талдау жасалды. Жаңа конструкциялы радиалды-ығыстыру орнағында баспақтау үдерісі құрылымы ұсақтүйіршікті шыбықтар мен сымдар алуға мүмкіндік беретіні көрсетілген. Динамикалық модельдеу арқылы сандық мәліметтер алынды және радиалды-ығыстыру орнағында шыбықтар мен сымдарды баспақтауда ауыр жүктелген элементтердің беріктік сипаттамаларының және кернеу-деформациялы күйінің негізгі таралу заңдылықтары белгілі болды. Ақпараттық технологияларды қолдана отырып, радиал-ығыстыру орнағының тиімді құрылымы анықталды және аталған орнақта шыбықтар мен сымдарды баспақтау кезінде деформациялаудың технологиялық режимін таңдау әдісі жасалып шығарылды. Радиалды-ығыстыру орнағында шыбықтар мен сымдарды баспақтау кезінде пайда болатын қауіпті діріл, сыртқы жұмысшы жүктеменің жұмыс диапазонына түспейтіндігі дәлелденді.

Түйін сөздер: радиал-ығыстыру орнағы, тұғыр, біліктер, қапастар, матрица, мойынтірек, серпімді деформация, шыбық, сым.

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КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ ПРЕССОВАНИЯ ПРУТКОВ И ПРОВОЛОКИ НА РАДИАЛЬНО-СДВИГОВОМ СТАНЕ НОВОЙ КОНСТРУКЦИИ

Аннотация. В статье предложен радиально-сдвиговый стан новой конструкции, позволяющий совмещением прокатки и прессования получать прутки и проволоку высокого качества. Представлен анализ результатов компьютерного моделирования напряженно-деформированного состояния и вибрации тяжелонагруженных элементов клети нового стана с использованием метода конечных элементов и деформационной модели прочности металла. Определено влияние изменений конструкции деталей станины на упругую деформацию тяжелонагруженных элементов клети радиально-сдвигового стана. Показано, что новый стан имеет достаточно высокую жесткость конструкции клети и удовлетворяет условию прочности. Отмечено, что прессование прутков малого размера или проволоки на предлагаемом стане приведет к получению готового проката с точными геометрическими размерами. В результате моделирования упругой деформации тяжелонагруженных элементов клетей нового стана разработаны мероприятия по их модернизации. В работе также исследовано напряженно-деформируемое состояние заготовок при прессовании прутков и проволоки на радиально-сдвиговом стане. Методом конечных элементов и программой MSC.SuperForge получены количественные данные и установлены основные закономерности распределения напряженно-деформируемого состояния, температуры при прессовании прутков и проволоки на радиально-сдвиговом стане с различными единичными обжатиями. Разработана рациональная технология прокатки. На основе известных и полученных данных сделан анализ влияния режимов прессования на формирование структур сталей и сплавов. Показано, что прессование на радиально-сдвиговом стане новой конструкции позволяет получить прутки и проволоку с мелкозернистой структурой. Динамическим моделированием получены количественные данные и установлены основные закономерности распределения напряженно-деформируемого состояния и прочностных характеристик тяжелонагруженных элементов при прессовании прутков и проволоки на радиально-сдвиговом стане. Путем применения информационной технологии определена рациональная конструкция радиально-сдвигового стана и разработана методика выбора технологических режимов деформирования при прессовании прутков и проволоки на данном стане. Доказано, что при прессовании прутков и проволоки на радиально-сдвиговом стане опасные вибрации не попадают в рабочий диапазон действующих внешних нагрузок.

Ключевые слова: радиально-сдвиговый стан, станина, валки, клети, матрица, подшипники, упругая деформация, пруток, проволока.

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METHODICAL SUPPORT OF INTEGRATED MANAGEMENT OF WATER RESOURCES OF THE BASIN OF TRANSBOUNDARY RIVERS

Abstract. Based on the principles of reasonable, equitable and rightful use of water resources in accordance with the concept, adopted at the «Agenda of the 21st Century» at the UN in Rio de Janeiro and developed by the European Environmental Agency – «DPSIR-analysis», as a method of systematizing the information and identifying the cause-effect connections in order to solve the problems of integrated water resources management in transboundary rivers, the system of integral criteria of geo-ecological restriction is justified, ensuring the restriction and prevention of the negative influence of transboundary impacts.

As an integral criterion for geo-ecological restriction, an indicator of the water availability curve taking into account climate change is developed, that is, the arithmetic average of the statistical series of the annual river flow, geomorphological schematization of the catchment area of the transboundary river basin, taking into account the heat and water availability of their landscape system, the maximum pollution of the river flow, territorial planning water use based on integrated parameters using climatic, geological and geo-morphological, hydrological and landscape factors, the ecological situation of the hydro-agrarian landscapes of the river basin catchment in "soil-plant-human" systems, the maximum permissible level of use of river basin water resources and ecological runoff, the available land resources of the river basin catchment and the ecological services of the river basin catchment, possible area of hydro-landscape systems in the catchment areas of river basins, a comprehensive assessment of environmental, economic and social damage caused by human activities.

Methodological substantiation of the criteria of geo-ecological restriction when using the water resources of the transboundary river basin, as a method of systematizing information and highlighting cause-effect relationships in order to solve the problems of integrated water resources management of transboundary rivers, covering all levels of the water use process from the formation and shopping of water resources and their watershed dispersal zones transboundary river basins can be used in the planning and implementation of integrated Water Management (IWRM).

Key words: water resources, transboundary rivers, concept, strategy, use, management, implementation, planning, integrated water resources management.

Relevance. To accelerate the transition to more sustainable methods of developing and managing water resources, based on the principles of reasonable, equitable and rightful use of water resources in accordance with the concept adopted on the «Agenda of the 21stCentury» at the UN in Rio de Janeiro, which is the fundamental norm of the legal regime of transboundary waters, according to which every state of the basin has the right within its territory to a reasonable and rightful share of the benefits from the use of the water of this basin. At the same time, the degree of equal use of transboundary waters which is reasonable and fair should be determined by taking into account the comprehensive consideration of all factors, including hydrographic, hydrological, hydrogeochemical and climatic conditions, as well as the use of water resources in the past and present to solve the economic and social problems of each state,

located in catchment of river basins. One of the factors in determining the reasonableness, equality, and justice is the degree in which the needs of each state can be met without causing significant damage to other States within the catchment areas of transboundary river basins. To solve this problem, it is necessary to form an integrated water resources management (IWRM) system for transboundary river basins, including mechanisms for organizing and jointly carrying out comprehensive measures aimed at reducing, limiting and preventing the negative influence of transboundary impacts, which requires the development and justification of criteria for geoecological restrictions that ensure the principles of reasonable, equitable and rightful use of water resources in accordance with the concept adopted on the «Agenda of the 21stCentury» [1,2,3].

The goal of the research is to develop the methodological support for planning and implementing the integrated water resources management in the transboundary river basins based on qualitative and quantitative integral criteria of geoecological restrictions, allowing the implementation of the principles of reasonable, equitable and rightful use of water resources in accordance with the concept adopted on the «Agenda of the 21stcentury».

Materials and research methods. The geoecological restrictions in the integrated water resources management of transboundary rivers are understood as the requirements and criteria for the environmentally acceptable use of the natural-resource potential of the catchments of river basins, confirming the preservation of the sustainability and sustainability of the natural system, their environmental and resource-generating functions.

To substantiate the integral criteria of geoecological restrictions in the integrated water resources management of transboundary rivers and their systematization, were used a concept developed by the European Environmental Agency «Driving force-Pressure-State-Impact-Responsibility»-DPSIR-analysis, as a method of systematization of information and the allocation of cause-effect relationships in order to solve environmental problems [European Environment Agency,1999] [4].

Research results. For balanced use of water resources of transboundary rivers, when planning and implementing IWRM, it is necessary to ensure the principles of reasonable, equitable and rightful use of water resources in accordance with the concepts adopted at the «Agenda of the 21stCentury» at the UN in Rio de Janeiro, which requires solutions:

2. Geomorphological schematization of the catchment area of a transboundary river basin taking into account the heat and water supply of their landscape system [5], possibly using the energy or work performed by the groundwater flow in the following form:

$$\Delta E = A_i = m_i \cdot g \cdot \Delta H = m_i \cdot g \cdot \Delta_i .$$

where ΔE – change in energy at the site ΔH ; ΔH , Δ_i - excess of the surface of the earth above the shore, m; m_i – average mass of underground water; g- acceleration of gravitational force.

2. Based on the long-term data of the hydrogeochemical regime and nutrient in the water resources of the transboundary river basin, an assessment of the quality and water pollution index of the environmental requirements of the fisheries and drinking water use [6], that is, methods based on the use of complex indicators, that is, determining the limits of permissible changes (ПДИ), are widely used to assess the quality of water resources and the ecological state of aquatic ecosystems in water management practice [7], threshold of critical action (ПДВВ) [8], maximum permissible concentration (ПДК) [8], hydrochemical pollution index (ГЗВ) [8], as well as methodological support N.G. Bulgakov [9], V.P. Yemelyanova [10], T.N. Moiseenko [11], V.V. Shabanov [12] and M.ZH. Burlibaev[13].

At the same time, to assess the quality of water and the ecological status of water bodies in the river basin, it is estimated using the method of V.V. Shabanov, using the coefficient of maximum pollution (K_{n3}) [12]:

$$K_{n3} = \frac{1}{N} \cdot \sum_{i=1}^{N} \frac{C_i}{ПДК_i} - 1,$$

where i – water pollutant number; N - amount of substances taken into account; $ПДК_i$ - maximum allowable concentration of substances taken into account; C_i - actual concentration of substances taken

into account; K_{n3} - coefficient of maximum pollution, characterizing the quality of water, the state of the water body of rivers and its water economic value, which are assessed according to the classification of water quality.

As structural characteristics of ecosystems, indicators of the species, size, trophic structure, flow structure can be used. For the quantitative characteristics of the structure most often used different indices, among which the most often - the Shannon index (H) [14]:

$$H = \sum(N_i / N) \cdot \lg 2(N_i / N),$$

where: N_i - number i - i-th species; N - number of all species.

3. Territorial water use planning based on integral parameters using climatic, geological, geomorphological, hydrological and landscape factors determining the ecologically acceptable limits for using the natural resource potential of the catchment area of a transboundary river basin are determined taking into account the geoecological restrictions proposed by Zh.S. Mustafayev and with co-authors [15,16]: lower threshold of maximum permissible level of water demand ($O_p^{ниж}$) – transpiration of plants, ensuring the formation of biological masses *(T)* and the upper maximum permissible level of the norm of water demand ($O_p^{верх}$) – ecological norms of water needs of agricultural land ($O_p^{э}$),providing targeted regulation and management of soil-forming processes on irrigated lands [22], and the biological irrigation rate (O_p) are determined on the basis of the bioclimatic method proposed by N.V.Danilchenko [17]: $E_v = E_o \cdot K_o \cdot K_б$ (where K_o - microclimatic coefficient; $K_б$ - biological coefficient), that is $O_p = E_v - (O_c \pm g + \Delta W)$, where ΔW - productive moisture in soil, mm.

4. On the basis of indicators of anthropogenic impacts, that is, demographic, industrial and agricultural, characterizing economic activities, the assessment of anthropogenic load on the catchment area of the river basin [18,19,20], can be used the generalized indicator ($K_{mн}$), which is determined by the formula [19]:

$$K_{кm} = \sqrt{\prod_{i=1}^{n} K_i^i},$$

where $K_i^i = \exp(-K_i)$- relative values of the level of anthropogenic load on the catchment areas of river basins or the coefficient of anthropogenic activity [19].

To assess the level of anthropogenic load on the drainage basin of transboundary rivers, was used the indicator of A.G. Isachenko, putting them in the form of a coefficient (K_i),characterizing the ratio of the individual actual technogenic load to their optimal value, which is taken as the level of the average load, that is, [20]:

- coefficient ($K_i^{пл}$), characterizing population density: $K_i^{пл} = П_{опт} / П_{фак}$, where $П_{фак}$ - actual population density, person/sq.km; $П_{опт}$ - optimal population density, which corresponds to the level of average load, person/sq.km;

- coefficient ($K_i^{пр}$), characterizing the density of industrial production: $K_i^{пр} = ПР_{опт} / ПР_{фак}$, where $ПР_{фак}$ – actual density of industrial production, thousand dollar/sq.km; $ПР_{опт}$ - optimal density of industrial production, which corresponds to the level of average load, thousand dollar/sq.km;

- coefficient ($K_i^{ра}$), characterizing the plowing of natural landscapes: $K_i^{ра} = F_{рас}^{опт} / F_{рас}^{фак}$, where $F_{рас}^{фак}$ – actual plowing of natural landscapes, % ; $F_{рас}^{опт}$ - optimal plowing of natural landscapes, which corresponds to the level of average load, % ;

- coefficient ($K_i^{жив}$), characterizing the density of livestock loading: $K_i^{жив} = N_{опт}^{жив} / N_{фак}^{жив}$,

where $N_{фак}^{жив}$ – actual density of livestock loading, conventional heads /sq.km; $N_{опт}^{жив}$ - optimal density of livestock load, which corresponds to the level of average load, conventional heads /sq.km.

At the same time, the total techno-genic load on the catchment areas of river basins was determined as the square root of the product of the relative values of the level of certain types of anthropogenic loads, as a result of which a generalized integral indicator can be obtained($K_{mн}$)characterizing the result of human activity[20].

5. Based on the indicators of anthropogenic activity, the assessment of the ecological situation of the hydro-landscapes of the catchment area of river basins in the systems «soil-plant-man» [22,23] can be done as follows, first consider the natural environment at the regional or local level, zoning by activity, not changing significantly on a spatial-temporal scale using the above negative reaction factors for humans - $\overline{NR} = NR_i / NR_{\max}$ and its habitation environment - $\overline{nr} = nr_i / nr_{\max}$ [22,23]:

- for human $\overline{NR} = \left(\sum_1^i \overline{D}i \cdot q_X \right) \sum_1^i \varepsilon_i(k)$;

- for its habitat $\overline{nr} = \left(\frac{\overline{D}_{вв}}{\overline{D}_{рв}} + q_X \right) \sum_1^i \beta \cdot \varepsilon_i(k)$,

where $\overline{D}i$ - the degree of contamination with chemicals of potable water for the supply of the population; $\overline{D}_{вв}$ - level of river water use for irrigation; $\overline{D}_{рв}$ - the level of use of return water for irrigation; ε_i - private parameters of the deterioration of the properties of the components of the natural system (for humans, this is the dynamics of diseases associated with the consumption of polluted water and air pollution- $\varepsilon_i(r)$, for soil, plants, and crops - the content of toxic salts in the soil, for groundwater - an increase in their mineralization and level - $\varepsilon_i(k)$); β - correction factor (for soil and groundwater $\beta = 1$, for agricultural crops $\beta > 1$); q_X - the intensity of the entry of toxic chemicals and nitrates into the soil and groundwater.

The intensity of the entry of toxic chemicals and nitrates into the groundwater ($q_X^{гв}$) and into the soil (q_X^n) estimated by empirical dependencies [22,23]:

$$q_X^{гв} = 1 - q_X^n;\ q_X^n = \exp\left[-(\alpha \cdot q_W + 1 - R_ф \right],$$

where α – constant, depending on the type of toxic chemicals; q_W - intensity of infiltration nutrition (in shares from the norm); $R_ф$ - infiltration resistance, which is determined by the formula: $R_ф = 1/ f_m$, here f_m – relative area occupied by soils with low soil thickness.

6. Assessment of the maximum allowable level of water resources use of the river basins and environmental flow, that is, disposable water resources for use in sectors of the economy [30].

For the environmental and economic justification of the maximum permissible level of use of natural resources in the context of anthropogenic activity, a retrospective analysis of the state of the components of the natural system and a long-term forecast of the expected consequences from the impact of various measures on them are necessary. As an integral indicator of assessing the environmental and economic efficiency of the complex use of natural resources, the total effect ($Z(x)$) can be used, which can be determined by the following formula [24]:

$$Z(x) = Z_n(x) - Z_э(x) - Z_{эк}(x) - Z_C(x) - ЗТ \cdot B_t,$$

where $Z_n(\overline{P}_n)$ – total profit of the natural-technical complex; $Z_n(x) = Z_n(\overline{P}_n - P_n(x))$; $Z_n(P_n(x))$ – natural complex profits in natural conditions; $Z_э(x) = Z_э(\overline{P}_э - P_э(x))$; $Z_э(\overline{P}_э)$ – economic damage from the deterioration of the quality parameters of the natural-technical system; $Z_э(P_э(x))$ – costs required for qualitative improvement of environmental parameters; $Z_{эк}(\overline{P}_{эк})$ – environmental damage from the deterioration of the quality parameters of the natural-technical system; $Z_{эк}(x) = Z_{эк}(\overline{P}_{эк} - P_{эк}(x))$; $Z_{эк}(P_{эк}(x))$ - costs necessary to improve the ecological conditions of the environment; $Z_c(x) = Z_c(\overline{P}_c - P_c(x))$; $Z_c(\overline{P}_c)$ – social damage from the deterioration of the quality parameters of the natural environment; $Z_c(P_c(x))$ – costs of improving the social conditions of the natural environment; $B_t = (1+e)^t$ – the coefficient of reduction in time of multi-time costs or discounting; t – calculation step number; e – efficiency coefficient; $ЗТ$ – society's costs for the implementation of environmental management systems.

On the basis of the Hurwitz criterion, it is possible to present a model of the design value of the coefficient of the ecological and economic activity of society when using natural resources.: $K_э^{пр} = \lambda \cdot K_э^{max} + (1-\lambda) \cdot K_э^{\min}$, где $K_э^{max}$ – the maximum possible value of the coefficient of economic sustainability of the natural system of the river basin; $K_э^{min}$ – the minimum value of the coefficient of economic sustainability of the natural system of the river basin; λ - empirical coefficient; $\lambda = 1 - \Delta Э$, here $\Delta Э$ – ecological state of the natural system of river basins [24].

7. Based on the principles of reasonable, equitable and rightful use of water resources of transboundary rivers, distribution of available water resources for use in economic sectors in the interstate level, in the administrative regions and districts [25] can be used the coefficient of available land resources($K_{зpi}$) of the catchment area of the river basin in the section of facies, which is determined by the formula [25]:

$$W_{бкi} = K_{зpi} \cdot (W_{oi} - \Delta W_{сэi}),$$

where W_{oi} – the volume of water resources of river basins, cubickm; $W_{сэi}$ - the volume of guaranteed sanitary-ecological water resources of river basins, ensuring the environmental sustainability of the natural system in the lower reaches.

8. Using the climate index of productivity of landscapes D.I.Shashko [26], determine the natural and potential bioclimatic potential of geomorphological facies of the catchment area of transboundary river basins using the system of «export-import» environmental services of water resources within the framework of interstate water distribution [21], i.e. the coefficient of ecological services of the catchment area of river basins, ensuring the balancing of the biological productivity of hydroagrolandscapes in the context of anthropogenic activities value, which is determined by the formula: $K_{бкi} = 1 - (Б_{кфi} / Б_{кфi}^{ср})$ и $\sum_{i=1}^{n} K_{бкi} = 0 \to const$ [19,25].

At the same time, the volume of water resources(W_i) for the provision of environmental services in order to increase «natural capital» ($ЕПК$) to potential natural capital ($ППК$) from the standpoint of the biological productivity of the plant and soil cover of certain landscape classes or catchment areas of river basins is determined by the formula [19,27]: $W_{бк(э-и)i} = K_{бкi} \cdot W_{бкi}$.

9. Based on the biological and ecological water requirements of vegetation and soil cover of landscape systems and disposable water resources in the context of geomorphological facies of the catchment area of transboundary rivers, determine the maximum possible area of hydro-landscape systems [28] taking into account the lack of regulation and over-regulation of the river flow, because of the level of rational use of river flows also depends on them, taking into account the intra-annual natural rhythm of their formation:

- in the unregulated zone, on the one hand, as indicators allowing to determine the maximum allowable($F_{n\partial o}$)and optimum(F_{oo}) area of irrigated land is the discharge of the river's available flow (Q_{rai}, cubic m/sec), i.e. the difference of natural discharge (Q_{oi}, cubic m/sec.) and ecological flow of the river ($Q_{\text{э}i}$,cubic m/sec.), and on the other hand, the norms of specific water requirements of the plant (q_{pi}, cubic m/sec. or l/sec. per 1 ha) and soil(q_{ni}, cubic m/sec. or l/sec. per 1 ha) covers formed in as a result of hydro-landscape systems in the watersheds of transboundary basins;

- in the zone of flow regulation, on the one hand, as indicators allowing to determine the maximum allowable ($F_{n\partial o}$) and optimal (F_{oo}) area of irrigated land is the volume of the river's disposable flow (W_{rai}, cubicm), that is, the difference of natural (W_{oi},cubic m) and ecological ($W_{\text{э}i}$,cubic m) volumes of the river basin, and on the other hand, the norms of water requirements of the plant (O_{pi}, cubic m/sec.or l/sec.per 1 ha) and soil covers (O_{ni},cubic m/sec. or l/sec. per 1 ha) of agricultural lands, formed as a result of hydro-landscape systems in the catchment areas of transboundary basins.

In the zone of unregulated flow of river basins, the maximum allowable area of irrigated land ($F_{n\partial o}$) is determined by the following formula:

$$F_{n\partial o} = \frac{(Q_{oi}^{\max} - Q_{\text{э}i}^{\max}) \cdot K_{ac}}{q_{pi}^{\max}} \cdot \eta_{k n\partial},$$

And the optimal area of irrigated land(F_{oo}) is determined by the following dependence:

$$F_{oo} = \frac{(Q_{oi}^{\max} - Q_{\text{э}i}^{\max}) \cdot K_{ac}}{q_{ni}^{\max}} \cdot \eta_{k n\partial}$$

where $F_{n\partial o}$- maximum allowable area of irrigated land, ha; F_{oo}- optimal area of irrigated land, ha; - the natural flow discharge of the river, cubic m/ha; - ecological flow discharge of the river, cubic m/ha; q_{pi}- the norm of specific water requirements of agricultural land cover, cubic m/s or l/s; q_{ni}- the norm of specific water requirements of the soil cover of agricultural land, cubic m/s or l/s; $\eta_{k n\partial}$- the efficiency of the water system; K_{ac}- coefficient of synchronization of river discharge and the norm of specific water demand for agricultural land, which is determined by the following expression:

$$K_{ac} = \frac{\sum_{i=1}^{n} K_{aci}}{n},$$

where n – the number of months in the vegetative (considered) period; K_{aci}- coefficient of synchronization of river flow and the rate of specific water requirements of agricultural land and the i–th month of the growing season (considered) period, which is determined by the following dependencies:

$$K_{aci} = [(Q_{rai} / Q_{rai}^{\max}) / (q_{pi} / q_{pi}^{\max}]; \; K_{aci} = [(Q_{rai} / Q_{rai}^{\max}) / (q_{ni} / q_{ni}^{\max}],$$

where $Q_{rai}^{\max}$ – the maximum value of the natural flow of the river in the vegetative (considered) period, cubic m/sec.; $q_{pi}^{\max}$- the maximum norm of specific water demand for vegetation cover of agricultural land within the growing season, cubic m/sec.; $q_{ni}^{\max}$- maximum norm of specific water demand for soil cover of agricultural land within the growing season, cubic m/sec.

In the zone of regulated flow of river basins, the maximum allowable area of irrigated land($F_{n\partial o}$) is determined by the following formula:

$$F_{n\partial o} = \frac{(W_{oi}^{\max} - W_{\exists i}^{\max}) \cdot K_{ac}}{O_{pi}^{\max}} \cdot \eta_{k n \partial},$$

and, the optimal area of irrigated land (F_{oo}) is determined by the following dependence:

$$F_{oo} = \frac{(Q_{oi}^{\max} - Q_{\exists i}^{\max}) \cdot K_{ac}}{O_{ni}^{\max}} \cdot \eta_{k n \partial}$$

where $F_{n\partial o}$ - maximum allowable area of irrigated land, ha; F_{oo} - optimal area of irrigated land, ha; Q_{oi} - natural flow discharge of the river, cub.m/s; $Q_{\exists i}$ - ecological flow of the river, cub.m/ha; $O_{pi}^{\max}$ - water requirement of vegetation cover of agricultural land, cub.m; $O_{ni}^{\max}$ - water demand of soil cover of agricultural land, cub.m/s or l/s.

At the same time, the coefficient of synchronization of river flow and the norm of specific water demand for agricultural land of the *i*-th month of a growing season (considered) period is determined by the following dependencies:

$$K_{aci} = [(Q_{rai} / Q_{rai}^{\max}) / (O_{pi} / O_{pi}^{\max}]; \; K_{aci} = [(Q_{rai} / Q_{rai}^{\max}) / (O_{ni} / O_{ni}^{\max}],$$

where $Q_{rai}^{\max}$ – the maximum value of the natural flow of the river in the vegetative (considered) period, cub.m/s; $O_{pi}^{\max}$ - the maximum water requirement of vegetation cover of agricultural land within the growing season, cub.m/s; $O_{ni}^{\max}$ - the maximum water requirement of soil cover of agricultural land within the growing season, cub.m/s.

10. Comprehensive assessment of environmental, economic and social damage from anthropogenic or economic activities associated with the use of natural resources for the sustainable development of economic sectors is determined by the method of Zh.S. Mustafayev [29], where economic (Э), socio-economic (ЭС) and social (С) damages are distinguished:

$$У_{ц} = Э + ЭС + С = (Э_{с} + Э_{п} + Э_{л} + Э_{в}) + (ЭС_{з} + ЭС_{п} + ЭС_{о}) + (С_{з} + С_{п} + С_{ж}),$$

where $Э_{с}$ - losses due to shortfall in production; $Э_{п}$ - losses from the reduction of the quality of products; $Э_{л}$ - costs of eliminating pollution; $Э_{в}$ - the cost of restoring or maintaining the normal state of the environment; $ЭС_{з}$ - losses in health care and social security due to increased incidence; $ЭС_{п}$ - losses due to migration caused by environmental degradation; $ЭС_{о}$ - the cost of additional rest required due to the unsatisfactory state of the natural environment; $С_{з}$ - - aesthetic losses due to the destruction of the natural environment; $С_{п}$ - psychological losses caused by unsatisfactory state of rest; $С_{ж}$ - losses caused by deterioration of the ecological conditions of life of society members.

Thus, it should be noted that before planning integrated water resources management (IWRM) in the catchment area of the transboundary rivers basin, it is necessary to answer a number of important questions about the necessity and feasibility of using them for sustainable development and ensuring the country's food security located in the catchment area of the transboundary rivers based on the principles of reasonable, equitable and rightful use of water resources in accordance with the concept adopted by the «Agenda of the 21st century»at the UN in Rio de Janeiro, which require solving complex problems of the rational and balanced use of natural resources within the framework of the applied methodological support.

Discussion of results. Thus, the developed and proposed system of methodological support, formed on the basis of the principles of reasonable, equitable and rightful use of water resources in accordance with the concept adopted on the «Agenda of the 21st Century» at the UN in Rio de Janeiro and developed by the European Environmental Agency «DPSIR-analysis», as a method of systematizing information and

highlighting cause-effect relationships to solve the problems of integrated water resources management of transboundary rivers, covering all levels of the water use process from the formation and storage of water resources and their watershed areas of transboundary basins can be used in the planning and implementation of integrated water resources management (IWRM).

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ТРАНСШЕКАРАЛЫҚ ӨЗЕН АЛАБЫНЫҢ СУ РЕСУРСТАРЫН ИНТЕГРАЦИЯЛЫҚ БАСҚАРУДЫ ӘДІСТЕМЕЛІК НҰСҚАМЕН ҚАМТАМАСЫЗ ЕТУ

Аннотация. БҰҰ-ның Рио-де-Жанейрода қабылдаған «XXI ғасырдың Күн тәртібі» тұжырымдамасына сәйкес ақылға қонымды, тең құқылы және әділ пайдалану қағидасы мен Еуропалық экологиялық агенттігі әзірлеген «DPSIR-талдау» құжаты негізінде ақпаратты жүйелеу әдістемесі ретінде қарастыру арқылы трансшекаралық өзеннің су ресурстарын бірлесіп басқару мәселелерін шешу жолдары қарастырылған. Олардың арасындағы себеп-салдар байланысын ашып көрсету арқылы трансшекаралық әсердің зиянын шектеу және алдын алу мақсатында геоэкологиялық шектеудің интегралдық сынақ көрсеткіштер жүйесіне негізделген.

Геоэкологиялық шектеудің интегралды өлшемі ретінде климат өзгерісін ескере отырып, сумен қамтамасыз ету қисығының көрсеткіші әзірленді, яғни өзеннің жылдық ағыны статистикалық қатарының орташа арифметикалық мәнін, ландшафттық жүйенің жылу және ылғалмен қамтамасыз етілу дәрежесін, шекаралас өзеннің су жинау алабының геоморфологиялық желісін, өзен ағынының шектелген ластануын, климаттық, геологиялық-геоморфологиялық, гидрологиялық және ландшафттық дәлелдеме негізінде құрылған суды пайдаланудың аймақтық бағдарламасының интеграл өлшемдерін, өзеннің су жинау алабы гидроагроландшафттарының «топырақ-өсімдік-адам» жүйесіндегі экологиялық жағдайын, өзен алабының су ресурстарын пайдаланудың шектелген-мүмкіндік деңгейін және экологиялық ағынды өзеннің су жинау алабындағы қолжетімді жер қорын және экологиялық қызметін, өзеннің су жинау алабындағы гидроагроландшафттардың шектелген-мүмкіндік ауданын, антропогендік қызметтің экологиялық, экономикалық, әлеуметтік шығынын кешенді бағалауға арналған көрсеткіштеріне негізделген.

Шекаралас өзендердің су ресурстарын пайдалануда геоэкологиялық шектеудің сынақ көрсеткіштері бағалау әдістемесін, ақпаратты талдау және себеп-салдарлық байланыстарды анықтаудың әдісі ретінде қарастыру арқылы шекаралас өзендердің су ресурстарын мақсатты басқару мәселесін шешу жолдары қарастырылған. Шекаралас өзеннің су жинау алабының барлық деңгейінде, яғни оның су ағынының қалыптасуынан бастап, таралу алабындағы қорлану аймағын қамтуға арналған су ресурстарын интеграциялық басқаруды жоспарлау және іске асыруда интегралдық көрсеткіштерді пайдалану жолдары қарастырылған.

Түйін сөздер: су ресурстары, трансшекаралық өзен, тұжырымдама, стратегия, пайдалану, басқару, іске асыру, жоспарлау, су қорларын интеграциялық басқару.

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МЕТОДИЧЕСКОЕ ОБЕСПЕЧЕНИЕ ИНТЕГРИРОВАННОГО УПРАВЛЕНИЯ ВОДНЫХ РЕСУРСОВ БАССЕЙНА ТРАНСГРАНИЧНЫХ РЕК

Аннотация. На основе принципов разумного, равноправного и справедливого использования водных ресурсов в соответствии с концепцией, принятой на «Повестке дня XXI века» в ООН в Рио-де-Жанейро и разработанного Европейским экологическим агентством – «DPSIR-анализ», как метода систематизации информации и выделения причинно-следственных связей с целью решения проблем интегрированного управления водными ресурсами трансграничных рек, обоснована система интегральных критериев геоэкологического ограничения, обеспечивающая ограничение и предотвращение негативного влияния трансграничного воздействия.

В качестве интегрального критерия геоэкологического ограничения разработан показатель кривой водообеспеченности с учетом изменения климата, то есть средняя арифметическая величина статистического ряда годового стока реки, геоморфологическая схематизация водосборной территории бассейна трансграничных рек с учетом тепло- и водообеспеченности их ландшафтной системы, предельной загрязненности речного стока, территориальное планирование водопользования на основе интегральных параметров с использованием климатических, геолого-геоморфологических, гидрологических и ландшафтных факторов, экологической ситуации гидроагроландшафтов водосбора речных бассейнов в системах «почва-растения-человек», предельно-допустимого уровня использования водных ресурсов речных бассейнов и экологического стока, располагаемых земельных ресурсов водособора бассейна рек и экологических услуг водосбора речных бассейнов, предельно-возможную площадь гидроагроландшафтных систем в водосборных территориях речных бассейнов, комплексная оценка экологического, экономического и социального ущерба при антропогенной деятельности.

Методологическое обоснование критериев геоэкологического ограничения при использования водных ресурсов бассейна трансграничных рек, метод систематизации информации и выделения причинно-следственных связей с целью решения проблем интегрированного управления водными ресурсами трансграничных рек, охватывающие все уровни процесса водопользования от формирования и магазинирования водных ресурсов и их зоны рассеивания водосборов бассейнов трансграничных рек могут быть использованы при планировании и реализации интегрированного управления водными ресурсами (ИУВР).

Ключевые слова: водные ресурсы, трансграничные реки, концепция, стратегия, использование, управление, реализация, планирование, интегрированное управление водными ресурсами.

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UNDERGROUND URANIUM BOREHOLE LEACHING

Abstract. Kazakhstan has the world's largest raw material base of proven industrial uranium reserves. The bowels of the Republic of Kazakhstan contain about 25% of the world's proven uranium reserves. A unique feature of uranium reserves is that 75% of them are concentrated in deposits associated with regional zones of formation oxidation, which can be mined using a relatively cheap and environmentally preferred method of underground leaching. The presence in Kazakhstan of significant reserves of well-explored uranium deposits, developed mining and processing capacities of uranium, as well as the current situation on the world uranium market determine the prospects for the development of Kazakhstan's uranium mining industryю.

Existing production technologies for the exploitation of hydrogenous uranium deposits do not meet the requirements of market economy: low labor productivity, high unit costs, require large capital investments, the technology is not competitive, and sulfuric acid is expensive. To create exemplary uranium mines, it is necessary and urgent to develop an innovative technology for the exploitation of hydrogenic uranium deposits. The main operational indicators determining the effectiveness of the application of SST include: leaching rate; average concentration of uranium in productive solutions; reagent consumption; productivity of productive solutions; the degree of extraction of uranium from the bowels; the volume of the solution spent on the extraction of uranium from a unit of ore mass (ratio W: T).

The article presents the results of solving the main technical and technological problems, allowing to develop an innovative technology for the exploitation of hydrogenic uranium deposits: we have developed a method for using pumping wells without changing their design as injection wells; it is not intended to use an inline injection well location system, which makes it possible to drastically reduce capital expenditure; It is planned to use an ordinary pumping well without changing its design using the "x" method; this well can operate both a pumping well and a pumping well. The pumping well will operate under the name "Piston Well" in the mode of pulsating flows when a chemical solution is supplied to an array of uranium hydrogen deposits; the development of a method for intensifying the leaching of useful components, including uranium; a way to drastically reduce the consumption of a chemical reagent (H2SO4). With the existing technology for producing a productive uranium solution, the specific consumption of sulfuric acid per 1 ton of uranium concentrate is 1: 100, i.e. per 1 ton of extraction of uranium concentrate requires a consumption of sulfuric acid of 100 tons

The work performed provides economic efficiency for the listed parameters of leaching of uranium.

Key words: geological features, theoretical justification, technology, mining, borehole underground leaching, uranium.

Introduction. The basis for the development and implementation in practice of uranium mining of the method of underground borehole leaching were achievements in the field of geological exploration and industrial assessment, epigenetic deposits of regional zones of reservoir and soil oxidation, advances in the field of hydrodynamics, geochemistry, hydrometallurgy.

Over the past years, collectives of Kazakhstani uranium mining enterprises have done a lot of work to improve uranium mining technology, increase labor productivity, reduce production costs,

and automate production processes. Considerable work has been done in the field of drilling and equipment of wells, improving the means of raising productive solutions, devices for their sorption-desorption redistribution [1,2].

The development and implementation of the method of underground borehole leaching of uranium is one of the most important scientific and technical achievements of the mining industry. The main advantages of the underground leaching method compared to traditional mining methods of field development are as follows [3-5]:

- the possibility of involving in the exploitation of poor and off-balance ores of deposits with complex geological and hydrogeological conditions, but with large reserves of uranium;
- significant reduction in capital investments and terms of commissioning;
- improving working conditions, reducing the number of miners and increasing labor productivity by 2.5-3.5 times;
- reduction of the negative impact of uranium mining on the environment.

Based on the modern achievements of geotechnological science and practice, the development of uranium mining by the method of downhole leaching goes along the path of introducing computer-aided mining technologies based on the full automation of all production processes; optimization of opening, preparation and mining schemes; the introduction and development of new technical means for the construction and development of wells, new structural materials; reduction of solvent costs, ion exchange resins; the introduction of electrodialysis plants, sorption-desorption concentration apparatuses such as SDK, polymer washing liquids, hydraulic fracturing and hydraulic washing of formations, new methods of electro-ultrasonic intensification of leaching and redistribution of productive solutions; the introduction of effective methods for monitoring the hydro-geochemical parameters of underground leaching sites and environmental rehabilitation of spent deposits [6-9].

The social significance of introducing the method of downhole leaching into uranium mining practice is extremely great. Radically, for the better, the nature of the work of miners and the radiation safety of the work have changed. A further increase in uranium production, based on the introduction of the latest scientific and technical achievements in the practice of developing infiltration deposits, will allow Kazakhstan to take a leading place among the world's uranium producers.

Methods. To solve this problem, theoretical substantiation methods were used for the technology of underground borehole leaching of uranium. About 25% of the world reliably explored uranium reserves are concentrated in the bowels of Kazakhstan. Total reserves and resources are estimated at 1,560 thousand tons of uranium, including category reserves (B + C 1 + C2) of 928 thousand tons. A unique feature of the republic’s uranium reserves is that about 75% of them are concentrated in deposits associated with regional zones of formation oxidation. This type of field is not widespread in the world and is being developed by the most progressive, relatively cheap and environmentally preferable method of underground borehole leaching.

The result of these works is the development of technology for underground borehole leaching of uranium in Kazakhstan. Kazakhstani uranium deposits associated with regional zones of formation oxidation are formed in the Shu-Sarysuyskaya and Syr-Darya depressions of the platform cover of the northern part of the Tien Shan uranium megawatch (Northern, Eastern and Western group of deposits). Deposits associated with zones of soil-layer oxidation are developed in the Ili River basin, outside the zone of activity of industrial enterprises and in the Akmola region of Northern Kazakhstan. Uranium deposits suitable for mining with sulfuric acid leaching through a system of wells drilled from the surface belong to the subgroup of infiltration (hydrogen). These deposits are the basis of the raw material base of the uranium industry of Kazakhstan and are concentrated in the Shu-Sarysuyskaya (Mynkuduk, Inkai, Budenovskoye, Zhalpak, Sholak-Espe, Uvanas, Moinkum, Kanzhugan) and Syrdarya (Irkol, Karamurun, Kharasan, Zarechnoye, Asarchik Kyl, Zha , Chayan, Lunar) uranium ore provinces. The largest of the deposits of the soil-formation oxidation zone and promising for development is the Semizbay deposit [10-14]. The distribution of reserves and resources by geological and industrial types of uranium deposits in Kazakhstan is shown in table.

Reserves and resources for geological and industrial types of uranium deposits in Kazakhstan

Type of deposit	Category reserves B+Ci+C_2		Reserves and resources B+Ci+C_2+Pi	
	thous. tons	%	thous. tons	%
Deposits associated with regional zones of reservoir oxidation	603	65	1160	75,3
Deposits associated with soil formation oxidation zones	82	8,8	97	6,0
Deposits of organogenic phosphate type	29	3,2	29	1,8
Vein stockwork deposits in folded complexes	214	23	274	16,9
Total	928	100	1560	100

The leaching rate is a value equal to the quotient of dividing the length of the ore layer worked out by the solution by the time during which a certain metal fraction is extracted from this layer. Leaching rate V_l is related to the filtering rate V_f by a linear relationship $V_l = \beta \cdot V_f$; where β – constant coefficient for specific ore-solvent combinations. The most important geotechnological parameter, the ratio, is based on this regularity L:S, that is, the ratio of liquid to solid (the ratio of the volume of the solution to the volume of the ore mass).

The reagent consumption for underground leaching of uranium depends on the reagent capacity of ore-bearing rocks, the type and nature of uranium mineralization, rock carbonate, productivity and effective thickness of formations, hydrodynamic conditions for pumping solutions through ore-bearing strata.

In the practice of underground leaching of uranium, the specific consumption of the reagent is 50-150 kg per 1 kg of metal, which is due to the reaction of the acid with other minerals and the spreading of solutions. Carbonates almost completely react with acid (1 kg of sulfuric acid is consumed per 1 kg of CaCO3), minerals of oxide iron, less intensely ferrous iron and some aluminosilicates (up to 10%) dissolve well (40-50%) [15-17]. At the stage of formation acidification, the reagent (sulfuric acid) consumption is usually 8-10 g / l for ores with high carbonate content and 20-30 g / l for non-carbonate ores. At the leaching stage, the concentration of sulfuric acid in working solutions ranges from 8 to 15 g / l.

The data in table, the data can be used in the evaluation of deposits for the use of underground borehole leaching. The developed classification system for signs of the suitability of infiltration uranium deposits for leaching is recommended for use in the design of PSV technology in Kazakhstan deposits.

The conditions for the formation of exogenous infiltration deposits are associated with the behavior of uranium in the upper parts of the earth's crust, in the zone of so-called hypergenesis, where the migration of chemical elements occurs at low temperatures and pressures. The formation of exogenous uranium deposits is associated with the epigenetic accumulation of uranium minerals during their migration and deposition.

Under the surface conditions of the hypergenesis zone, under the influence of water, air and organic matter, the minerals of the ore-bearing rocks are oxidized and uranium migrates (transfers) by infiltration flows. Natural waters of the hypergenesis zone are true and colloidal solutions of various concentrations. The intensity of migration of chemical elements depends on the acidity and alkalinity of natural waters.

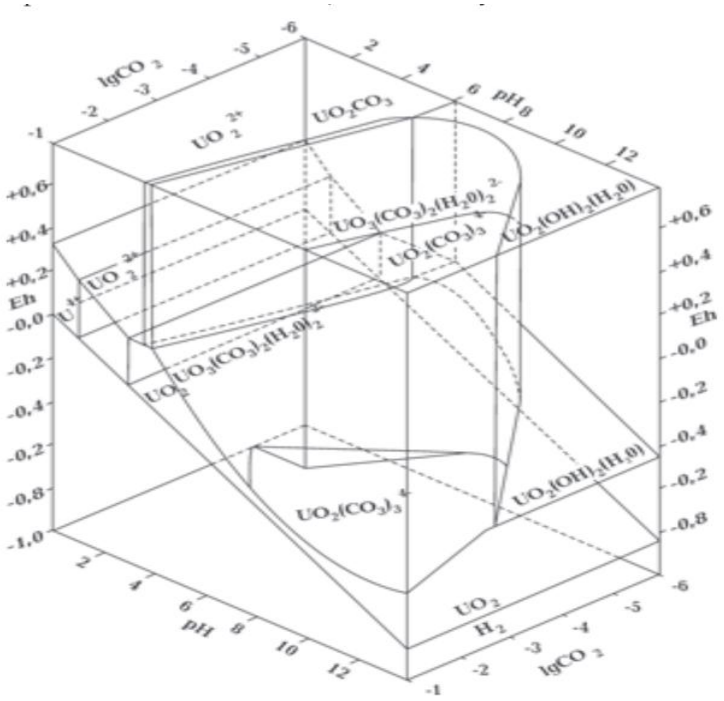
In natural waters in the form of ions and undissociated molecules contains almost all chemical elements, most of which are in a state of strong scattering (about n × 10-5 g / l or less) and only Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}, Na^+, K^+, Mg^{2+}, Ca^{2+}, SiO_2 are contained in significant quantities. A strong influence on the physicochemical characteristics of natural waters is exerted by H + and OH- ions [18]**.** The oxidizing environment of groundwater is characterized by the content of free oxygen, the redox potential is Eh> 0.1 V, often above 0.4 V and can reach 0.6-0.7 V. Uranus is in U^{6+} shape, iron is predominantly in the shape Fe^{3+} and only in strongly acidic environments can Fe^{2+} exist. Sulfur is exclusively in form SO_4^{2-}. Under certain conditions, there are VO_4^{3-}, SeO_3^{2-} and SeO_4^{2-}, MoO_4^{2-}, MoS_2, ReS_2.

Recovery environment without H_2S - water does not contain free oxygen, Eh обычно ниже 0,4в, иногда ниже нуля. Under these conditions, iron and manganese are in the form Fe^{2+} and Mn^{2+}, migrate easily. If H_2S is present in water, If H is present in water, then Eh<0, iron, manganese, copper, zinc and other chalcophilic elements precipitate. Uranium precipitates to form U^{4+}compounds. The presence of

dissolved oxygen in natural waters increases the solubility of primary uranium minerals in an acidic sulfate medium, and less intensively in alkaline carbonate. The tetravalent uranium oxides and mixed oxides are completely dissolved in the carbonate medium only in the presence of oxidizing agents. Uranium silicates, phosphates and humates dissolve in an alkaline medium. In natural waters, depending on the total mineralization, chemical composition, pH of the medium and the concentration of uranium in water, ions may be present: UO_2^{2+}, $UO_2(OH)^+$, $[UO_2(CO_3)_2\ (H_2O)_2]^{2-}$ $[UO_2(CO_3)_3]^{4-}$, as well as undissociated molecules of UO2 (OH) 2. Chemical reactions in the zone of hypergenesis occur at a pressure close to 1 atm. and temperature not exceeding the first ten degrees**.**

The conditions of existence of uranium compounds in the hypergenesis zone are graphically represented by the diagram in the parameters Eh, pH, pressure CO_2, since these parameters are the most important characteristics of natural waters. The diagrams depict the equilibrium conditions, that is, the relations between the compounds after reaching thermodynamic equilibrium. Figure by R. Garrels [5,19] shows a diagram of the stability field of uranium compounds as a function of Eh, pH and general Σ CO_2 the amount of carbonate in produced water (P=1 Atmosphere pressure, T=25°C).

Figure shows that hexavalent uranium is almost completely complexed with the formation of uranyl dicarbonate and uranyl tricarbonate ion complexes.



Stability of some uranium compounds in formation water at 25 ° C
and 1 atm total pressure as a function of pH, Eh and amounts of dissolved carbonate components

With noticeable ΣCO_2 the stability field of uranyl oxide hydrate is displaced. Such complexation proceeds so efficiently that, at a relatively high ΣCO_2 value, the fields of these complexes displace the stability field UO_2 (uraninite). From this it becomes clear that carbonate-containing waters are strong solvents of uranium. Watering the hypergenesis zone with water containing up to 8-10 mg / oxygen increases the water Eh and promotes the conversion of U4 $^+$ to U6 $^+$. If natural water contains up to 2g / l or more carbon dioxide, then uranium migration is also enhanced.

H_2S hydrogen sulfide present in water, which reduces uranium to the tetravalent state, contributes to its precipitation from solution.

When uranium minerals are dissolved by natural waters in the hypergenesis zone, especially under oxidizing conditions, the state of chemical equilibrium between the solid and liquid phases is practically not achieved due to the mobility of the water and the buffer effect of the host rocks on the pH of the water. The forms of uranium in natural waters are very diverse. According to V.V. Shcherbina [5,20], in the zone of hypergenesis, uranium in aqueous solutions can be transported in the following forms:

- soluble uranyl sulfate UO_2SO_4;
- colloidal solution of hydroxide composition $[UO_2(OH)_2]_n$, negative charge carrier;
- readily soluble complex carbonates composition $Na_4[UO_2(CO_3)_3]$;
- readily soluble complex alkaline humate compounds.

The possibility of migration of uranium in aqueous solutions in the form of compounds arises from the chemical properties of uranium, its ability to react with other elements, form ions of different valencies, form soluble complexes and be sorbed by colloids.

Natural waters have a high dissolving power. The dissolving ability of water is caused by large dipole moments of molecules ($\mu = 1.8$) and a high dielectric constant (80.0) of water [1,5,21].

There is a relationship between solubility, heat and dissolution entropy:

$$nRTlna = L + T\Delta S = L + T\sum_{L}^{i} S$$

where, n – number of ions forming a molecule of uranium salt; a – saturated solution activity; L - heat of dissolution; T - absolute temperature; ΔS – entropy of dissolution; $\sum S^i_L$ - the sum of dissolution entropy ions equal to the change in the entropy of an ion upon its transition from the crystal lattice to a solution with an activity equal to 1.

Discussion. A prerequisite for the implementation of underground leaching technology should be good permeability of the medium containing uranium mineralization for the solution. With fairly good permeability indicators, even deposits of poor uranium ores prove to be profitable for mining. Each uranium deposit is always individual in its natural features, the technical and economic indicators of the exploitation of deposits by underground leaching depend on these features. Moreover, the feasibility of using underground leaching technology for mining a particular uranium deposit is based on the parameters of two factors: the possible volume of uranium production per unit time and the possible cost of producing a unit of uranium.

The main operational indicators that determine the effectiveness of the use of UBL include:

- leaching rate;
- average concentration of uranium in productive solutions;
- reagent consumption;
- productive solution performance;
- the degree of extraction of uranium from the bowels;
- the volume of solution spent on the extraction of uranium from a unit of ore mass (ratio L:S).

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УРАНДЫ ЖЕРАСТЫ ҰҢҒЫМАЛАРЫН ШАЙМАЛАУ

Аннотация. Қазақстан әлемдегі ең ірі уран өнеркәсіптік қорының шикізат базасына ие. Қазақстан Республикасының жер қойнауында әлемдік барланған уран қорының шамамен 25 %-ы бар. Уран қорларының бірегей ерекшелігі, олардың 75 %-ы жерасты ұңғылап шаймалаудың салыстырмалы арзан және экологиялық жағынан қолайлы тәсілмен өңделуі мүмкін қабаттық тотығу аймақтарымен байланысты кен орындарында шоғырланған. Қазақстанда қорлар бойынша елеулі, жақсы барланған уран кен орындарының, дамыған өндіруші және өңдеуші уран қуаттарының болуы, сондай-ақ әлемдік уран нарығының қазіргі заманғы конъюнктурасы Қазақстанның уран өндіру өнеркәсібін дамыту перспективасын алдын ала айқындайды.

Уранның гидрогенді кен орындарын пайдаланудың қазіргі технологиялары нарықтық экономика талаптарына сай емес: еңбек өнімділігінің төмендігі, өнім бірлігінің өзіндік жоғары құны көп мөлшерде тамшыландыруды талап етеді, технология бәсекеге қабілетсіз, күкірт қышқылының шығыны көп. Үлгілі уран

кеніштерін құру үшін гидрогенді уран кен орындарын пайдаланудың инновациялық технологиясын әзірлеу қажет және өзекті. Жерасты ұңғылап шаймалауды (ЖҰШ) қолданудың тиімділігін анықтайтын негізгі пайдалану көрсеткіштеріне мыналар жатады: сілтілеу жылдамдығы; өнімді ерітінділердегі уранның орташа концентрациясы; реагенттің шығыны; өнімді ерітінділер бойынша өнімділік; жер қойнауынан уранды алу дәрежесі; тау-кен массасы бірлігінен уранды алуға жұмсалатын ерітіндінің көлемі (С:Қ қатынасы).

Мақалада уранның гидрогенді кен орындарын пайдаланудың инновациялық технологиясын әзірлеуге мүмкіндік беретін негізгі техникалық-технологиялық міндеттерді шешу нәтижелері келтірілген: біз айдау ұңғымалары ретінде конструктивтік ресімдеуін өзгертпей, сору ұңғымаларын пайдалану тәсілін әзірледік; айдау ұңғымаларын орналастырудың бірқатар жүйесін қолдану көзделмеген, бұл капитал салу шығынын күрт қысқартуға мүмкіндік береді; қарапайым сору ұңғымасын «х» тәсілінің көмегімен конструктивті рәсімдеуін өзгертпей қолдану қарастырылған, бұл ұңғыма сору және айдау ұңғымасы ретінде жұмыс істей алады. Сору ұңғымасы уранның гидрогенді шоғырының массивіне химиялық ерітінді беру кезінде пульсациялайтын ағын режимінде «поршенді ұңғыма» атымен жұмыс істейтін болады; пайдалы компоненттерді, оның ішінде уранды шаймалау үдерісін қарқындату тәсілін әзірлеу; химиялық реагент шығынын күрт қысқарту тәсілі (H2SO4) қарастырылды. Уранның өнімді ерітіндісін өндірудің қазіргі технологиясы кезінде 1 т уран концентратына күкірт қышқылының үлес шығыны 1: 100 қатынасын құрайды, яғни уран концентратын өндірудің 1 т күкірт қышқылының шығыны 100 т болады.

Орындалған жұмыс уранды сілтілеудің аталған параметрлері бойынша экономикалық тиімділікті қамтамасыз етеді.

Түйін сөздер: геологиялық ерекшеліктер, теориялық негіздеу, технология, өндіру, ұңғымалық жерасты сілтілеу, уран.

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ПОДЗЕМНОЕ СКВАЖИННОЕ ВЫЩЕЛАЧИВАНИЕ УРАНА

Аннотация. Казахстан обладает крупнейшей в мире сырьевой базой разведанных промышленных запасов урана. Недра Республики Казахстан содержат около 25% мировых разведанных запасов урана. Уникальной особенностью запасов урана является то, что 75% из них сосредоточены в месторождениях, связанных с региональными зонами пластового окисления, которые могут быть отработаны относительно дешевым и экологически предпочтительным способом подземного скважинного выщелачивания. Наличие в Казахстане значительных по запасам, хорошо разведанных месторождений урана, развитых добывающих и перерабатывающих уран мощностей, а также современная конъюнктура мирового рынка урана предопределяют перспективу развития уранодобывающей промышленности Казахстана.

Существующие технологии добычи эксплуатации гидрогенных месторождений урана не отвечают требованиям рыночной экономики: низкая производительность труда, высокая себестоимость единицы продукции, требуют в больших размерах капвложения, технология не конкурентоспособная, большие расходы серной кислоты. Для создания образцовых урановых рудников необходима и актуальна разработка инновационной технологии эксплуатации гидрогенных урановых месторождений. К основным эксплуатационным показателям, определяющим эффективность применения СПВ, относятся: скорость выщелачивания; средняя концентрация урана в продуктивных растворах; расход реагента; производительность по продуктивным растворам; степень извлечения урана из недр; объём раствора, расходуемого на извлечение урана с единицы горнорудной массы (отношение Ж:Т).

В статье приведены результаты решения основных технико-технологических задач, позволяющих разработать инновационную технологию эксплуатации гидрогенных месторождений урана: нами был разработан способ использования откачных скважин без изменения их конструктивного оформления в качестве закачных скважин; не предусмотрено применение рядной системы расположения закачных скважин, что дает возможность резко сократить расход капиталовложения; предусмотрено применение обыкновенной откачной скважины без изменения ее конструктивного оформления с помощью «х» способа эта скважина может работать как откачная, так и закачная скважина. Откачная скважина будет работать под именем «Поршневая скважина» в режиме пульсирующих потоков при подаче химического раствора в массив

гидрогенной залежи урана; предусмотрена разработка способа интенсификации процесса выщелачивания полезных компонентов, в том числе урана; способ резкого сокращения расхода химического реагента (H2SO4). При существующей технологии добычи продуктивного раствора урана удельный расход серной кислоты на 1 т концентрата урана составляет 1:100, т.е. на 1 т добычи концентрата урана требует расход серной кислоты 100 т.

Выполненная работа обеспечивает экономическую эффективность по перечисленным параметрам выщелачивания урана.

Ключевые слова: геологические особенности, теоретическое обоснование, технология, добыча, скважинное подземное выщелачивание, уран.

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RADIATION SITUATION ON THE TERRITORY OF SHUCHINSK-BOROVSKAYA RESORT AREA AND MEASURES ON THE RADIATION RISKS REDUCTION

Abstract. The study is directed on receiving of the objective information on the radio-ecologic situation on the territory of Shuchinsk - Borovskaya resort area (hereinafter – SBRA). Such information is demanded by permanent residents as well as by the persons on vacations (holiday-makers), who temporary stay on the given territory. Burabai and Zhukei granite massifs are located on the territory of this area. Radioactive anomalies in the natural media: soils, bottom sediments, water and air of the soils - are linked to these massifs.

During the present study it was found out that the highest radiation danger on the territory of Shuchinsk-Borovskaya resort area, presented by soil radon in 11 out of 22 settlements in Burabai and Birzhan Sal districts. There the detailed radio-ecological mapping is required as regards the level of radiation risks for the population health, development and realization of the address anti-radon measures.

The study was performed within the Scientific–Technical Program: BR05236529 «Complex evaluation of the ecosystems of Shuchinsk - Borovskaya resort area with determination of the environmental load for the purpose of the recreation potential' stable use» for the years 2018-2020».

Key words: radon, radiation situation, uranium, radon-dangerous area, Shuchinsk-Borovskaya resort area.

Introduction. Shuchinsk-Borovskaya resort area is the most important intensively developing recreation area of the Republic of Kazakhstan. The main condition for stable development of Shuchinsk - Borovskaya resort area is: control on the natural peculiarities of the territory, optimization of the recreation potential' use under decrease of negative impact on the environment and creation of favorable conditions for living of local population.

Radiation situation is one of the most important characteristics of the environmental well-being of any territory. The natural and man-made components are singled out in its formation.

Methods. Radiometric investigations were conducted in 22 settlements (town of Shuchinsk, 15 settlements in Burabai district, 6 settlement in Birzhan Sal district).

Radiometric survey was conducted along the streets of the settlements, anticipating to cover the whole area of a settlement. Survey was done using the certified dosimeters DKS-96. The fixed points of the activity' measurement were allocated every 50 m, between these points – the continuous listening was done.

The complex of studies included the radon investigations as radon is widely spread danger for population health. This is the second (after smoking) reason for development of lung cancer in the world. The radon investigations included determinations of EBVA momentary values (equivalent balanced volumetric activity) of radon as well as the integral values of radon volumetric activity in each settlement

Water samples for alpha- and beta-activity were taken from the drinking water sources as well as from large water bodies of the resort area.

Amounts and methods of sampling, radiometric and radon measurements of radon were performed taking into account the Methodic Instructions of the Ministry of Health of the Republic of Kazakhstan [1].

The modern data on the level of radiation situation were analyzed taking into account the earlier performed investigations (JSC «VolkovGeology» in 2005-2008 and LLP «ECOSERVICE-C» in 2010-2011).

Results and Discussion. Radiation situation on the territory of Shuchinsk - Borovskaya resort area is determined, first of all, by Kokshetau or the Northern Kazakhstan uranium-bearing province, in which this area is located [2]. On the territory of Shuchinsk-Borovskaya resort area, based on the results of radio-hydro-lithological-chemical survey [2], the micro-basins with area of 100-140 km^2 with increased activity of radium-226 were singled out. The following settlements: Zelenyi Bor, Molbasa, Burabai and Sarybulak are located within the contour of these micro-basins. Radium-226 is the direct source of radon, which introduces the significant impact into the radioactive doze for the population. Besides, more than a dozen of water sources with the increased radioactivity is determined by the investigations conducted earlier.

In 2010 the specialists of LLP «ECOSERVICE-C» performed the selective radon investigations in Birzhan Sal district, accompanying it by radio-metric investigations and sampling from the water sources in settlements: Andykozha Batyr and Nevskyi (Donskoy rural county) and Trambovka, Karlovka, Kyzyl-yum and Zhukei (Ulginskyi rural county).

Radio-active anomalies in the soils, water and air of the soils and grounds are spatially connected to Burabai and Zhukei granite massifs, located among strongly metamorphized Paleozoic rocks: schist, sandstones and conglomerates.

On the radar satellite image these massifs look like the ring structures (figure 1). During the analysis the vertical displacements were used by a pair of the radar images of the space apparatus Sentinel-1 of the year 2018. For visualization and convenience of visual comprehension of the satellite images the pseudo-colorful composites of red, green and blue color were formed: VV – signal intensity in the vertical-vertical polarization VV; VH - signal intensity in the vertical-horizontal polarization VH and NDI - quotient of division of intensity in polarization VV by intensity in polarization VH.

The granites' content – biotite and corniferous - biotite fine - medium-grained and medium-grained porphyry-like structure [3]. Content of potassium in both granite massifs is very high, which corresponds to the content of potassium in the leucocratic granites in the Central Kazakhstan [4]. The anomalous manifestations of uranium and thorium are related to these granites. According to the data of JSC VolkovGeology' specialists, in these granite massifs the increased content of uranium was noted being more than 10 g/ton (124 Bq/kg) and thorium more than 35 g/ton (184 Bq/kg) [2].

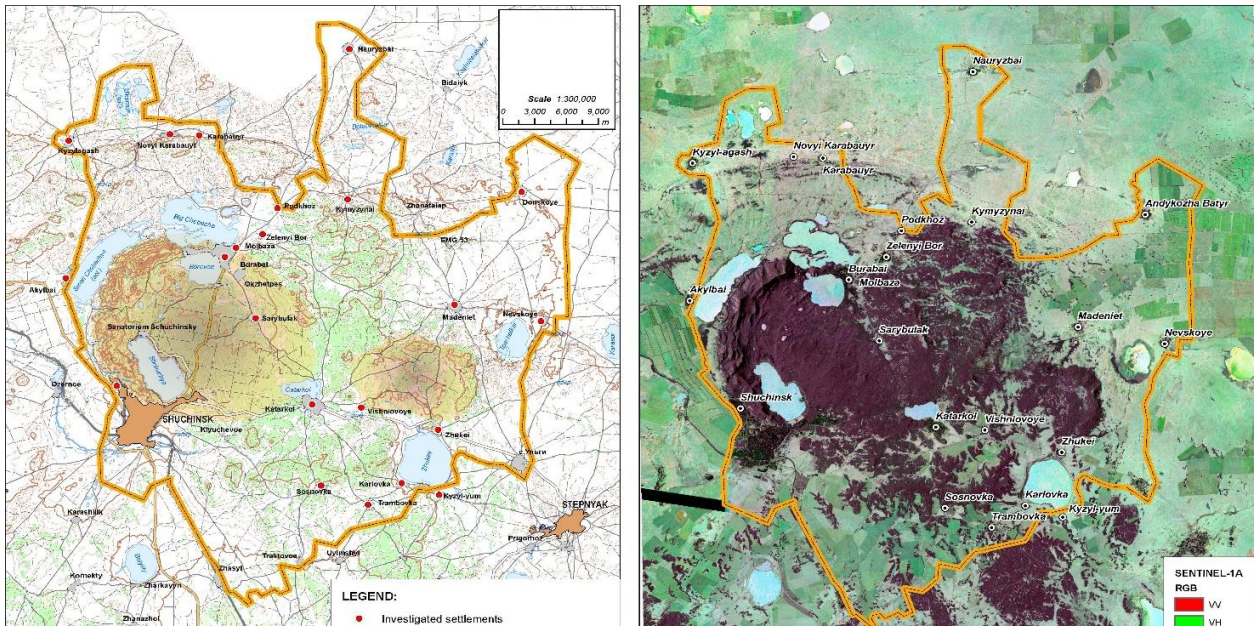

Figure 1 – Areas of location of Burabai and Zhukei granite massifs (on a fragment of the physical map and map of vertical displacements based on a pair of radar images of Sentinel-1 space apparatus of the year 2018 for the territory of Shuchinsk - Borovskaya resort area)

The second important factor, which influences the territory' radon danger, is the manifestation of the bursting tectonics. The geological map of the territory under study (figure 1) reflects not only contours of the granite massifs and small bodies, but also numerous bursting disturbances, which strengthen the ring structure exactly around Borovskoy and Zhukei granite massifs [5,6].

Radiometric survey conducted in 2018-19 determined the average value of the Power Equivalent Dose (PED) of the outdoor gamma-radiation amounted to 0,160±0,031 mcZv/h. The increased values of PED average values in the settlements conform with contours of Borovskoy and Zhukei granite massifs.

Only one anomalous PED value of 0,61 mcZv/h was found out. Additional radiometric survey conducted in 2019 revealed that this anomaly and the series of the increased PED values in the neighboring settlements are related to the increased radioactivity of the modern road pavement made of granite crushed stone.

In 2018-19 the momentary measurements of radon EBVA were done in 169 dwelling houses. To rise the reliability of the results, measurements of radon EBVA in 76 dwelling and public buildings conducted in the years 2010-12 were added (table 1). In the years 2010-12 as well as in the year 2019 the radon EBVA values were proved by the results received by the integral detectors.

Results of momentary measurements of radon EBVA in the indoor air of dwelling and public buildings in Shuchinsk - Borovskaya resort area in 2010-2012, 2018 and 2019

Name of an area, district	Number of definitions	Median value, Bq/m^3	Number of EBVA values >100, but <200 Bq/m^3	Number of EBVA values >200 Bq/m^3
Shuchinsk - Borovskaya resort area	217	72	21	26
Burabai	127	77	12	16
Birzhan Sal	90	49	9	10

The number of EBVA values from 100 to 199, more than 200 and median values of 50 and more Bq/m^3 are singled out in the Table 1. EBVA values of 100 and 200 Bq/m^3 are the average annual standards for the new buildings, constructed later that the year 1999, and old buildings. And median value for the settlement territory of 50 Bq/m^3 and more, as the experience of our radon investigations shows, is EBVA level at the sites with radon danger. Number of such settlements amounted to 11 out of all 22 settlements in Shuchinsk - Borovskaya resort area. If make EBVA distribution at the radon-dangerous sites more detailed, it is possible to find additional anomalous EBVA values. That's why, singling out such contours within the settlement, it is important to calculate their areas and to compare them with the total area of the settlement. If the share of such areas is more than 10% of the total area of the settlement, it is necessary to continue the investigations of radon EBVA' distribution in the settlement. The higher is the share of radon-dangerous sites, the larger should be the amount of additional investigations.

So, the highest radiation danger on the territory of Shuchinsk-Borovskaya resort area may be presented by radon in 11 out of 22 settlements of Burabai and Birzhan Sal districts, where radon is connected to Borovskyi and Zhukei granite massifs and accompanying discontinuous disturbances (figure 2).

So, it is determined that at 37% of the area of the settlements located in Shuchinsk-Borovskaya resort area it is necessary to conduct radon investigations in order to reveal the buildings, in which the application of anti-radon protection is required!

Analysis of radioactivity of water samples taken from large in the resort area showed that in 7 out of 8 water bodies water average alpha-activity amounted to 0,6 Bq/l, beta-activity - 0,43 Bq/l. Anomalous values were received for water taken from Bolpash Sor. There alpha-activity amounted to 4,06 Bq/l, beta-activity - 1,82 Bq/l. There are no standards as regards alpha-activity for water taken from the water bodies, that's why it should be accepted: if water from these water bodies is planned to be used for domestic-drinking purposes, it is necessary to conduct additional investigations regarding the radionuclide analysis. It is necessary to point out, that not high radioactivity of water, possibly, is related to the self-treatment ability, noted in these lakes (Chebachie, Burabai and Shortandy) [7].

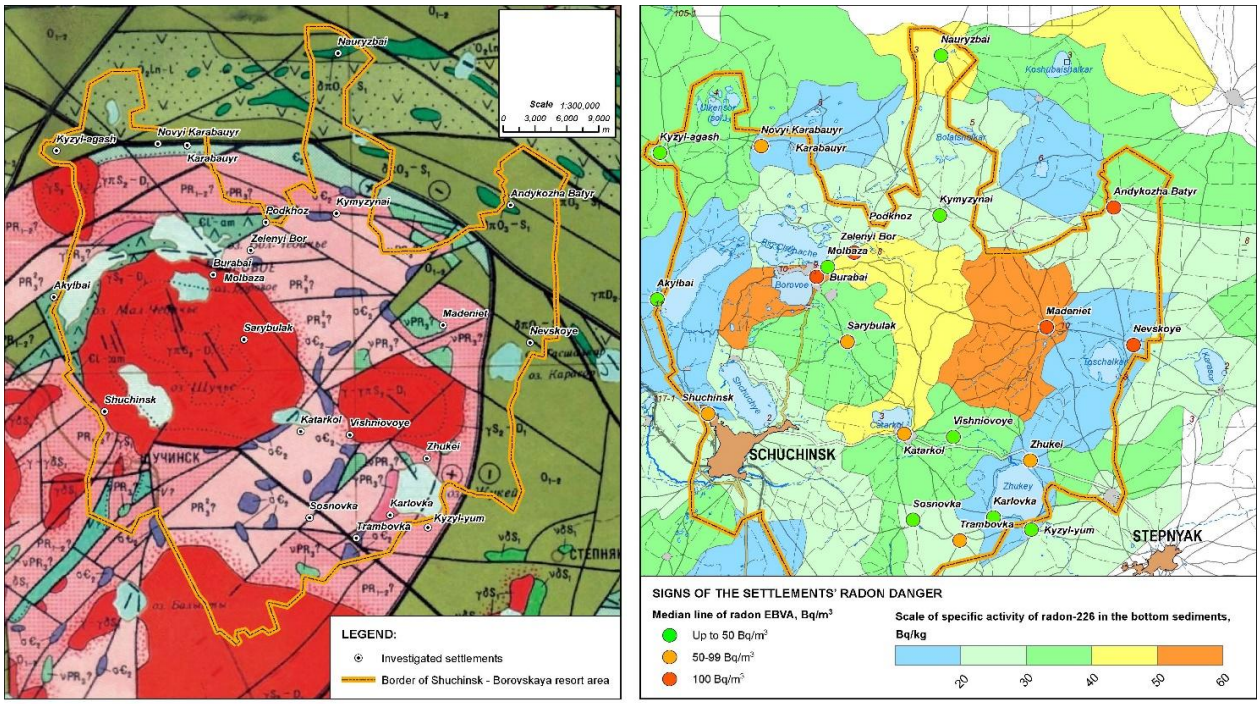

Figure 2. Segments of geological map [12] and maps of radium-226 distribution in the bottom sediments in micro-basins located within Shuchinsk - Borovskaya resort area [4].

Figure 2 – Segments of geological map [5,6] and maps of radium-226 distribution in the bottom sediments in micro-basins located within Shuchinsk - Borovskaya resort area [2]

So, it may be point out that the highest radiation danger on the territory of Shuchinsk - Borovskaya resort area may be posed by radon on the separate sites located in the settlements of Burabai and Zelenoborskyi rural counties of Burabai district and Donskoy rural county of Birzhan Sal district, in 11 out of 22 settlements of Shuchinsk - Borovskaya resort area.

It is recommended to realize the obligatory detailed radon investigations in these settlements within the radon-dangerous sites already singled out.

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ЩУЧИНСК-БУРАБАЙ КУРОРТТЫҚ АЙМАҚ ТЕРРИТОРИЯСЫНДАҒЫ РАДИАЦИЯЛЫҚ ЖАҒДАЙ ЖӘНЕ РАДИАЦИЯЛЫҚ ҚАУІП-ҚАТЕРДІ АЗАЙТУ ЖӨНІНДЕГІ ІС-ШАРАЛАР

Аннотация. Зерттеу Щучинск-Бурабай курорттық аймағының (әрі қарай – ЩБКА) радиоэкологиялық жағдайы туралы ақпараттарды теңқұқылы алуға бағытталған. Бұл ақпарат осы аймақтың тұрақты тұрғындары, демалушылары, сондай-ақ уақытша мекендеушілер арасында сұранысқа ие. Радиоэкологиялық зерттеулерді жүргізу барысында радиациялық жағдайды бағалау үшін ең соңғы әдістемелік атқарымдар қолданылды. Бұл тәсіл зерттеліп жатқан аймақта радиациялық жағдай қауіп-қатерді азайту жөніндегі ұсыныстарды таңдау барысында басымдылықты жайғастыруға мүмкіндік берді. ЩБКА төңірегінде радиациялық жағдайды бағалау жұмыстары 2018-2019 жылдары қолға алынған егістік радиоэкологиялық зерттеу нәтижесі бойынша орындалды. Радиометриялық тексеру 22 елдімекенде жүргізілді (Щучинск қаласы, Бурабай ауданының 15 елдімекені, Біржан сал ауданының 6 елдімекені). ДКС-96 дозиметрлерін қолдана отырып, радиометриялық бейнелеу елдімекен көшелерін бойлай елдімекеннің барлық ауданын жабатындай етіп жүргізілді. Белсенділікті өлшеудің нақтыланған нүктесі – 50 м, осы нүктелер арасында үздіксіз тыңдалды. Радондық зерттеулер радонның ЭТКБ-ның (эквивалентті тепе-тең жоғары белсенділігі) жылдам мәнін, сондай-ақ әрбір елдімекендегі радонның жоғары белсенділігінің интегралды мәнін анықтауды қамтиды.

Альфа және бета белсенділігі үшін суды іріктеу ауызсу көзінде де, курорттық аймақтың ірі су қоймаларында да жүргізілді. Радонды радиометриялық және радонды өлшем сынамаларын алу көлемі мен әдістемесі ҚР Денсаулық сақтау министрлігінің әдістемелік ұсынымдарын ескере отырып орындалды. Бұдан басқа 2005-2008 жылдары «Волковгеология» АҚ және 2009-2013 жылдарда «ЭКОСЕРВИС-С» ЖШС өткізілген радиоэкологиялық зерттеулердің бұрын жасалған нәтижелері қолданылды.

Щучинск-Бурабай курорттық аймағы (әрі қарай – ЩБКА) Көкшетау төңірегінде немесе Солтүстік Қазақстанның уранды шеткі аймағында орналасқан. ЩБКА төңірегінде бұрын жүргізілген зерттеулер бойынша радия-226 жоғарылатылған активтері негізінде микрохауыздар ерекшеленген, жоғарылатылған радиоактивтер арқылы оннан артық су көздері анықталды. Жердегі, судағы және топырақ пен жердің ауадағы радиоактивті ауытқушылықтары, Бурабай және Жукей гранитті алқаптарымен кеңістікте байланысқан. Аумақтың радон қауіптілігіне әсер ететін екінші маңызды фактор – жарылғыш тектониканың көрінісі. 2018-2019 жылдардағы радиометриялық тексерумен 0,160±0,031 мк^{3}в/сағ құрайтын сыртқы гамма-сәулеленудің эквивалентті доза қуатының (ЭДҚ) орташа мәні анықталды.

Елдімекендердің орташа ЭДҚ мәнінің жоғарылауы Боровский және Жукей гранит массивтерінің контурларына сәйкес келеді. Бұл аномалия және көршілес ауылдардағы ЭДҚ мәнінің жоғарылауы гранит қиыршық тастарымен заманауи жол қабатының радиоактивтілігінің жоғарылауына байланыстылығы анықталды.

76 тұрғын және қоғамдық ғимараттардағы (2010-2012 жж. өлшеулер) өлшеу нәтижелерімен толықтырылған 169 тұрғын ғимараттардағы радон ЭТКБ жедел мәнін (2018-2019 ж. өлшеу) бағалау негізінде аталған көрсеткіштің жалпы ЩБКА бойынша медианалық мәні 70 Бк/м^3, Бурабай ауданында 81 Бк/м^3, Біржан сал ауданында 49 Бк/м^3 құрайтыны анықталды. Көпжылдық радонды зерттеулеріміздің тәжірибесі көрсеткендей, ауыл аумағы бойынша медианалық мәні 50 Бк/м^3 және одан да көп мекендер – радон қаупі бар учаскелердегі ЭТКБ деңгейі болып саналатыны анықталды.

Бұл зерттеуде осындай 11 ауыл анықталды. Курорттық аймақтың ірі су қоймаларынан алынған су сынамаларының радиоактивтілігін талдау 8 су қоймасының 7-де судың орташа альфа-белсенділігі 0,6 Бк/л, ал бета-белсенділігі 0,43 Бк/л құрағанын көрсетті, аномалды мән Болпаш Сордан алынған суда (альфа-белсенділігі 4,06 Бк/л, бета-белсенділігі 1,82 Бк/л) көрсетті. Су қоймаларынан су үшін радиоактивтілік бойынша нормативтер жоқ, егер бұл су қоймаларының суы шаруашылық ауызсу қажеттілігіне пайдаланылса, онда радионуклидтік талдау бойынша қосымша зерттеулер жүргізу керек. Судың жоғары емес радиоактивтілігі осы көлдерде (Чебачье, Бурабай және Шортанды) атап өтілетін өздігінен тазалайтын қабілетіне байланысты болуы мүмкін (Тұрсынова Айс., Д. Ж. Куншығар, 2016).

Зерттеу нәтижесі көрсеткендей, ЩБКА төңірегінде Бурабай және Біржан сал аудандарының 22 елдімекеннің 11-інде, радиациялық қауіп-қатерді топырақ радоны төндіруі мүмкіндігі анықталған, онда халық денсаулығына радиациялық қауіп-қатер деңгейі мен радонға қарсы мекендік шараларды өңдеу және жүргізу үшін егжей-тегжейлі радиоэкологиялық картаға түсіруді жүзеге асыруды жалғастыру қажет.

Зерттеу «2018-2020 жылдарға тыныңу әлеуетін орнықты қолдану мақсатында экологиялық жүктемені анықтаумен бірге Щучинск-Бурабай курорттық аймағында экожүйені кешенді бағалау» (BR05236529) ғылыми-техникалық бағдарламасы аясында жүргізілді.

Түйін сөздер: радон, радиациялық жағдай, уран, радондық қауіпті аймақ, Щучинск-Бурабай курорттық аймағы.

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РАДИАЦИОННАЯ СИТУАЦИЯ НА ТЕРРИТОРИИ ЩУЧИНСКО-БОРОВСКОЙ КУРОРТНОЙ ЗОНЫ И МЕРЫ ПО СНИЖЕНИЮ РАДИАЦИОННЫХ РИСКОВ

Аннотация. Исследование направлено на получение объективной информации о радиоэкологической ситуации на территории Щучинско-Боровской курортной зоны (далее ЩБКЗ). Эта информация востребована как постоянными жителями, так и отдыхающими, временно пребывающими на данной территории. При проведении радиоэкологических исследований использованы последние методические наработки по оценке радиационной ситуации. Такой подход позволил расставить приоритеты при выборе рекомендаций по снижению угроз радиационной опасности на исследуемой территории.

Оценка радиационной ситуации на территории ЩБКЗ проведена по результатам полевых радиоэкологических исследований, выполненных в 2018 и 2019 годах. Радиометрическое обследование проведено в 22 населенных пунктах (город Щучинск, 15 населенных пунктов Бурабайского района, 6 населенных

пунктов района Биржан Сал). Радиометрическая съемка с использованием дозиметров ДКС-96 выполнялась по улицам населенного пункта с таким расчетом, чтобы закрыть всю площадь населенного пункта. Фиксированные точки измерения активности проводились через 50 м, между этими точками – непрерывное прослушивание. Радоновые исследования включали определения мгновенных значений ЭРОА (эквивалентная равновесная объемная активность) радона, так и интегральных значений объемной активности радона в каждом населенном пункте.

Отбор проб воды на альфа- и бета-активность выполнен как из питьевых водоисточников, так и из крупных водоемов курортной зоны. Объемы и методики отбора проб, радиометрических и радоновых измерений радона выполнялись с учетом Методических рекомендаций Минздрава РК. Современные данные об уровне радиационной ситуации анализировались с учетом ранее выполненных исследований (АО «Волковгеология» в 2005-2008 годы и ТОО «ЭКОСЕРВИС-С» в 2010-2012г.).

ЩБКЗ расположена на территории Кокчетавской или Северо-Казахстанской ураноносной провинции. На территории ЩКБЗ ранее проведенными исследованиями выделены микробассейны с повышенными активностями радия-226, определено более десятка водоисточников с повышенной радиоактивностью. Радиоактивные аномалии в грунтах, воде и воздухе почв и грунтов пространственно увязываются с гранитными массивами Бурабай и Жукей. Вторым важным фактором, влияющим на радоновую опасность территории, является проявление разрывной тектоники.

Радиометрическим обследованием 2018-2019 годов определено среднее значение мощности эквивалентной дозы (МЭД) внешнего гамма-излучения, составляющее 0,160±0,031 мкЗв/ч. Повышенные значения средних значений МЭД населенных пунктов согласуются с контурами Боровского и Жукейского гранитных массивов. Было обнаружено лишь одно аномальное значение МЭД 0,61 мкЗв/ч. Установлено, что данная аномалия и ряд повышенных значений МЭД в соседних поселках связаны с повышенной радиоактивностью современного покрытия дорог гранитным щебнем.

На основании оценки мгновенных значений ЭРОА радона в 169 жилых зданиях (замеры 2018-2019г.), дополненных результатами замеров в 76 жилых и общественных зданиях (замеры 2010-2012г.), было определено, что медианное значение данного показателя в целом по ЩБКЗ составляет 70 Бк/м^3, в Бурабайском районе - 81 Бк/м^3, в Биржан Салском - 49 Бк/м^3. Медианное значение по территории поселка в 50 Бк/м^3 и более, как показал опыт наших многолетних радоновых исследований, это уровень ЭРОА на участках с радоновой опасностью. В данном исследовании было выявлено 11 таких поселков.

Анализ радиоактивности проб воды из крупных водоемов курортной зоны показал, что по 7 из 8 водоемов средняя альфа-активность воды составила 0,6 Бк/л, а бета-активность 0,43 Бк/л, аномальные значения получены для воды из Болпаш Сора (альфа-активность 4,06 Бк/л, а бета-активность 1,82 Бк/л.).

Для воды из водоемов нет нормативов по радиоактивности, если вода этих водоемов будет использоваться для хозяйственно-питьевых нужд, то следует провести дополнительные исследования по радионуклидному анализу. Невысокая радиоактивность вод, возможно, связана с отмечаемой на этих озерах (Чебачье, Бурабай и Шортанды) самоочищающей способностью (Турсунова Айс., Куншыгар Д.Ж., 2016).

Исследование показало, что наибольшая радиационная опасность на территории ЩБКЗ, представлена почвенным радоном в пределах 11 из 22 населенных пунктов Бурабайского и Биржан Салского районов, где необходимо продолжение детального радиоэкологического картирования по уровню радиационного риска для здоровья населения, разработки и проведения адресных противорадоновых мероприятий.

Исследование выполнено в рамках научно-технической программы: BR05236529 «Комплексная оценка экосистем Щучинско-Боровской курортной зоны с определением экологической нагрузки в целях устойчивого использования рекреационного потенциала» на 2018-2020 годы».

Ключевые слова: радон, радиационная ситуация, уран, радоноопасная зона, Щучинско-Боровская курортная зона.

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REGARDING THE BIOPOLYMERS HEAT STABILITY FORMATION

Abstract. Any biopolymer used as raw material for further treatment for food purposes besides the conformity with sanitary-hygienic regulation, physical-chemical and organoleptic regulation requirements should possess the specific technological properties that allow to manufacture high quality and safe finished products. All these pertain to raw milk. One of the basic technological characteristics is heat stability i.e. the ability of milk to sustain high temperature treatment while keeping at the same time the initial colloidal-disperse state of proteins that form its composition.

The article presents the methods of heat stability determination. It bases on both visual estimation and the usage of different instruments, created in the investigation process and fixation of physical characteristics or milk components.

The basic factors effecting the intravital formation of raw milk heat stability namely zootechnics, biochemical and physical have been also addressed in the article.

The authors describe several zootechnical factors, such as animal breeding and genetic traits, lactation periods, feed allowance and year season, housing conditions and level of health. It was proved that in order to obtain milk products manufactured under high temperature treatment, utilization of cow's milk of cows subjected to selective choice is preferable relating to accumulation in their A-alleles milk proteins; the maximum stability shows the milk produced within the 4th and the minimal within the 10th months lactation; full-value and the balance of the ration can be provided by pasture forage for cow or usage a twelve month confinement of soiling food, probiotic vitamins, mineral concentrates separately or as the complex additives; three times milking comparing to two times milking raises milk yield per lactation by 15-18% and effects positively the animals udder health state that is expressed by lower amount of somatic cells in milk.

The data covering the effect of milk composition, its components ratio density, titratable and active acidity on protein system stability are presented. The different correlation of milk heat stability depending on fat mass fraction, total protein and whey proteins, size and casein micelle fraction composition, salt composition and index of milk system physical state in the whole are considered.

Key words: biopolymers, raw milk, heat stability, methods of control, zootechnical, biochemical and physical factors.

The world milk production made up 844 million of tons in 2018 from which the part of the Eurasian Economic Union amounted to 5.4% (45.5 mln t). Russia ranks 6th place (30.3 mln t) among Top-10 best producers: USA (98.7 mln t), India (89.8 mln t), Brazil (33.8 mln t), Germany (33.0 mln t), China (30.8 mln t), France (25.5 mln t), New Zeuland (21.4 mln t), Turkey (20.0 mln t), Pakistan (16.7 mln t). In 2019 milk production in RF increased up to 31.3 mln t, that corresponds to 85.1% of self – sufficiency. For 2020 the task was to produce about 32.0 mln t and achieve the index of 86.5% which in the nearest years, according to the Doctrine of Food Safety of RF, should make up 90% [1]. When implementing the positive dynamics in raw milk production the primary attention should be payed to its quality conditioned by sanitary-hygienic, physical-chemical, organoleptic and technological properties among which heat stability is of great importance.

The scientific literature uses different synonyms of "heat stable" term: "thermostability", "heat stability", "heat tolerance". In dairy production practice this term implies the capacity of milk to withstand high temperature treatment (115-140^{o}C) while preserving initial protein colloid-disperse properties, meaning that casein should remain in the colloid suspension and whey proteins – in the solution. Since the share of heat stable milk (available for high temperature impact) makes up from 60 to 80 % in different the RF regions during the summer-autumn period (even less for winter-spring period), the attention of Russian and foreign scientists is inter alia concentrated at investigation of mechanism of protein heat coagulation and the factors effecting the system stability as well as the problem of its het stability improvement under heating. Some scientists determined the relation between milk heat stability and its protein and mineral composition; the theory of salt balance was created and developed under which the basic factor of milk stability against heating is its mineral composition [2-4].

Due to the fact that the mechanism of milk proteins heat coagulation process up to the present time has not been fully determined and milk stability under heating is characterized by not only one index of its physical-chemical state but by the complex of a number of factors (active acidity, concentration of free ions of calcium, magnesium, phosphorous, citrates, mas protein fraction and separate protein components, protein hydration rate, etc.), the common method of heat stability determination which can consider all nuances of the system variability integrally is lacking. Thus the scientists offer different methods between which the total aptitude and correlation have not been revealed [2,5,6]. The following methods of heat stability determination are the best known and more often used:

- the alcohol test – the method is based on the detection of milk proteins coagulation under the action of ethyl alcohol within the definite period of time;
- the thermal test – this method sets up the duration of proteins coagulation in milk samples placed into oil or glycerin bath at 115-140^{o}C;
- the flask test – determines the lack of coagulation in milk samples subjected to thermal action in ultrathermostat at 135^{o}C within 5 min;
- the calcium-chloride test – the method is based on the investigation of milk protein fraction stability under the action of calcium chloride solution and high temperature within the specific period of time;
- phosphate test – monosaturated potassium phosphate is used as the coagulant which is added to milk with immersion of the sample for the definite time into the boiling water bath;
- RAMSDEL – the type of the phosphate test where different amounts of monosaturated potassium phosphate are added into the milk;
- the acid-boiling test – the combination of thermal effect and acid (hydrochloric and sulfuric) rangering them by the volume is used as influence on milk protein.

Among the mentioned above methods of heat stability determination only the alcohol test is the standardized method (GOST 25228-82 "Milk and cream. Method of determination of termostability on alcohol test") due to simplicity of performance that was widely used in the industry as the rapid method for detection of not thermostable milk.

It should be mentioned that the thermal test is the most reliable and objective method, possessing high sensitivity and accuracy of the results. It also allows to immediately determine milk proteins stability under high temperature action without considering the effect of the added denaturants. However, due to the complex instrumental execution and the duration of measurement taking, the mentioned method cannot be used in the industry but only as the arbitral method.

The described above methods are based on the visual evaluation of thermal stability. To except the subjectivity during investigation the different test methods have been developed including the express control methods based on , for example, determination of electric conductivity size; detection of protein coagulation case by the hydro-mechanical method ("Thermol-1"); determination of calcium ions amount determined by the potentiometric method using ion-selective electrode; determination of titratable and active acidity quantity ratio, etc. Nowadays the mentioned methods are not widely used.

A lot of studies determined the following basic factors effecting life long formation of raw milk thermal stability:

- zootechnics (breed and genetic the animals characteristics, lactation period, feed allowance and year season, housing conditions, state of health);
- biochemical and physical (milk composition, proportion of its ingredients, density, titratable acidity, pH value).

It is known that milk of different breeds of cows has different physical-chemical composition, incl. protein amount, casein and fractions and minerals ratio that in turn effect milk thermostability. Thus, the top-priority of the zootechnical science is the selection of cow's breeds of highly productive milk of dairy farming, possessing not only high yield and mass fraction of fat and protein in milk, but milk with the specific technological properties that allow to manufacture high quality products requiring high temperature treatment during production as well [7,8].

Thus, the first calving cows of red-multicolored breed (control group) compared with Leningrad type black-multicolored breed (experimental group) being at non tethering maintenance in cowshed-transformers food allowance of which composed feed mixtures, milking and the primary milk treatment was performed in the industrial milking parlor. It was determined that milk samples of the control group corresponded on average to the 3d group of thermal stability by alcohol test and the experimental – to the 2d group. Thus the milk of the last group was more stable against high temperature treatment its usage was preferable in the manufacture of long-term storage sterilized products [9].

The investigation of milk protein component heat stability of the cows of Bestuzhevskiy, Airshirsky, Holstein breeds and their hybrids of different genotype showed that the milk of Holstein breed possesses the best capacity to stand ultrahigh temperature (endure the heat test within 72,2 min), the lesser – Bestuzhevsky (39.9 min). At cross-breeding of Bestuzhevsky (B) cows with Airshirsky (A) and Holstein (H) breeds these properties were significantly improved comparing to maternal breed and achieved the best figures in three breeds hybrids B x A x H (62.8 min) [10]. The data covering milk thermostability increase were published depending on increase of blood portion of farther-holstein breed in the genotype of hybrids cows: the milk of Holmogorsky-Holstein breed in the second generation endured 50.4 min of heat treatment but in the fourth generation – 68.2 min [11].

The works relating to the improvement of productivity of the red-multi colored breed cows due to usage of bull-breeders of Holstein cows are presented. Evaluation of the physical-chemical and technological properties of milk from cows-daughters of the first and second lactation being maintained without tether in boxes, milking – in milking parlor DeLaval "Elochka" type showed that cows part producing heat stable milk was increased by 60-89% [12]. Moreover the selection works proved that usage of Holstein breed increases the productive qualities of the red-multicolored cows. The cows of new genotype with blood portion in Holstein breed gave 75% during lactation period higher milk yield (by 1.7 times), milk portion of the first group of thermostability was increased by 1.6 times, the second group – by 1.5 times [13]. It gives the ground for continuation of the selection works in this field.

It has been proved that milk stability against heat treatment is conditioned by heredity that is evidenced by breed, linear and genotypic differences under the defined milk property. Milk of black-multicolored and red-steppe breeds is characterized by higher thermostability due to small casein micelles content than milk of Simmental and Kostromsky breeds, containing more calcium, that results in faster rennet coagulation. It has been also determined that milk of Tatarstan breed cows possesses higher stability at sterilization temperature and keeps protein in the native state up to 74% and milk of Holstein cows – up to 70% due to high milk casein stability (up to 90% and 84% respectively) [14].

A lot of data was obtained in studies of thermostability and cheese aptitude of milk from cows with different genotypes by milk proteins such as alfa S1-casein (*CSNISI*), beta-casein (*CSN2*), kappa-casein (*CSN3*) and beta-lactoglobulin (*BLG*). On the basis of genotyping of the black-multicolored and Holstein cows according to *CSN3* gene by the PCR-RFLP method of analysis, it was shown that milk from cows with *BB* genotype *CSN3* possessed reduced thermostability (39,3±5,43 min), *AA* genotype – increased thermostability (57.2±1,61 min) and milk of the animals with *AB* genotype took the intermediate position (56.5±2.52 min) [15,16,17].

The presence of *B* allele beta-casein in cow's genome improves the milk technological characteristics and allows to use it cheese making and *A*-allele – effects positively the thermostability. The studies of the question of genetic *CSN2* gene polymorphism of Tatarstan Republic cattle showed that *A* allele variant of *CSN2*-gene prevails (gene frequency 0.90-0.95) [18].

The investigation of the technological milk properties of the black-multicolored cows with different genotypes of β-lactoglobulin showed that the highest themostability (58.9±4.67 min) possesses milk from cows having in their genome the allele variant of *A* gene and the lesser (52.7 ± 2.52 min) – *B* gene [19].

The presented data relating to relation of milk from different thermostability groups on genotype by kappa-casein of first calving black-multicolored, red-multicolored and red-steppe breeds. It was

determined that the milk of the I and II groups gave 67% cows of the red-steppe breed, 60% – red-multicolored breed, 15% – black-multicolored breed besides the last animals gave only milk of the II group [20].

Thus, in order to receive the milk products manufactured with high temperature treatment, it is better to use milk from cows which passed the selection on the accumulation of *A*-allele in milk proteins in their genotype.

The composition and properties of milk depend as well on cow's lactation period. Usage of raw milk received from healthy cows after 7 days after the calving and 5 days before the calving is regulated by law for dairy products manufacture. It is determined that milk thermostability of tatarstan type cows and Holstein breed within the lactation period is subjected to significant changes, e.g. the better stability possessed the milk received within the 4^{th} and the lesser – within the 10^{th} month of lactation. The highest part of milk thermostability (87.5-100%) related to the I and II groups was observed in the period of the 7^{th} month. The stable negative correlation was observed between lactation variability of milk by thermostability and the amount in it the protein in the whole as well as its separate fractions. [14,21]. It was detected as well that milk independent on cows breed (Holstein, Cholmogor, Tatarstan) and their cross breed of different genotype 15 days prior to the start didn't stand heat treatment required for manufacture of sterilized products [11].

It is evident that the technological peculiarities of milk are influenced certainly the fodder type, their balance in cows' ration, regime of feeding, housing conditions as well as seasonal factors having the systematic character. The increased part of the concentrates at low level of carbohydrates, vitamins and minerals in cows' nutrition within long time results in reduction of milk thermostability. Pasture forage or usage of soiling food all the year round at stabling improve milk thermostability [2,22]. For example, it is determined that inclusion of granular birch bark into lactating cows diet in the dosage of 10 g per 10 kg of live weight even after 7 days increases thermostability from the III to the I group [22]. Other investigations showed the positive effect on the heat stability of milk from the cows with feeding ration with addition of probiotic oreparations, e.g. lactic acid bacteria that made it possible to increase milk part from the Ist group by thermostablity from 30% to 40% [23]. Administration into the fodder buffer mixtures, protein, vitamins, minerals concentrates separately or as complex additives improves milk thermostability as well [5,24].

Dairy plants receive collected milk which meets all established sanitary-hygienic, physical-chemical and organoleptic requirements. The individual peculiarities in the composition and properties of milk from separate cows do not significantly effect the raw milk quality. In the case of deviation from physically normal state of health the lactating animals milk secretion disorder, yield reduction, decrease of casein, lactose, fat, potassium, phosphorus, magnesium, calcium in milk take place and on the contrary a lot of whey proteins, sodium, chlorine appear. Due to these the technological characteristics of milk are deteriorated incl., heat stability is decreased which extent of variation depends on severity of illness [2].

Along with feeding the milking is significantly influenced by the method of maintenance and the order of cows' milking which acquire special meaning in high-productive herds. It has been determined that threefold milking comparing to twofold increases lactation by 15-18% and effects positively of the animals udder state of health that is expressed in lower number of somatic cells in milk; exceeding of the regulated figures of which (legislatively fixed level – at most $7.5x10^5$ of somatic cells in 1 cm^3) is the sign of udder mastitis and disturbance of mammary gland secretory function. At threefold milking the number of cows with somatic cells more than $1x10^6$ made up only 2.6% whereas at twofold milking – 6% [25,26]. The works relating to the creation of the methods of milk quality forecasting prior to its milking by determination of bioelectrical potential of surface localized biologically active centers are of great interest. The direct correlation relation between thermostability of milk proteins and the level of average potential which is influenced by the secretion intensity in mammary gland including conditioned by microflora provoking mastitis and reducing casein micelles stability against high temperature impact [27].

Raw milk thermostability besides its dependence on zootechnical factors is mainly conditioned by the biochemical composition and physical state of milk. The scientists detected different correlations of milk heat stability depending on mass fat fraction, total protein and whey proteins, the size and composition of casein micelle fraction, salt composition, titratable and active acidity, density, etc.

For example, in the evaluation of the collected milk composition classified according to the groups of therostability by alcohol test the higher amount of minerals 0.66% was fixed in nonthermostable milk (III-V groups) comparing to thermostable (I-II groups) – 0.47%, whey proteins -0.61% and 0.52% and the ratio of calcium to phosphorus –1,6 and 1,4 respectively. The non-thermostable milk had bigger casein micelles (by 2.4%), higher titratable acidity (by 10.6%), contained slightly more dry matters (by 1.3%) and dry skimmed milk residues (by 1.8%) and less casein amount (by 3.7%) at practically equal part of total protein 3.06%, lactose (by 0.9%), phosphorus (by 11.8%), citrates (by 10.7%). Herewith the fact of prevailing of the negative effect on titratable acidity thermostability was determined (coefficient of correlation 0.38) and the sharp reduction of heat stability at mass part of whey proteins more than 0.9% [4,14].

The analysis of the interconnection between total protein, whey proteins, β-lactoglobulin, α-lactalbumin and proteozo-peptone fraction showed that increasing of their level as a rule resulted in decreasing of milk capacity to keep its initial heat stability. The largest correlation dependence was determined on total protein content (-0.283) and milk whey proteins (-0.190). Thus at high level of total protein and whey proteins (3.439% and 0.799%), average (3.392% and 0.754%) and low (3.294% and 0.746%) milk sustained without visible coagulation 46.1:51.9:60.2 min and 45.3:53.7:54.0 min. The investigation by β-lactoglobulin and proteozo-peptone fraction showed 49.6:52.5:55.3 min and 47.5:53.6:57.6 min. The correlation coefficient made up in average: -0.139 and -0.159. Slightly different picture of heat stability was observed in α-lactalbumin 49.4:55.6:48.1 min. Thus the author confirmed the supposition that total protein level renders greater negative effect than whey proteins on milk thermostability [10].

The other scientists carried out the whole year analysis of milk thermostability depending on the ratio of its basic components. It was stated that increase of mass fraction of fat in milk effects positively its heat stability. The coefficient of correlation between fat content, ratio of fat to protein and thermostability made up 0.134-0.136. Moreover, the preferable ratio between fat and protein 1.21-1.50 for milk system was determined. Besides it was mentioned that if milk contains less than 2.5% of protein and density is less than 1,027 g/cm^3 or more than 1,032 g/cm^3 the part of non-thermostable milk is increases (up to 18.2-21.6% of the tested samples). Simultaneously more than 55% of milk samples with mass protein fraction 3.01-3.25% were related to I-II groups by thermostability. The increase of milk acidity to more than 20^{o}T resulted in the increase of non-thermostable milk part (to 60%) [5,28]. The obtained data were confirmed by the studies [26] and namely: milk with 3.07-3.10% of protein showed the largest part of thermostability of I-II groups (with reduction of protein amount to 2.9% milk thermostability was reduced to III-IV groups); fixation of milk density in the range of 1.027-1.028 g/cm^3 showed thermostable milk (with density 1.025 g/cm^3 and the part of non-thermostable milk was increased sharply); milk coagulation began titratable acidity lower 15^{o}T or higher 19^{o}T.

Fresh milk has subacid medium (the average value of active acidity (pH) makes up to 6.75, fluctuation range of pH 6.65-6.85) and as a rule at such values it stands high temperature action without visualization of casein coagulation. There is no direct relation between milk active acidity and its thermostability. Meanwhile, it was stated that one of the reasons for the reduction of casein micelles negative charge and decreasing of hydrate coating size resulting in casein particles aggregation and their destabilization during heating is the change of milk active acidity. The increase of calcium ions concentration with decreasing of pH values results in coagulation [2,9,29].

Thus the directed intravital formation of raw milk thermostability allows to minimize usage of different additional technological methods of milk heat stability improvement and obtain qualitative raw milk for dairy products manufacture including the technologies which stipulate usage of high temperature treatment of milk.

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БИОПОЛИМЕРДІҢ ЖЫЛУҒА ТӨЗІМДІЛІГІН ҚАЛЫПТАСТЫРУ

Аннотация. Тағамдық мақсат үшін одан әрі қайта өңдеу барысында шикізат ретінде пайдаланылатын кез келген биополимер санитарлық-гигиеналық, физика-химиялық және органолептикалық сипаттамаларға қойылатын талаптарды қанағаттандырумен қатар, сапалы және қауіпсіз дайын өнімді шығаруға мүмкіндік беретін белгілі бір технологиялық қасиеттерге ие болуы керек. Мұның бәрі шикі сүтке қатысты. Оны әрі қарай өңдеу мүмкіндігінің негізгі технологиялық сипаттамаларының бірі, әсіресе, зарарсыздандырылған өнімдерді өндіруде жылуға төзімділігі болып саналады, яғни оның құраушы ақуыздарының алғашқы коллоидты-дисперсті күйін сақтау барысында сүттің жоғары температуралық өңдеуге төтеп беру мүмкіндігі.

Мақалада жылуға төзімділікті визуалды бағалауға (алкогольдік, жылулық, тигелдік, кальций хлориді, фосфатты, қышқылды-қайнатылған сынамалар), сонымен қатар зерттеу негізінде жасалған және сүттің физикалық сипаттамалары мен компоненттерін тіркеуге арналған түрлі құрылғыларды қолдану әдістері ұсынылған. Сонымен қатар, шикі сүттің жылуға төзімділігіне әсер ететін негізгі факторлары, атап айтқанда, зоотехникалық, биохимиялық және физикалық қарастырылған.

Зоотехникалық факторлардың ішінде, мысалы, жануарлар тұқымы мен генетикалық сипаттамалары, лактация кезеңі, азықтандыру рационы мен жыл маусымы, ұстау шарттары, денсаулығының жай-күйі сипатталған. Жоғары температурада өңдеу арқылы өндірілген сүт өнімдерін алу үшін сиыр сүтін қолданған жөн, ол үшін генотипінде А-аллел ақуыздарын жинақтау үшін селекциялық жұмыстар жүргізілген; лактацияның 4 және 10-айында алынған сүт анағұрлым төзімді; толық және теңдестірілген тамақтануды сиыр жаю немесе көкпен азықтандыру, пробиотикалық препараттар, түрлі буферлік қоспалар, ақуыз, дәрумендер және минералды концентраттарды жеке-жеке немесе жыл бойы қоректендіруге арналған кешенді қоспалар түрінде қамтамасыз етуге болады; қосарланған сауумен салыстырғанда, үш есе сауу, лактация кезінде сүттің өнімділігі 15-18% жоғарылайды және жануарлар желінінің денсаулығына жағымды әсер етеді, бұл сүттегі соматикалық жасушалардың төмен құрамы арқылы көрінеді.

Мақалада сүттің құрамына әсері, оның құрамдас бөліктерінің қатынасы, тығыздығы, титрлеу және белсенді қышқылдығы ақуыз жүйесінің тұрақтылығы келтірілген. Майдың, ақуыздың және сарысу ақуыздарының массалық үлесіне, казеин-мицелла фракцияларының мөлшері мен құрамына, тұздың құрамына және тұтастай алғанда сүт жүйесінің физикалық күйінің мәніне байланысты сүттің жылуға төзімділігінің түрлі арақатынасы көрсетілген.

Жылуға төзімді сүттің ғылыми-техникалық көзін талдау негізінде минералды тұздар, сарысу ақуыздары мен кальцийдің фосфорға қатынасы төмен болады. Сонымен қатар, жылуға төзімді емес сүттің құрамында казеин мицелласы ірі, титрлеу қышқылдығы жоғары, құрамында бірнеше қатты заттар бар және құрғақ майсыз сүт қалдықтары, ал аз мөлшерде казеин, лактоза, фосфор және цитрат бар. Жалпы ақуыз, сарысуы бар ақуыз, β-лактоглобулин, α-лактоальбумин және протеоза-пептон фракциясының арақатынасын талдау олардың деңгейінің жоғарылауы арқылы, әдетте, сүттің бастапқы жылуға төзімділігінің сақтау қабілетінің төмендейтінін көрсетті. Кейбір зерттеушілер сүттегі майдың массалық үлесін оның жылуға төзімділігіне арттырудың оң әсерін анықтады. Сонымен қатар, май мен ақуыздың арақатынасы анықталады.

Осылайша шикі сүттің жылуға төзімділігінің өмір бойына бағытталған қалыптасуы сүттің термиялық төзімділігін арттыру және сүт өнімдерін өндіру үшін жоғары сапалы сүт шикізатын алу үшін түрлі қосымша технологиялық әдістерді азайтуға мүмкіндік береді, технологиясы жоғары температуралы сүтті өңдеуді қолдануды көздейді.

Түйін сөздер: биополимерлер, шикі сүт, жылуға төзімділік, бақылау әдістері, зоотехникалық, биохимиялық және физикалық факторлар.

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К ВОПРОСУ ФОРМИРОВАНИЯ ТЕРМОУСТОЙЧИВОСТИ БИОПОЛИМЕРОВ

Аннотация. Любой биополимер, используемый как сырье для дальнейшей переработки на пищевые цели, кроме соответствия регламентируемым требованиям по санитарно-гигиеническим, физико-химическим и органолептическим показателям, должен обладать определенными технологическими свойствами, позволяющими осуществлять выпуск качественной и безопасной готовой продукции. Все это в полной мере относится к сырому молоку. Одной из основных технологических характеристик возможности его дальнейшей переработки, особенно в производстве стерилизованной продукции, является термоустойчивость, т.е. способность молока выдерживать высокотемпературную обработку при сохранении первоначального коллоидно-дисперсного состояния входящих в его состав белков.

В статье приведены методы определения термоустойчивости, основанные как на визуальной оценке (алкогольная, тепловая, тигловая, хлоркальциевая, фосфатная, кислотно-кипятильная пробы), так и с использованием различных приборов, созданных на базе исследования и фиксирования физических характеристик, либо составных частей молока.

Рассмотрены основные факторы, влияющие на прижизненное формирование термоустойчивости сырого молока, а именно зоотехнические, биохимические и физические.

Среди зоотехнических факторов выделены и описаны такие, как порода и генетические особенности животных, период лактации, кормовой рацион и сезон года, условия содержания, состояние здоровья. Показано, что для получения молочной продукции, вырабатываемой с использованием высокотемпературной обработки предпочтительнее применять молоко коров, в отношении которых проведены селекционные работы по накоплению в их генотипе А-аллелей белков молока; наибольшей устойчивостью обладает молоко, полученное в течение 4-го, а наименьшей – в течение 10-го месяца лактации; полноценность и сбалансированность рациона можно обеспечить за счет пастбищного содержания коров или использования при круглогодичном стойловом содержании зеленой подкормки, препаратов пробиотического действия, различных буферных смесей, белковых, витаминных, минеральных концентратов по отдельности или в виде комплексных добавок; трехкратное доение по сравнению с двукратным повышает удои за лактацию на 15-18% и положительно влияет на состояние здоровья вымени животного, которое выражается в более низком содержании соматических клеток в молоке.

Представлены данные по влиянию состава молока, соотношения его составных частей, плотности, титруемой и активной кислотности на стабильность белковой системы. Приведены различные корреляции тепловой стабильности молока в зависимости от массовой доли жира, общего белка и сывороточных белков, размера и состава фракций мицелл казеина, солевого состава и значений показателей физического состояния молочной системы в целом.

На основе анализа научно-технических источников в термоустойчивом молоке зафиксировано более низкое содержание минеральных солей, сывороточных белков, соотношение кальция к фосфору. Наряду с этим, нетермоустойчивое молоко имело более крупные мицеллы казеина, более высокую титруемую кислотность, содержало несколько больше сухих веществ и сухого обезжиренного молочного остатка и меньшее количество казеина, лактозы, фосфора, цитратов. Также анализ взаимосвязи содержания общего белка, сывороточных белков, β-лактоглобулина, α-лактоальбумина и протеозо-пептонной фракции показал, что при увеличении их уровня, как правило, снижается способность молока сохранять свое первоначальную тепловую стабильность. Некоторыми исследователями установлено положительное влияние увеличения массовой доли жира в молоке на его термостойкость. Кроме этого, определено предпочтительное соотношение между жиром и белком.

Таким образом, направленное прижизненное формирование термоустойчивости сырого молока позволит минимизировать использование разнообразных дополнительных технологических приемов повышения тепловой устойчивости молока и получать качественное молочное сырье для производства молочной продукции, в т.ч. технология которой предусматривает применение высокотемпературной обработки молока.

Ключевые слова: биополимеры, сырое молоко, термоустойчивость, методы контроля, зоотехнические, биохимические и физические факторы.

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CALCULATION OF KINETIC PARAMETERS OF THERMAL DECOMPOSITION OF COALS OF VARIOUS DEPOSITS OF KAZAKHSTAN

Abstract. The article studies the influence of the heating rate and the fractional composition of OMC on the kinetic parameters of the process of thermal destruction, it is revealed that an increase in the heating rate leads to a decrease in the degree of thermochemical destruction of OMC. The coals of the Saryadyr deposit (Pyatimetrovyi, Nadezhnyi), Maykube (Shoptykol), Bogatyr (Ekibastuz) were taken as research samples. The dependence of the kinetic parameters of thermal destruction of coal in the temperature range of the main decomposition of OMC on the rate and temperature of heating and fractional composition, as well as between the kinetic parameters at different stages of the main decomposition of coal, is analyzed. It was found that the heating rate of β samples of coal significantly increases the temperature T_{max} and the destruction rate v_{max}, and also reduces the activation barriers of the process. A study was also conducted of the effect of heating in the temperature range of 30-900 ° C on the degree of thermochemical destruction of coal samples Saryadyr (Pyatimetrovyi, Nadezhnyi), Maykube (Shoptykol), Bogatyr (Ekibastuz). The results showed that the coals of the Maykube deposits are subjected to maximum decomposition (more than 40% by weight). This indicates their lower thermal stability, and hence the lower stage of metamorphism with respect to other coals studied, due to the content of a large amount of oxygen in them in the form of functional, ether groups and other forms. In this case, the process of thermal decomposition occurs at lower temperatures, during which a large number of low molecular weight volatile substances are formed in the form of vapors of resins and gases, and very few non-volatile liquid-phase products are formed, i.e. the stage of transition to the plastic state is absent. These factors are in agreement with the fact that these coals contain a large amount of volatile (51-57%).

The coals of the Bogatyr and Saryadyr deposits, when heated, have the lowest reactivity (decomposition degree less than 30%), which is due to the low amount of oxygen-containing compounds and a high carbon content. Minimal weight loss is also associated with a lower moisture content (2-3%). The higher stage of metamorphism of these coals is due to the fact that their structure has a high degree of crosslinking and a large number of developed polyaromatic formations.

Key words: coal, thermal destruction, decomposition stage, heating rate, kinetic parameters.

Introduction. Most of the kinetics of thermal destruction are based on the results of thermal analyzes (thermogravimetry, differential thermal analysis, derivatography, etc.) [1,2]. Among the methods of thermal analysis of solid fuels, differential thermal and differential thermogravimetric analysis methods are most widely used [3]. The thermogravimetric method allows one to obtain the TG (temperature dependence of the sample mass) and DTG (temperature dependence of the rate of change of sample mass) curves when the temperature of the system changes according to a given linear law [4]. These experimental curves make it possible to judge the thermal stability of the test substance, the composition and thermal stability of substances that are formed at intermediate stages. This method is especially

effective if a sample of a substance emits a sufficient amount of volatile substances as a result of various physicochemical processes (evaporation, combustion, etc.) [5].

Depending on the temperature conditions of the process, two research schemes are distinguished: 1) an isothermal scheme, when the sample is placed in a stationary temperature field; 2) non-isothermal circuit, when the sample is heated at a constant speed. One of the main advantages of the isothermal method is that the experimental data lend themselves very easily to rigorous mathematical processing. But there are also disadvantages that are expressed in the long duration of the experience, the complexity of observing the conditions isothermal, the impossibility of determining the activation energy according to the results of one experiment. The non-isothermal method is devoid of all the shortcomings of the isothermal method; therefore, this method has become widespread, allowing for a relatively short time to obtain great information about the nature of the decomposition process with registration of all stages of the transformation in a wide temperature range [6]. The most common differential thermal and thermogravimetric methods of analysis. The application of these methods allows one to calculate the kinetic parameters of the corresponding processes, the thermal effects of the reaction, the onset temperature of decomposition, and other important characteristics [7].

The aim of this work is to determine the kinetic parameters of the process of thermal decomposition of coal from the Saryadyr (Pyatimetrovyi and Nadezhnyi) and Maykube deposits and the Bogatyr mine.

Research methodology. To characterize the process of thermal decomposition of coal, the following indicators were selected: loss of mass of samples in various temperature ranges; temperature T_{max}, speed T_{max}, speed constants k_{max}, corresponding to the highest mass loss rate (i.e., the maxima of the main decomposition on the DTG curves at the inflection points); preexponential factor k0 and activation energy Eact related to the stages of the main thermal decomposition of coal.

The presence of various competing sequentially parallel processes during the thermochemical transformations of coals (according to the molecular and radical-chain mechanism) often leads to fluctuations in the total reaction order in the range 0.5-1.5. It is impossible to describe the whole process of coal decomposition using one first-order equation (monomolecular transformation), since in real conditions the decomposition of the organic mass of coal (OMC) occurs under the mutual influence of substances of different nature constituting OMC [8, 9]. But the process of basic thermal decomposition can be described by the equation of formal kinetics of the first order and calculate the Act. Therefore, due to the variety and complexity of physicochemical transformations, these kinetic parameters describe not certain reactions, but the total processes of thermal decomposition of OMC, therefore they are considered as “effective parameters” of formal kinetics [10].

The kinetic parameters of the basic thermal decomposition of OMC were determined based on the equations of nonisothermal formal kinetics [11]. The mathematical processing of the curves was carried out in accordance with the procedure [12]

Thermogravimetric analysis to study the kinetics of thermal destruction of coal was carried out in an inert nitrogen atmosphere at different heating rates within 3-15 deg / min and coal fractions with granule sizes d = 0.2-5 mm, the DTG curves of Saryadyr coal (Pyatimetrovyi and Nadezhnyi) are presented. Maykube and Bogatyr in a nitrogen environment.

Results and its discussion. It was revealed that the change in the mass of coal occurs in five stages. The temperature range 25 -110 °C corresponds to stage I, which corresponds to the release of pyrogenic water. Stage II corresponds to the interval 110-450 °C, where, under the influence of temperature, gaseous substances, mainly carbon dioxide and hydrogen sulfide, begin to be released from the molecule of organic matter of coal. The jump in the mass change of stage III at a temperature of 450-560 0C is explained by the fact that resin begins to be released in this temperature range, this stage is usually associated with the bituminization process, when the bulk of the coal tar begins to form, but there is not enough heat to evaporate it. With further heating (above 560 ° C) a small amount of gas is released, the resin is almost not released, therefore, at stage IV, the yield of volatile components is not significant. Then, at stage V, another jump in mass loss is observed in the temperature range of 860-900°C, this is due to the fact that in this temperature range there is an active decomposition of the mineral part of coal.

The analysis of the curves revealed three stages of the main decomposition of the OMC of the studied coals on the differential DTG curves, where peaks with maxima of the mass loss rate (inflection points) are observed (figure 1).

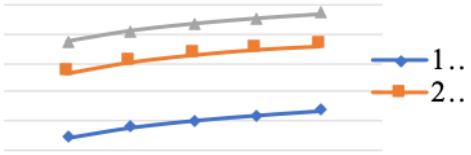

Figure 1 – Dependence of temperature at inflection points on coal heating rate at different decomposition stages

First stage with maximum at T_{max} temperatures in the range 134-226^{0}C is related to evaporation of water, release of oxygen-containing gases due to decomposition of side groups of macromolecules (since carbon-oxygen bonds are least stable in thermal terms). At this stage, it is preferable to break the bonds between the main structural units, cleavage and partial disintegration of the side chains, partially remove O_2, N, S [13]. The volatile yield in this temperature region is low. In the 2nd stage, a peak is observed with a maximum of at 357-453^{0}C, which is responsible for increasing the intensity of the thermosynthesis reaction group due to increased reactivity of the substances of the heated OMC. At the same time reactions of decomposition of oxyaromatic and heterocyclic fragments can take place, as well as thermochemical transformations of humic substances and synthesis of new more heat-resistant compounds based on them, increase in the number of non-organic bonds, the rate of formation of volatile substances increases [14]. In the third stage with peak with maximum at 462-553^{0}C thermal flow reactions of the most thermostable organomineral complexes develop, by the end of this stage the extraction of the main mass of resin and gaseous hydrocarbons is observed, the process is completed with formation of semi-coke.

With a further increase in the temperature, the aromatization and polycyclization reactions intensify (with the removal of gaseous products, mainly H_2, and in a smaller amount - CH_4, CO, N_2), the formation of higher molecular weight polycyclic systems of a mesh structure [15].

At heating rates β from 6 to 15 deg / min at the stage of the decomposition of WMD at temperatures T_{max} in the range of 462–553 °C, peaks with a maximum mass loss rate are weakly expressed with a tendency to decrease with increasing β. This is associated with the imposition of several processes and the impossibility of their separate assessment for the calculation of kinetic parameters.

The results of processing DTG curves at various heating rates in the range of 3-15 deg / min are presented in tables 1-4.

The degree of coal conversion of the Saryadyr deposit (Pyatimetrovyi) during thermolysis decreases with a decrease in the residence time of coal particles in the high temperature zone, as evidenced by a slight decrease in coal mass loss (from 31.6-30.9%) in the range of 3-15 deg / min) at increasing the heating rate (table 1).

Table 1 – Mass losses of samples of coal samples brand Saryadyr (Pyatimetrovyi) in various temperature ranges and T_{max} values at the stages of decomposition

Speed heating ° C / min	Loss of mass from the sample,%			Tmax, C	
	30-300°C	300-600°C	30-900°C	Decomposition stages	
				1	2
3	4.796	26.899	31.641	35.16	681.79
6	3.549.	25.863	29.422	61.53	438.63
9	3.561	25.446	29.183	69.95	450.38
12	3.507	25.642	29.306	71.58	454.06
15	4.457	26.478	30.935	77.32	461.51

For coal of the Saryadyr (Nadezhny) field of the grade, a certain decrease in the loss of coal mass is shown, a decrease in the loss of coal mass from 28.3 liters to 22.1%, with an increase in the heating rate in the range of 3-15 deg / min (table 2).

Table 2 – Mass loss of samples of coal samples brand Saryadyr (Nadezhnyi)
in various temperature ranges and Tmax values at the stages of decomposition

Speed heating ° C / min	Loss of mass from the sample,%			Tmax, C	
	30-300°C	300-600°C	30-900°C	Decomposition stages	
				1	2
3	2.930	25.164	28.269	111.94	450.13
6	2.896	19.768	22.674	60.89	453.33
9	2.506	19.611	22.134	75.24	460.67
12	2.916	19.496	22.535	77.12	465.22
15	2.766	19.341	22.107	78.45	471.87

For brown coal samples of the Maykube deposit of grade B_3 (Shoptykol) in the range of 3-15 deg / min, there is a slight increase in the weight loss of the sample from 19.3 to 38.3%, for samples of coal of the Bogatyr deposit (Ekibastuz) a decrease in weight loss from 21, 3 to 19.4% (tables 3,4).

This is due to the brand of the studied coal samples Saryadyr (Pyatimetrovyi and Nadezhnyi), Bogatyr belong to stone, and Maykube brown B_2 grades, respectively, due to the different structure of the morphological composition, the trend of the weight loss of the samples is different.

Table 3 – Mass losses of samples of samples of coal grade B_3 Maykube (Shoptykol)
in various temperature ranges and T_{max} values at the stages of decomposition

Speed heating ° C / min	Loss of mass from the sample,%			Tmax, C	
	30-300°C	300-600°C	30-900°C	Decomposition stages	
				1	2
3	1.909	17.579	19.380	71.26	484.6
6	10.800	29.367	40.648	75.90	439.38
9	9.619	29.108	38.849	80.95	442.42
12	9.819	27.658	37.477	87.87	483.43
15	10.108	28.043	38.336	90.20	452.16

Table 4 – Mass loss of samples of coal samples brand Bogatyr (Ekibastuz)
in various temperature ranges and T_{max} values at the stages of decomposition

Speed heating ° C / min	Loss of mass from the sample,%			Tmax, C	
	30-300°C	300-600°C	30-900°C	Decomposition stages	
				1	2
3	2.009	19.225	21.369	52.67	448.76
6	1.661	17.342	19.080	57.83	462.90
9	2.866	19.814	22.674	62.74	453.33
12	1.866	17.215	19.081	68.35	477.51
15	1.909	17.579	19.380	71.26	484.67

The analysis of the obtained data shows that for all samples of the studied coals in the temperature ranges of 30-300 ° C, the mass loss of the OMC has the smallest values (table 3.3-3.4). In the temperature range 300-600 ° C, where the second and third maxima are observed, higher mass losses of OMC are observed. Apparently, this is due to the release of the bulk of the vapor of the resin and gaseous hydrocarbons with the simultaneous formation of vapor of the so-called pyrogenic water. In the general temperature range of 30–900 °C, the mass loss of OMC is low, due to the high ash content and low volatility.

An increase in the size of coal particles d = 0.2-5 mm leads to a slight increase in the degree of decomposition of OMC (7-8%) and does not significantly affect the kinetics of the studied process.

Table 5 – Kinetic parameters of thermal destruction of OMC of coal

Speed heating ° C / min	Decomposition stages					
	1 stage			2 stage		
	k_{max}, 10^{-3} c^{-1}	k_0, 10^2 c^{-1}	$E_{акт}$, кДж/моль	k_{max}, 10^{-3} c^{-1}	k_0, 10^4 c^{-1}	$E_{акт}$, кДж/моль
3	1,35	2,72±0,13	43,7±0,92	1,23	1,45±0,03	98,2±3,7
6	1,65	7,42±0,64	46,3±2,76	1,19	1,94±0,12	93,3±2,9
9	1,47	1,89±0,11	40,3±2,61	1,34	0,71±0,03	86,8±3,6
12	1,69	2,78±0,18	44,8±2,23	1,52	0,54±0,06	82,6±3,4
15	1,39	1,65±0,06	38,3±1,75	1,32	0,47±0,02	80,1±4,8

As the study showed, when passing from one stage of the main decomposition to another for the coals under study and when the temperature increases at various speeds in the range from 3 to 15 deg / min, with an increase in the heating rate, a significant increase in Eact (approximately twice) is noted. The difference between the activation barriers of the 1st and 2nd stages within the same heating rates is 38-54 kJ / mol. Moreover, the probability of rupture of certain types of bonds during the destruction process increases noticeably, as evidenced by the differences between the values of k_0 at the first and second stages (by 1-2 orders of magnitude, i.e., k_{01} ~10^2 c^{-1}, k_{02} ~10^3-10^4 c^{-1}).

In general, it can be noted that the calculated values of the activation energy are commensurate with the energies of chemical bonds. An increase in the heating rate β from 3 to 15 deg / min at all stages of decomposition for the studied OMC coals leads to a shift in the temperature values Tmax (corresponding to the maximum decomposition) towards large values ($\Delta T_{max} \approx 100^0$C) and an increase in the rate v_{max} of the destruction of the OMC. The value of the velocity v_{max} at the 2nd stage is higher than at the 1st. In this case, the approximation of points by a straight line allows us to obtain approximate dependences between v_{max} and β, shown in figure 2 (R^2 is the reliability of the approximation). At the same time, the difference between the velocities at the inflection points Δv_{max} at the 1st and 2nd stages also increases with increasing heating rate β and the relationship between Δvmax and β is described by a similar function close to linear ($y = 0.011 \cdot x - 0.026$, $R^2 = 0.967$).

Thus, an increase in the heating rate has a more significant effect on the speed of the process with a higher activation barrier, and also contributes to a slight decrease in the E_{act} values at the 2nd stage of decomposition (98.2-80.1 kJ / mol). However, this does not have such a significant effect on the overall degree of decomposition of coal, which is most likely due to the compensation of a higher heating rate with a shorter duration of the thermolysis process (and vice versa).

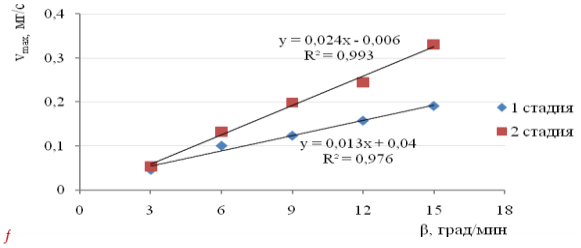

Figure 2 – Dependence of the rate of destruction at the inflection points on the rate of heating of coal at various stages of decomposition

As can be seen from the data in tables (1-4), the coals of the Maykube deposits are subjected to maximum decomposition (more than 40% by weight). This indicates their lower thermal stability, and hence the lower stage of metamorphism with respect to other coals studied, due to the content of a large amount of oxygen in them in the form of functional, ether groups and other forms. In this case, the process of thermal decomposition occurs at lower temperatures, during which a large number of low molecular weight volatile substances are formed in the form of vapors of resins and gases, and very few non-volatile liquid-phase products are formed, i.e. the stage of transition to the plastic state is absent. These factors are in agreement with the fact that these coals contain a large amount of volatile (51-57%).

The coals of the Bogatyr and Saryadyr deposits, when heated, have the lowest reactivity (decomposition degree less than 30%), which is due to the low amount of oxygen-containing compounds and a high carbon content. Minimal weight loss is also associated with a lower moisture content (2-3%). The higher stage of metamorphism of these coals is due to the fact that their structure has a high degree of crosslinking and a large number of developed polyaromatic formations [16,17]. When such fuels are heated, the resin yield is negligible. In this case, mainly reactions of cleavage from macromolecules of relatively small groups and side chains occur, followed by cyclization and ordering of the structure.

Conclusions. Thus, the influence of the heating rate and the fractional composition of OMC on the kinetic parameters of the process of thermal destruction was studied, it was revealed that an increase in the heating rate leads to a decrease in the degree of thermochemical destruction of OMC. The dependence of the kinetic parameters of thermal destruction of coal in the temperature range of the main decomposition of OMC on the rate and temperature of heating and fractional composition, as well as between the kinetic parameters at different stages of the main decomposition of coal, is analyzed. It was found that the heating rate of β samples of coal significantly increases the temperature Tmax and the destruction rate vmax, and also reduces the activation barriers of the process. A study was also conducted of the effect of heating in the temperature range of 30-900 ° C on the degree of thermochemical destruction of coal samples of stone Saryadyr (Nadezhnyi) brand, Saryadyr (Pyatimetrovyy) brand, Bogatyr brand and brown Maykube brand B_3.

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ҚАЗАҚСТАННЫҢ ТҮРЛІ КЕН ОРЫН КӨМІРІ ТЕРМИЯЛЫҚ ЫДЫРАУ КИНЕТИКАСЫНЫҢ ПАРАМЕТРЛЕРІН ЕСЕПТЕУ

Аннотация. Мақалада термиялық деструкция процесінің кинетикалық параметрлеріне КОМ фракциялық құрамы мен қыздыру жылдамдығының әсері зерттелді, қыздыру жылдамдығының артуы КОМ термохимиялық деструкция дәрежесін азайтатыны анықталды. Зерттеу үлгісі ретінде Сарыадыр (Пятиметровый, Надежный), Майкөбе (Шоптыкөл), Богатырь (Екібастұз) кен орнының көмірі алынды. Көмір термодеструкциясы кинетикалық параметрлерінің КОМ негізгі ыдырау температурасының қыздыру жылдамдығы мен температурасына және фракциялық құрамына тәуелділігі, сондай-ақ көмірдің негізгі ыдырау сатысындағы кинетикалық параметрлер арасындағы тәуелділігі талданды. Көмірдің β үлгілерінің қыздыру жылдамдығы T_{max} температурасы мен V_{max} деструкция жылдамдығының мәнін едәуір жоғарылатады, сондай-ақ процестің активациялық кедергілерін азайтады. Сонымен қатар, 30-900°С температуралық интервалдағы қызудың Сарыадыр (Пятиметровый, Надежный), Майкөбе (Шоптыкөл), Богатырь (Екібастұз) көмір үлгілерінің термохимиялық деструкция дәрежесіне әсері зерттелді. Зерттеу нәтижесі көрсеткендей, Майкөбе кен орнының көмірі барынша ыдырауға ұшырайды (массаның 40%-дан астамы). Бұл олардың термиялық тұрақтылығының төмен екендігін көрсетеді, яғни құрамында функционалдық, эфирлік топ және басқа да нысандар түріндегі оттегінің көп мөлшеріне байланысты, метаморфизм басқа зерттелген көмірмен салыстырғанда төменгі сатыны көрсетеді. Бұл ретте термиялық ыдырау процесі төмен температурада басталады, ол кезде шайыр мен газ бу түрінде төмен молекулалы ұшпа зат мөлшері көбейеді, ал ұшпайтын сұйық фазалы өнімдер өте аз, яғни пластикалық күйге өту сатысы жоқ. Көрсетілген факторлар аталған көмірдің ұшқыштығы көп мөлшерді (51-57%) қамтитынын көрсетеді. Богатырь, Сарыадыр кен орны көмірінің күлі көп, қыздыру кезінде ең төмен реакциялық қабілетке ие (ыдырау дәрежесі 30%-дан аз), бұл құрамында оттегі бар қосылыс санының аздығына және көміртегі құрамының жоғарылығына байланысты болып келеді. Аз мөлшерде ылғалға (2-3%) байланысты масса шығыны да аз болады. Көмір метаморфизмінің жоғары сатысы олардың құрылымының жоғары дәрежесіне және дамыған полиароматикалық көпсанды түзілімдерге байланысты. Көмір массасының

өзгеруі бес сатыда жүреді. 25^{0}С-110^{0}С температуралық интервалына пирогенді судың бөлінуі I сатыға сәйкес келеді. II кезең 110-450 ^{0}С аралығына сәйкес, мұнда температура әсерінен көмірдің органикалық затының молекуласынан бірінші кезекте газ тәріздес заттар, негізінен көміртек диоксиді және күкіртті сутегі бөлінеді. III саты 450-560 ^{0}С температурада массаның кенеттен өзгеруі, температураның осы интервалында шайырдың бөлінуі арқылы түсіндіріледі, бұл сатыны әдетте көмір шайырының негізгі массасы пайда болған кезде битуминизация процесімен байланыстырады, бірақ бұл ретте оны буландыру үшін жылу жеткіліксіз. Одан әрі қыздыру кезінде (560 ^{0}С жоғары) аз мөлшерде газ бөлінеді, IV кезеңде ұшатын компоненттердің шығуы айтарлықтай болмағандықтан, шайыр аса бөлінбейді. Одан әрі V сатыда 860-900 ^{0}С температуралық интервалда массаны жоғалтуда тағы бір өзгеріс байқалады, бұл осы температуралық интервалда көмірдің минералды бөлігі белсенді ыдырайды.

Қисықтарды талдауда ДТҚ дифференциалды қисықтардағы зерттелетін көмірдің КОМ негізгі ыдырау үдерісінің үш сатысы анықталды, онда массаны жоғалту жылдамдығының максимум шыңы байқалады (иілу нүктелері).

Түйін сөздер: көмір, термиялық деструкция, ыдырау сатысы, қыздыру жылдамдығы, кинетикалық параметрлер.

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РАСЧЕТ КИНЕТИЧЕСКИХ ПАРАМЕТРОВ ТЕРМИЧЕСКОГО РАЗЛОЖЕНИЯ УГЛЕЙ РАЗЛИЧНЫХ МЕСТОРОЖДЕНИЙ КАЗАХСТАНА

Аннотация. В статье проведено изучение влияние скорости нагрева и фракционного состава ОМУ на кинетические параметры процесса термической деструкции, выявлено, что увеличение скорости нагрева приводит к уменьшению степени термохимической деструкции ОМУ. В качестве образцов исследования взяты угли месторождения Сарыадыр (Пятиметровый, Надежный), Майкубе (Шоптыколь), Богатырь (Экибастуз). Проанализирована зависимость кинетических параметров термодеструкции угля в интервале температур основного разложения ОМУ от скорости и температуры нагрева и фракционного состава, а также между кинетическими параметрами на разных стадиях основного разложения угля. Установлено, что скорость нагрева β образцов угля заметно повышает значения температуры T_{max} и скорости v_{max} деструкции, а также снижает активационные барьеры процесса. Также проведено исследование влияния нагрева в температурном интервале 30-900°С на степень термохимической деструкции образцов углей Сарыадыр (Пятиметровый, Надежный), Майкубе (Шоптыколь), Богатырь (Экибастуз). Результаты показали, что максимальному разложению подвергаются угли месторождений Майкубе (более 40% от массы). Это указывает на их меньшую термическую устойчивость, а значит и более низкую стадию метаморфизма относительно других исследованных углей из-за содержания в них большого количества кислорода в виде функциональных, эфирных групп и других формах. При этом процесс термического разложения наступает при более низких температурах, во время которого образуется большое количество низкомолекулярных летучих веществ в виде паров смол и газов, а нелетучих жидкофазных продуктов образуется очень мало, т.е. стадия перехода в пластическое состояние отсутствует. Указанные факторы находятся в согласии с тем, что данные угли содержат большое количество летучих (51-57 %). Угли месторождения Богатырь, Сарыадыр высокозольные при нагревании обладают наименьшей реакционной способностью (степень разложения менее 30%), что обусловлено низким количеством кислородсодержащих соединений и высоким содержанием углерода. Минимальные потери массы связаны также с меньшим содержанием влаги (2-3%). Более высокая стадия метаморфизма данных углей обусловлена тем, что их структура обладает высокой степенью сшитости и большим количеством развитых полиароматических образований. Определено, что изменение массы угля происходит в пять стадий. Температурному интервалу 25^{0}С -110^{0}С соответствует стадия I, что соответствует выделение пирогенной воды. II стадия соответствует интервалу 110-450 ^{0}С, где под действием температуры из молекулы органического вещества угля начинают выделятся, в первую очередь, газообразные вещества, в основном диоксид углерода и сероводород. Скачок в изменении массы стадии III при температуре 450-560 ^{0}С объясняется тем, что в данном интервале температур начинает выделяться смола, эту стадию обычно связывает с процессом битуминизации, когда начинает образовываться основная масса угольной смолы, но при этом недостаточно тепла для ее испарения. При дальнейшем нагревании (выше 560 ^{0}С) выделяется небольшое количество газа, смола почти не выделяется, поэтому на стадии IV выход летучих компонентов незначительный. Далее на стадии V в температурном интервале

860-900 ^{0}C наблюдается еще один скачок в потере массы, это объясняется тем, что в данном температурном интервале происходит активное разложение минеральной части угля. При анализе кривых выявлены три стадии основного разложения ОМУ исследуемых углей на дифференциальных кривых ДТГ, где наблюдаются пики с максимумами скорости потери массы (точки перегиба)

Ключевые слова: уголь, термическая деструкция, стадия разложения, скорость нагрева, кинетические параметры.

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ELECTROFLOTATION EXTRACTION OF LANTHANUM AND SCANDIUM HYDROXIDES FROM AQUEOUS SOLUTIONS

Abstract. Currently, rare earth metals play a key role in the production of materials for high-tech consumption spheres, such as the electronic and electro-optical industries, information technology, biomedicine, environmental protection, and energy conservation. In addition, rare earths are widely used in traditional areas of consumption, in particular, metallurgy.

The washing waters of the listed industries contain a sufficient amount of valuable rare-earth elements, which requires the development of new methods and approaches to its efficient extraction. One of the promising methods for extracting metal compounds from aqueous solutions is electroflotation. Therefore, the study of electro-flotation extraction of lanthanum and scandium compounds from aqueous solutions, as well as increasing the efficiency of the process, is an urgent task.

In this paper, the influence of surfactants on the efficiency of electroflotation extraction of scandium and lanthanum from aqueous solutions $NaNO_3$, Na_2SO_4, NaCl and $Na_2CO_3$is studied. It is found that the use of surfactants is favorable for lanthanum compounds electroflotation extraction. The presence in the solution of anionic surfactant helps to increase the degree of extraction of lanthanum compounds in all the studied solutions up to 94 - 98% after 20 minutes of treatment. In this work, the influence of the medium composition on the ξ–potential of $La(OH)_3$ particles was investigated. Since the pH values of the solutions used in the experiments were close to the isoelectric point of $La(OH)_3$, the absolute values of the ξ–potential are rather small. Surfactants caused no significant change in the ξ–potential, which favors their electroflotation.

The electrokinetic potential of scandium particles is positive in nitrate and chloride solutions. It is possible to trace a correlation between the zeta potential and the surfactant type in NaCl, Na_2SO_4, and Na_2CO_3 solutions. Cationic surfactants shift the value of the electrokinetic potential in the positive direction, while anionic ones shift the ξ–potential in the negative direction. No such trend is observed in sodium nitrate solutions. Perhaps, this is related to complex adsorption phenomena in the course of coadsorption of different ions at the surface of $Sc(OH)_3$ particles in the $NaNO_3$ solutions.

On the other hand, in the case of $Sc(OH)_3$, addition of surfactants decreases the extraction efficiency. However, in the Na_2CO_3 solution, the addition of anionic surfactant NaDDS to the extent of extraction of scandium compounds increases to 91%.

Key words: electroflotation, surface-active substance, electrokinetic potential of particles, disperse phase, lanthanum and scandium compounds.

1. Introduction. Electrochemical technologies are widely used in the field of wastewater treatment and processing of technological solutions containing both inorganic [1-11,35] and organic [1,6,12-22] pollutants. Electroflotation and electrocoagulation can be efficiently used not only in sewage treatment

with removal and destruction of pollutants, but also for separation of rare and scarce elements from aqueous solutions [6,10,23]. It seems promising to convert ions of scarce elements to the form of insoluble compounds, i.e. hydroxides; sulfides, etc., and separate them from the solution by means of electroflotation and electrocoagulation.

The efficiency of electroflotation extraction of metal compounds was found to depend on such factors, as the solution pH, initial ion metal concentration, current load, disperse phase surface characteristics (charge and particle size), presence of the supporting electrolyte, such as Na_2SO_4, NaCl, Na_2CO_3, $NaNO_3$, hydrodynamic regime of electrolysis, etc. [24-26]. Special attention should be paid to the effect of organic surfactant additives and flocculants on electroflotation in aqueous solutions. Surfactants are often applied for optimization of the separation process; they affect the bubble size [27,28] and therefore the oxygen transfer rate. Moreover, surfactants can also be extracted from aqueous solutions using electroflotation [29].

However, it should be noted that the influence of surfactants on electroflotation may be more complicated than just the decrease in the bubble size. Surfactants can be adsorbed at the surface of the insoluble phase, which can lead to a change in the surface charge of the solid phase and thus affect the electroflotation efficiency. The regularities and mechanism of the effect of surfactants on flotation extraction of metal compounds have not yet been sufficiently studied.

The aim of the present work is to study the influence of different SAS: namely, anionic ones (sodium dodecylsulfate (SDS)), cationic ones(didecyldimethylammonium chloride (D4)), and non-ionic ones - (poly(ethylene oxide) (PEO–1500)) on electroflotation extraction compounds of lanthanum and scandium as accompanying elements.

2. Materials and methods. Electroflotation extraction of the studied metal compounds was carried out from model solutions containing such salts as Na_2SO_4, NaCl, Na_2CO_3, and $NaNO_3$ (1.0 g L^{-1}). The initial concentration of lanthanum and scandium ions in model solutions was $c_i = 50$ mg L^{-1}. The surfactant concentration in solutions was equal to1 mg L^{-1}. pH of solutions was adjusted by adding concentrated sodium hydroxide solutions. These solutions were decarbonized using the method described in [30].

Extraction efficiency α (%) from the solution of poorly soluble metal compounds was calculated as the ratio of the difference of the initial ion concentration (c_i, mg L^{-1}) and the final ion concentration (c_f, mg L^{-1}) in the solution to the initial concentration:

$$\alpha = \frac{c_i - c_f}{c_i} * 100\%.$$

The mass concentration of lanthanum and scandium ions was measured according to a standard technique using TermoScientific XSERIES II mass-spectrometer with inductively coupled plasma.

ξ-potentials (particle surface charges) for the disperse phase of poorly soluble scandium and lanthanum compounds were determined using Malvern ZetasizerNano laser analyzer for millionths-of-an-inch and nanorange particles.

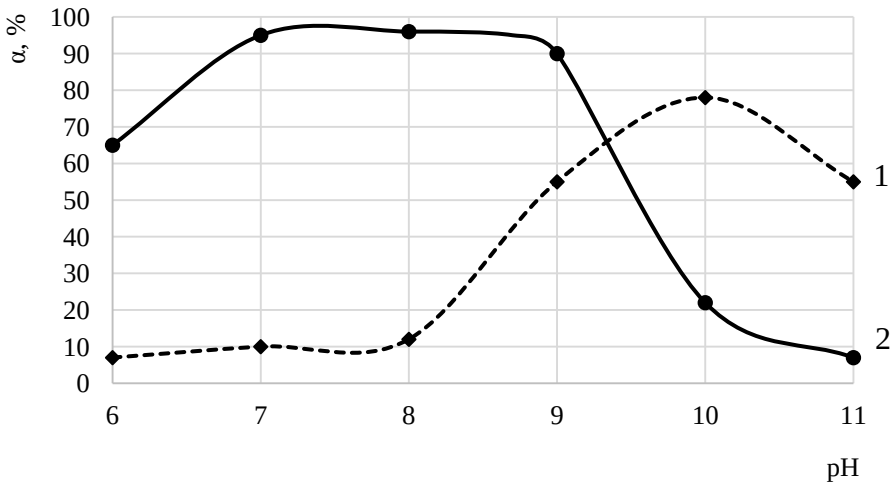
The measurements were carried out using the equipment of the Mendeleev Center for Multiple Access.

3. Results and discussion.

3.1 The choice of solution pH. Metal ions must be converted to poorly soluble compounds (hydroxides, sulphides, phosphates, etc.) before extracting them from aqueous solutions. The choice of solution pH is very important for efficient treatment of aqueous solutions containing lanthanum or scandium ions. Figure shows the dependence of metal compound extraction efficiency on the solution pH.

The experimental results show that the maximum efficiency (98 %) in extracting scandium compounds is observed at pH 7, which corresponds to the optimal pH range of 6–7 for formation of scandium hydroxide. The maximum efficiency in extraction of lanthanum compounds is 78 % with pH 10.

The above is fully relevant for the solutions of sodium chloride, nitrate, and sulfate. Formation of low–soluble lanthanum carbonate is also possible in the sodium carbonate solution. In this case, the chemical composition of the dispersed phase can be written as $x La_2(CO_3)_3 \cdot y La(OH)_3$.



Conditions: c(NaCl) = 1 g L^{-1}; cLa^{3+}= 50 mg L^{-1}; cSc^{3+}= 50 mg L^{-1}; i_v = 0.4 A L^{-1};time 20 min.
Dependence of metal compound extraction efficiency on the solution pH:
1 - lanthanum compounds; 2 - scandium compounds

3.2 Electroflotation extraction of lanthanum. From the literature, it is known that the efficiency of the process of electroflotation is significantly affected by the charge of the particles, as well as the composition of the medium. In this work, the influence of the medium composition on the ξ–potential of $La(OH)_3$ particles was investigated. It was established experimentally that in solutions of $NaNO_3$ and NaCl at pH = 10 the potential of the particles is from +8 to +12 mV, in solutions of Na_2SO_4, due to the adsorption of SO_4^{2-}-ions - takes negative values and ranges from -8 to - 2 mV.

Since the pH values of the solutions used in the experiments were close to the isoelectric point of $La(OH)_3$ (10.4) [31], the absolute values of the ξ–potential are rather small. Surfactants caused no significant change in the ξ–potential, which favors their electroflotation.

At the same time, the efficiency of electroflotation is increased greatly after adding surfactants into solutions under electroflotation treatment (table 1). Since SAS applied in the present study did not change ξ–potential significantly, the positive effect is mainly due to increasing wettability of hydrated oxide particles caused by adsorption of surfactants molecules at their surface [9, 34-36].

Table 1 – The extraction efficiencies of insoluble lanthanum compounds in some supporting electrolytes after surfactant adding. Conditions: pH = 10; $c_0(La^{3+})$ = 50 mg L^{-1}; c (supporting electrolyte) = 1 g L^{-1}; c (surfactant) = 1 mg L^{-1}; i_v = 0.4 A L^{-1};time 20 min.

Surfactant	Supporting electrolyte								
	$NaNO_3$			Na_2SO_4			NaCl		
	Electroflotation time, min								
	5	10	20	5	10	20	5	10	20
	Extraction efficiency α, %								
No SAS	55	58	22	79	68	33	51	80	56
D4	75	96	98	81	94	97	80	86	88
NaDDS	75	93	96	77	96	97	80	99	98
PEO–1500	78	97	96	45	52	56	92	96	95

The results presented in Table 1 show that electroflotation of $La_2O_3 \cdot xH_2O$ in the absence of surfactants is inefficient. The increase in electroflotation duration cannot solve the problem since the efficiency of electroflotation even decreases with time. Apparently, this is due to the fact that the flotocomplex formed during electroflotation is unstable and can be easily destroyed. Surfactants stabilize the flotocomplex, which allows achieving a high extraction level exceeding 95 %. It can be noted only the

decrease in electroflotation extraction efficiency in the presence of non-ionic surfactant PEO–1500 observed in sodium sulfate solutions.

3.1 Electroflotation extraction of scandium. According to data presented in figure, pH equal to 7.0 was chosen for $Sc_2O_3{\cdot}xH_2O$ electroflotation extracting. The ξ–potential of $Sc_2O_3{\cdot}xH_2O$ is still unknown [32]. Approximate value of 7.2 was reported in [33]. Based on this value, one can suggest that the solution pH chosen for electroflotation extraction of scandium hydrated oxides is close to $Sc_2O_3{\cdot}xH_2O$ isoelectric point.

ξ–potentials of $Sc_2O_3{\cdot}xH_2O$ particles were small in absolute value in all investigated solutions. The ξ–potential is negative in both sulfate- and carbonate-containing solutions. The electrokinetic potential is positive in nitrate and chloride solutions. It is possible to trace a correlation between the zeta potential and the surfactant type in NaCl, Na_2SO_4, and Na_2CO_3 solutions. Cationic surfactants shift the value of the electrokinetic potential in the positive direction, while anionic ones shift the ξ–potential in the negative direction. No such trend is observed in sodium nitrate solutions. Perhaps, this is related to complex adsorption phenomena in the course of coadsorption of different ions at the surface of $Sc(OH)_3$ particles in the $NaNO_3$ solutions. The PEO–1500 non-ionic surfactant causes almost no change in the ξ–potential in sodium chloride and sodium nitrate solutions. However, the zeta–potential shifts towards more negative values after addition of PEO–1500 into Na_2SO_4 and Na_2CO_3 solutions.

Addition of surfactants to the solution under electroflotation leads to an expected decrease in the average particle size. This effect is most pronounced in both chloride and nitrate solutions, whereas in solutions of Na_2SO_4 or Na_2CO_3 the average size of hydroxide particles decreases to a lesser extent. In a solution of Na_2CO_3, the average particle diameter of the dispersed phase is 26–29 μm, and in the presence of anionic and cationic surfactants, it decreases to 21–23 μm. A smaller size of hydroxide particle may facilitate formation of a flotocomlex during electroflotation.

Results of experiments on electroflotation of a scandium-containing dispersed phase (table 2) show that electroflotation extraction is most efficient in sodium chloride solutions. At the same time, the efficiency of electroflotation is lower in sulfate and nitrate solutions, where addition of surfactants even leads to a decrease in the electroflotation efficiency. Probably, this is related to an increase in the absolute value of the ξ–potential that causes a decrease in the flotocomplex stability.

Table 2 – Extraction degree of insoluble scandium compounds in some supporting electrolytes after adding of surfactants. Conditions: pH = 7; c_0 (Sc^{3+}) = 50 mg L^{-1};c (supporting electrolyte) = 1 g L^{-1};c (surfactant) = 1 mg L^{-1};i_v = 0.4 A L^{-1}.

Surfactant	Supporting electrolyte											
	$NaNO_3$			Na_2SO_4			NaCl			Na_2CO_3		
	Electroflotationtime, min											
	5	10	20	5	10	20	5	10	20	5	10	20
	Extraction efficiency α, %											
No SAS	97	98	99	91	93	92	94	98	98	47	49	56
D4	94	96	97	17	21	41	56	81	88	69	75	77
NaDDS	51	53	64	33	20	22	65	71	99	90	91	91
PEO–1500	48	72	80	23	55	88	81	86	90	38	46	58

Anionic surfactant NaDDSwas found to suppress the electroflotation process in $NaNO_3$, Na_2SO_4 and NaCl solutions. On the other hand, the results obtained in sodium carbonate solutions in the presence of SDS can be considered as promising. The degree of extraction of scandium compounds from a solution containing NaDDS increases from 56% to 91%. Apparently, this is related to a different chemical composition of the dispersed phase particles in sodium carbonate solutions. One can say that the phase formed in carbonate solutions most probably contains not only hydroxides, but also insoluble carbonates. The regularities of electroflotation of such particles differ from hydroxide particles.

4. Conclusions. From the obtained experimental data it is established that electroflotation of scandium is highly efficient in surfactant–free solutions. The addition of surfactants causes a decrease in the electroflotation efficiency. The only exception is sodium carbonate solutions. In this case, the addition of the anionic surfactant is useful.

On the other hand, surfactants significantly improve the efficiency of $La(OH)_3$ electroflotation. The presence in the solution of anionic surfactant helps to increase the degree of extraction of lanthanum compounds in all the studied solutions.

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СУЛЫ ЕРІТІНДІЛЕРДЕН ЛАНТАН ЖӘНЕ СКАНДИЙ ГИДРОКСИДТЕРІН ЭЛЕКТРОФЛОТАЦИЯЛЫҚ ЖОЛМЕН БӨЛІП АЛУ

Аннотация. Қазіргі кезеңде сирек кездесетін жер металдары жоғары технологиялық салаларда, атап айтқанда, электронды және электрооптикалық сала, ақпараттық технология, биомедицина, қоршаған ортаны қорғау, энергияны үнемдеу салаларында материалдар өндірісінде ерекше орын алады. Сирек кездесетін жер металдары дәстүрлі салаларда, яғни металургия саласында да кеңінен қолданылады. Өндірістің жоғарыда келтірілген салаларының ағынды суында жеткілікті дәрежеде құнды болып саналатын сирек кездесетін жер металдары кездеседі, сондықтан оларды бұл ағынды судан бөліп алудың жаңа әдістерін ойлап табуды қажет етеді. Бұл бағытта электрофлотация әдісі – сулы ерітінділерден металл қосылыстарын бөліп алудың перспективті әдістерінің бірі болып саналады. Сол себепті лантан мен скандий қосылыстарын сулы ерітінділерден электрофлотациялық жолмен бөліп алу және бұл үдерістің тиімділігін жоғарылату өзекті мәселелердің бірі.

Жұмыста скандий мен лантанды сулы ерітінділерден электрофлотациялық жолмен бөліп алу тиімділігіне беттік активті заттардың әсері зерттелді. Беттік активті заттарды қолдану арқылы лантан қосылыстарын электрофлотациялық жолмен бөліп алуға болатындығы анықталды. Ерітіндідегі аниондық беттік активті заттар барлық зерттелген ерітінділерде 20 минуттық өндеуден соң лантан қосылыстарын бөліп алу дәрежесінің 94-98 %-ға дейін жоғарылауына алып келеді. Бұл жұмыста орта құрамының $La(OH)_3$ бөлшектерінің ξ–потенциалына әсері зерттелді. Эксперименттерде қолданылған ерітінділердің pH көрсеткіші $La(OH)_3$-тің изоэлектрлік нүктесіне жақын болғандықтан ξ–потенциалының абсолютті көрсеткіштері төмен. Беттік активті заттар ξ–потенциалының өзгеруіне әсерін тигізбейді.

Нитратты және хлоридті ерітінділерде скандий бөлшектерінің электрокинетикалық потенциалы оң. ξ–потенциалы және NaCl, Na_2SO_4 және Na_2CO_3 ерітінділеріндегі беттік активті заттар типі арасында корреляцияны бақылауға болады. Катионды беттік активті заттар электрокинетикалық потенциал мәнін оң бағытқа, ал анионды беттік активті заттар ξ–потенциалын теріс бағытқа ығыстырады. Ал натрий нитраты ерітіндісінде мұндай тенденция байқалмайды. Бұл $NaNO_3$ ерітінділерінде $Sc(OH)_3$ бөлшектерінің бетінде әртүрлі иондардың соадсорбциясы кезінде күрделі адсорбция құбылыстарының жүруіне байланысты болуы мүмкін. Екінші тарапынан, беттік активті заттар $Sc(OH)_3$-тің бөліп алу дәрежесінің тиімділігін төмендетеді. Алайда Na_2CO_3 ерітіндісіне анионды беттік активті зат NaDDS-ті қосқанда скандий қосылыстарын бөліп алу дәрежесі 91 %-ға дейін жоғарылайды.

Түйін сөздер: электрофлотация, беттік-активті зат, бөлшектің электрокинетикалық потенциал, дисперсті фаза, лантан және скандий қосылыстары.

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ЭЛЕКТРОФЛОТАЦИОННОЕ ИЗВЛЕЧЕНИЕ ГИДРОКСИДОВ ЛАНТАНА И СКАНДИЯ ИЗ ВОДНЫХ РАСТВОРОВ

Аннотация. В настоящее время редкоземельные металлы играют ключевую роль в производстве материалов для высокотехнологичных сфер потребления, таких как электронная и электрооптическая отрасли, информационные технологии, биомедицина, охрана окружающей среды, энергосбережение. Кроме того, редкие земли находят широкое применение в традиционных сферах потребления, в частности металлургии. Промывные воды перечисленных отраслей промышленности содержат достаточное количество ценных редкоземельных элементов, что требует разработки новых методов и подходов к его эффективному извлечению. Один из перспективных методов извлечения соединений металлов из водных растворов – электрофлотация. Поэтому исследование электрофлотационного извлечения соединений лантана и скандия из водных растворов, а также повышение эффективности процесса является актуальной задачей.

В работе изучено влияние поверхностно-активных веществ на эффективность электрофлотационного извлечения скандия и лантана из водных растворов. Установлено, что использование поверхностно-активных веществ приводит к электрофлотационному извлечению соединений лантана. Наличие в растворе анионного поверхностно-активного вещества способствует повышению степени извлечения соединений лантана во всех исследованных растворах до 94 – 98 % после 20 минут обработки. В данной работе было исследовано влияние состава среды на ξ–потенциал частиц $La(OH)_3$. Поскольку значения pH растворов, использованных в экспериментах, были близки к изоэлектрической точке $La(OH)_3$, абсолютные значения ξ–потенциала довольно малы. Поверхностно-активные вещества не вызвали значительных изменений ξ–потенциала, что способствовало их электрофлотации.

Электрокинетический потенциал частиц скандия положителен в растворах нитратов и хлоридов. Можно проследить корреляцию между ξ–потенциалом и типом поверхностно-активного вещества в растворах NaCl, Na_2SO_4 и Na_2CO_3. Катионные поверхностно-активные вещества смещают значение электрокинетического потенциала в положительном направлении, а анионные смещают ξ–потенциал в отрицательном направлении. В растворах нитрата натрия такой тенденции не наблюдается. Возможно, это связано со сложными явлениями адсорбции при соадсорбции различных ионов на поверхности частиц $Sc(OH)_3$ в растворах $NaNO_3$. С другой стороны, добавление поверхностно-активных веществ снижает эффективность извлечения $Sc(OH)_3$. Однако в растворе Na_2CO_3 добавление анионного поверхностно-активного вещества NaDDS степень извлечения соединений скандия увеличивается до 91%.

Ключевые слова: электрофлотация, поверхностно-активное вещество, электрокинетический потенциал частиц, дисперсная фаза, соединения лантана и скандия.

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INFORMATION APPROACH TO TESTING FOR ADEQUATE KNOWLEDGE ASSESSMENT

Abstract. Adequate assessment of knowledge in the course of testing is one of the main conditions for successful educational process as it has an effect on the examinee's training motivation, informs a teacher about the extent of material digestion and gives a possibility to the supervisory authorities to estimate correctly the quality of training. The present work considers the process of testing as two sequential processes: 1 - a process of formation of a trainee's answer to a test; 2 - a process of formation of an expert assessment of an answer. Considering application of a cybernetic approach and activity of constituent elements, the process of testing is described as a process of information transfer through two series-connected channels with a noise. The first channel displays a process of an answer formation by a trainee: an input is a probability vector of a trainee's knowledge level (proficiency level), an output is a probability vector of an answer level. The second channel displays a process of formation of a trainee's answer assessment by an expert. An input of the second channel is a probability vector of answers quality level, an output is a probability vector of probable estimates. The work offers noise control measures (upon obtainment of an adequate assessment) for open and closed testing.

Key words: an active element, a training system, a cybernetic approach, a channel with noise, an open testing, a closed testing, an assessment formation noise, an answer formation noise.

Introduction. Development of information-oriented society requires solution of a number of problems in the sphere of education [1]. It is generally accepted, that synthesis of different sciences is one of the methods for successful generation of new ideas. In the work [2] it is marked that consideration of educational system from the point of cybernetics provides a possibility to apply laws, principles and mechanisms known in the modern control theory for its optimization. Bespalko's works are widely known for their proposed decisions for technological issues of training with an application of basic information system concepts of information transfer relationship to communication channels throughput.

In conditions of a universal computerization we can see a growing role of the training system [3] as an educational system element.

Training system objectives:

1. To arm future experts in the shortest time with knowledge and skills to put such knowledge into practice.

2. To get in the shortest time an information about adequate digestion of knowledge and skills to put such knowledge into practice.

The attention should be paid to a trainee which is a basic element of the training system. A trainee's objective does not always coincide with an objective of the system, i.e. he/she is an active element [4] and depends on a psychological profile. Today interest to psychological and social profiles of a trainee is constantly growing due to training customization. This interest can be traced in a set of publications on

this subject [5,6,7]. The issues of self-reported grades test results application are described in [8]. The work [9] considers how the students' motivation affects the use of outcomes tests to measure institutional effectiveness. Grade point averages for English and math as well as cumulative grade point averages were also used in the analysis. [10] highlights methods of detection of cheating on classroom tests by error-similarity analysis procedures using multiple answer-sheet forms. Thus, the work [5] highlights the results of polling according to which 72% of students live from session to session, i.e. knowledge acquisition is not a primary task (a student should have a finger in every pie). Just 38% of respondents consider that the present-day student should aspire to new knowledge. Thereby, we can divide all students into two categories.

The aim of the students falling into the first category is to pass their knowledge examination with maximum success and less training as they do not have any interest in obtaining of new knowledge and skills.

The aim of the students of the second category is to gain new knowledge and skills as much as possible in the course of training and to use all gained knowledge and skills for successful examination.

The first type of students is not interested in obtainment of knowledge, only in getting a good mark (at least fair mark is enough in the absence of knowledge) [11-14].

In general, researches on test efficiency improvement can be divided into two main groups:

2- Development of test work out rules [15, 16].

3- Development of rules for assessment, adjustment of test points [17,18,19] (for guessing, correlation of test level to the level of trainees, etc.).

Methods. Cybernetic approach to description of a test system. Considering the test system from the point of view of cybernetics [20], the following main elements should be detached: **a trainee** (student) and **an expert** (teacher). Figure 1 shows the test system comprising of series-connected elements: a trainee, an input (adjustable) which is represented by a test, an output which is represented by an estimation. Feedback is presented by the most common option - adaptive testing.

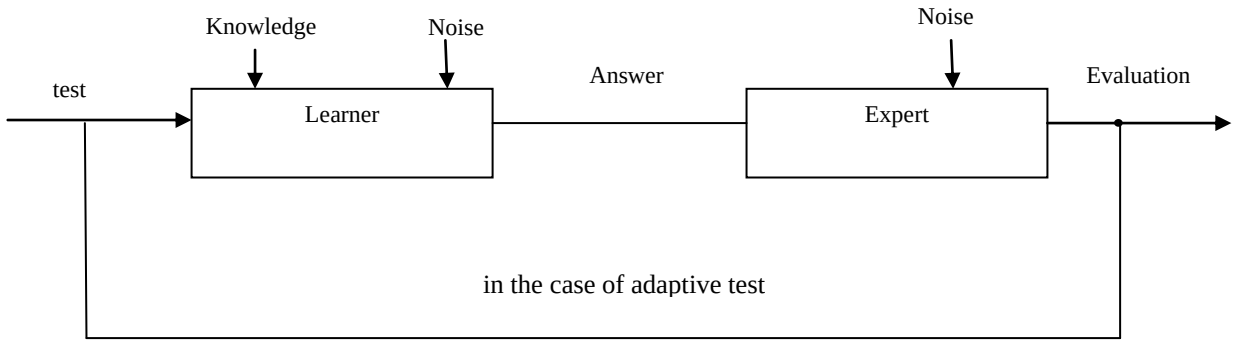

Figure 1 – Evaluation formation rules

An output of the first element, which is a trainee, is an answer formed on the basis of external interferences:

- knowledge obtained by a trainee;
- test conditions (level of comfort, a possibility of getting a prompt message, roulette game, etc.) let us call them an answer formation noise.

A trainee's answer shall be an input of the second element and estimation shall be an output. The estimation adequacy is influenced by the following:

- knowledge estimation rules
- competence of an expert.
- an expert situation (level of comfort, personal sympathy to a trainee, etc.), let us call it an assessment formation noise.

Thus, the considered system conditions are determined by knowledge of a trainee, an answer formation noise, knowledge estimation rules and competence of an expert.

Test performance procedure can be split into two main processes:

1 – a process of a test answer formation by a trainee;

2 – a process of an answer assessment formation by an expert.

Consequently, the factors which disturb making an adequate assessment of knowledge can have an influence on:

1– an answer of a trainee (an answer formation noise)

2 – an assessment formation by an expert (an assessment formation noise).

According to the considered scheme an estimation reliability is influenced by existence of two noises: an answer formation noise and an assessment formation noise.

In the theory of information a notion "*thesaurus"* is applied for definition of the whole data set possessed by an individual.

It is obvious that the test result – an estimation depends on relationship of a trainee's thesaurus of knowledge, a test and an expert competence. Thus, we shall hardly get an unbiased assessment if a test thesaurus significantly exceeds a thesaurus of knowledge of a trainee and a thesaurus of knowledge of the latter, i.e. a thesaurus of an answer is higher than an expert competence. Present-day developments in the sphere of testing assume consideration of a discrepancy of a thesaurus of knowledge and a thesaurus of test (IRT – technologies) [18,19,21].

A test subsystem as a communication channel with noise. Let us assume that a scale of answers assessment has *m* number of possible values.

Thereby, a level of answer showing its quality can be determined based on *m* possible values and, respectively a level of knowledge can be presented by *m* possible estimates.

The test system given in Fig.1 can be considered as series-connected channels with noise.

The first channel (channel 1) displays a process of an answer formation by a trainee: an input is a probability vector of a trainee's knowledge level (proficiency level), an output is a probability vector of an answer level. The second channel displays a process of formation of a trainee's answer assessment by an expert. An input of the second channel (channel 2) is a probability vector of answers quality level, an output is a probability vector of probable estimates.

Assessment in a closed form test has a high level of formalization, i.e. a noise in channel 2 is almost absent.

Therefore, a solution of the test adequacy problem can be seen in a struggle against an answer formation noise, i.e. check of only channel 1.

In the open testing an assessment formation noise takes a dominant position. Therefore, the test adequacy problem solution can be seen in a struggle against an assessment formation noise, i.e. check of only channel 1.

Let us consider a trivial description of a communication channel with noise. A source condition is determined by a probability vector $p(a_i)$ i = 1..m. (For channel 1 this vector determines probable qualification level of trainees, for channel 2 this vector determines probable answer quality levels).

If we transfer *m* number of signals A and expect to get *m* number of signals B, noise influence in the communication channel is completely described by a channel matrix [22]. On the part of a message source a channel matrix describing a communication channel looks as follows:

a/b	b_1	b_2	….	b_j	…	b_m
a_1	$P(b_1/a_1)$	$P(b_2/a_1)$	…	$P(b_j/a_1)$	…	$P(b_m/a_1)$
a_2	$P(b_1/a_2)$	$P(b_2/a_2)$	….	$P(b_j/a_2)$	….	$P(b_m/a_2)$
….	….	….	…..	….	….	…
a_i	$P(b_1/a_i)$	$P(b_2/a_i)$	….	$P(b_j/a_i)$	….	$P(b_m/a_i)$
…	….	….	…..	….	….	….
a_m	$P(b_1/a_m)$	$P(b_2/a_m)$	…..	$P(b_j/a_m)$	…..	$P(b_m/a_m)$

$P(b_j/a_i)$ values shall be determined as conditional probability of b_j receiver state at transfer of a_i source condition.

(For channel 1- a conditional probability is to get an answer of quality b_j at proficiency level (level knowledge) a_i; for channel 2 - a conditional probability is to get an estimate of level b_j at answer quality (level) a_i.

Diagonally stretching probabilities determine a correct receipt, other probabilities determine a false receipt. Value of numbers in the channel matrix columns usually decrease while they are farther from the main diagonal. And in case of complete absence of noise all values except for the ones located along the main diagonal are equal to zero [14].

In the test system the diagonally stretching probabilities are:

1) For channel 1 - probabilities of adequate answers, answers coinciding with the level of knowledge,

2) For channel 2 - probabilities of adequate assessment, i.e. an assessment coinciding with the level of answers.

Other conditional probabilities are connected with information transfer distortion:

1) For channel 1 - probabilities of information transfer distortion appear in the course of answer formation by a trainee (an answer formation noise)

2) For channel 2 - probabilities of information transfer distortion appear in the course of score assigning by an expert (an assessment formation noise).

Today the credit education system provisions an 11-point scoring system of knowledge assessment ranging from 4 to 0 (see table 2).

Table 2 – Student knowledge assessment

Score	Literal equivalent	In percentage terms, %	In points
Excellent	A	95-100	4
	A-	90-94	3.67
Good	B+	85-89	3.33
	B	80-84	3.0
	B-	75-79	2.67
Fair	C+	70-74	2.33
	C	65-69	2.0
	C-	60-64	1.67
	D+	55-59	1.33
	D	50-54	1.0
Poor	F	0-49	0

Thus, the considered matrix is equal to 11 and conditional probabilities determine the process of information distortion. For channel 1 these distortions estimate discrepancy of an answer with knowledge and for channel 2 - discrepancy of assessment with an answer. It should be noted, that the purpose of the teacher is performance of a test with identity matrix, i.e. with a matrix with ones on the main diagonal. The student's aim is an identity matrix with ones in the first column (on condition that a_1 is the highest knowledge score 4….. a_{11} is the lowest knowledge score 0; b_1 is the highest score 4 ….. b_{11} is the lowest score 0).

Results. *A proposal for organization of a closed testing.* In a closed test noise in channel 2 is almost absent due to high formalization.

The main reasons for " the answer formation noise", noise in a channel are as follows:

– outside help – a prompt message, a crib, etc.;

– "roulette game" at choosing an answer.

The work [3] proposes a game method of testing as a method of struggle against the outside help (prompt message) [23].

In a closed testing fight against roulette game or a possibility of guessing is the main reason for inadequacy of the answer to knowledge.

The work gives an analysis of the results considering "roulette game" at knowledge assessment. Thus, [17] offers test points adjustment. Three-parameter Birnbaum model is proposed for assessment in conditions of probable guessing. [18-19].

The test forming is proposed in [24].

For the fight against "roulette game" it is possible to apply the same methods which are used in information systems for noise control:

– redundant encoding;

– filtration.

Let us consider the main idea of redundant encoding: during transfer additional (adjusting) bits are added to information bits. They detect and correct transfer errors. The simplest method is a double transmission of message and comparison of the received messages on receiving end. In case of received messages equality we can say that the transfer is reliable.

We shall analyse a process of the closed testing when a trainee by a reason of lackness of knowledge chooses one of the proposed answers by chance. We assume that there are proposed 5 answers and only one is correct. In this case of 1/5 probability it is possible to pass a test by random choice (roulette game). If a testee passes a test only in case of correctly answering two questions closely related to a subject, then a probability to pass a test at "roulette game" is equal to $(1/5)^2$, etc. Let *a* be an event at which an examinee doesn't know an answer to the first question; *b* – an event at which an examinee doesn't know an answer to the second question. The questions must be selected in a way that $p(b/a) = 1 - \varepsilon$, where ε is a small value, i.e. ignorance of one question almost obligatory leads to ignorance of another one.

Continuing the reasoning, we can put three questions and consider the answer correct if the correct answers were chosen for all three questions. In this case a probability to pass a test with ignorance of material (roulette game) is already equal to 1/125.

The second method of fight against information distortion in the channel with noise is filtration. For test system it is equivalent to a multilevel testing. In this situation the first given question is more simple (for getting a fair mark) and if a correct answer is specified then it is offered to answer more difficult question (for getting a good mark), etc. In this case a probability to pass a three-level test by chance is equal to the product of conditional probabilities, i.e. it is less or equal to 1/125. Meanwhile, the questions must be on the same subject and the second question should be more difficult than the first one.

Proposals for an open test arrangement. The first problem of an open test is a problem of giving of marks for the answers. A number of works is devoted to the issues of an open test results assessment. If to consider that an answer formation noise is absent, then a task of an open test reliability improvement results in a fight against assessment formation noise, i.e. a noise in channel 2.

As it was highlighted in the paragraph - a trivial method of noise control is an antinoise coding (a repetition at its simplest form) and filtration. Therefore, it is obvious that for successful mark allotment:

- it should be proposed to the expert to assess the same answer repeatedly for many times (as a procedure - it can be a proposal for consideration of a test for several times at different time periods with rather big time intervals or among rather large number of other tests without information about the person by which the test was developed).

- to assess the same answer by the specialists with different levels of expertise where an expert with the lowest level of competence (thesaurus) either estimates an answer as unsatisfactory or gives answers with the lowest marks to an expert with higher level of competence who has a right to put a higher mark, etc.

Conclusion. As a final point of educational process, testing is one of its most important components. The main questions related to test arrangement are - test development and assessment of an answer to it.

This work considers the test system from the point of view of cybernetics. The test process is described as two sequential processes: a process of an answer obtaining from a trainee and a process of assessment by an expert. There are distinguished the factors which have a negative influence on adequate assessment of knowledge of a trainee. They are: an answer formation noise (a result of the trainee's activity) and an assessment formation noise. Generally, in order to solve an issue of noise control it is proposed to consider the test system as two sequential communication channels with noise. The work compares two main test system types - open and closed. As the technology of the closed test holding assumes that the main reason for assessment inadequacy is an answer formation noise and a technology of an open test holding assumes that the main reason is an assessment formation noise, we consider one channel with noise.

This allows to offer for the test noise control the same methods that are used in information systems for detachment of a "correct" signal from noisy signal: redundant encoding and filtration.

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ТЕСТІЛЕУДЕ АДЕКВАТТЫ БАҒА АЛУДЫҢ АҚПАРАТТЫҚ ТӘСІЛІ

Аннотация. Тестілеуде адекватты баға алу – оқыту үдерісі жетістігінің негізгі шарттарының бірі, өйткені сынақтан өтушіні білім алуда ынталандыруға әсер етеді, материалды меңгеру дәрежесі туралы оқытушыны хабардар етеді және бақылаушы инстацияларға оқыту сапасын бақылау мүмкіндігін береді.

Мақсатына жету үшін (оқыту жүйесінің мақсаттарына да) оқытушы келесі негізгі міндеттерді шешуі керек:

1. Студентті ұсынылған материалды білуге қызықтыру;
2. Қарастырылатын тақырыпты түсіну үшін материалды жақсы түрде ұсыну;
3. Қысқа уақыт аралығында студент беріліп жатқан білім туралы көп ақпарат алатындай білімді тексеруді ұйымдастыру.

Білімді тексеру білім беру процесінде маңызды орын алады, өйткені оның нәтижелері:

- пәнді оқудағы мотивацияға әсер етеді;
- материалды игеру дәрежесі туралы оқытушыға хабарлайды;
- қадағалау органдарына оқыту сапасына бағалау мүмкіндігін береді.

Бұл жұмыста тестілеу процесі екі тізбекті процесс ретінде қарастырылған:

- тестке білім алушының жауабын қалыптастыру процесі;
- жауапқа сарапшының баға қою процесі.

Тест құрастыру және тест нәтижелерін бағалау кезінде келесі жағдайды ескеру қажет:

- сұрақтың күрделілігі;
- жауап уақыты;
- тестілеу шарттары.

Сұрақтың күрделілігі мен жауап беру уақытын анықтау әдістері студенттерді қатыстыруға байланысты, демек, олар тестілерді бағалау нәтижесіне әсер етеді. Білім алушылардың бір тобына бірдей тест сұрақтарының күрделілігі орташа дәрежеде, ал екінші топқа жоғары болуы мүмкін. Тестілеуді түрлі тәсілдермен жүргізуге болады. Жұмыста, сондай ақ, тест тапсырмаларының жіктелу жолдары келтірілген.

Білім алушының білімін дұрыс бағалауға теріс әсер ететін факторлар анықталды. Олар – жауапты қалыптастыру (білім алушының белсендігі нәтижесі) мен бағалауды қалыптастыру шуылы. Жалпы алғанда, шуылмен күресу сұрақтарын шешу үшін тестілеу жүйесін шуылы бар тізбекті екі байланыс каналы ретінде қарастыру ұсынылады. Тестілеудің жабық формасын жүргізу технологиясы дұрыс бағаламаудың негізгі себебі – жауапты қалыптастыру шуылы, ал тестілеудің ашық формасын ұйымдастыру – бағаны қалыптастыру шуылы ретінде есептеуге мүмкіндік беретіндіктен шуылы бар бір канал қарастырылады.

Бұл жағдай шуылмен күресу үшін ақпараттық жүйелерде шуыл сигналдан дұрыс сигналды алу үшін артық кодтау мен фильтрацияны қолдануға мүмкіндік береді. Кибернетикалық тәсілді қолданып әрі құрама элементтердің белсендігін ескеріп, тестілеу процесі екі тізбекті қосылған шуылды арнадағы ақпаратты тасымалдау процесі ретінде сипатталады. Бірінші арна білім алушының жауабын қалыптастыру процесін көрсетеді: оның кірісі – білім алушының білім деңгейінің ықтималдылық векторы, шығысы жауап деңгейінің ықтималдылық векторы болып саналады. Екінші канал студенттердің жауабы бойынша сарапшының баға қалыптастыру процесін көрсетеді. Екінші каналдың кірісі жауаптың сапалық деңгейінің ықтималдылық векторы, шығысы бағалардың ықтималдылық векторы болып есептеледі. Ашық және жабық тестілеуде шуылмен күресу шаралары ұсынылады.

Түйін сөздер: белсенді элемент, оқыту жүйесі, кибернетикалық тәсіл, шуылы бар арна, ашық тестілеу, жабық тестілеу, бағалауды қалыптастыру шуылы, жауапты қалыптастыру шуылы.

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ИНФОРМАЦИОННЫЙ ПОДХОД К ПОЛУЧЕНИЮ АДЕКВАТНЫХ ОЦЕНОК ПРИ ТЕСТИРОВАНИИ

Аннотация. Получение адекватных оценок в процессе тестирования является одним из основных условий успешности образовательного процесса, так как влияет на мотивацию в обучении самого испытуемого, информирует преподавателя о степени усвоения материала и дает контролирующим инстанциям возможность судить о качестве обучения.

Преподаватель для достижения своей цели (а значит и цели обучающей системы) должен решить следующие основные задачи:

1) заинтересовать студента в познании предлагаемого материала;

2) представить в наилучшей форме материал для познания рассматриваемой темы;

3) организовать проверку знаний так, чтобы получить максимальную информацию о полученных студентом знаниях в наикратчайший промежуток времени.

Проверка знаний является ключевым моментом образовательного процесса, так как ее результаты

1 - влияют как на мотивацию в обучении самого испытуемого,

2 - информирует преподавателя о степени усвоения материала,

3- дают контролирующим инстанциям возможность судить о качестве обучения.

В настоящей работе рассмотрен процесс тестирования как два последовательных процесса:

1 - процесс формирования обучаемым ответа на тест,

2 - процесс формирования экспертом оценки за ответ.

При составлении тестов и оценивании результатов тестирования требуется учитывать: сложность вопроса; время ответа; условия проведения тестирования. Методы определения сложности вопроса и времени ответа связаны с привлечением обучающихся, а значит, они влияют на результат оценивания тестов. Так, для одного коллектива обучающихся одни и те же тесты могут быть средней сложности, а для другого – повышенной. Тестирование же можно проводить в разных вариантах. В работе приведены классификации тестовых заданий.

Выделены факторы, отрицательно влияющие на получение адекватной оценки знания обучаемого. Ими являются следующие:

- шум формирования ответа (результат активности обучаемого);

- шум формирования оценки.

В общем случае для решения вопроса борьбы с шумами предлагается рассматривать систему тестирования как два последовательных канала связи с шумом. Сравниваются две основные системы тестирования – открытая и закрытая. На основании того, что технология проведения закрытой формы тестирования позволяет считать основной причиной неадекватности оценки шум формирования ответа, а организация открытой формы тестирования – шум формирования оценки, рассматривается один канал с шумом.

Это позволяет предложить для борьбы с шумом тестирования те же методы, что используются в информационных системах для выделения «правильного» сигнала из зашумленного: избыточное кодирование и фильтрацию.

Применяя кибернетический подход и учитывая активность составляющих элементов, процесс тестирования описывается как процесс передачи информации в двух последовательно соединенных каналах с шумом. Первый канал отображает процесс формирования ответа обучаемым: его входом является вектор вероятностей уровней знания (состояний подготовленности) обучаемого, выходом- вектор вероятностей уровней ответа. Второй канал отображает процесс формирования оценки экспертом на ответ обучаемого. Входом второго канала является вектор вероятностей уровней качества ответа, выходом- вектор вероятностей возможных оценок.

Предлагаются меры по борьбе с шумом (по получению адекватных оценок) при открытом и закрытом тестированиях.

Ключевые слова: активный элемент, обучающая система, кибернетический подход, канал с шумом, открытое тестирование, закрытое тестирование, шум формирования оценки, шум формирования ответа.

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THERMODYNAMIC BASES OF METAL MECHANICAL PROCESSING BY CUTTING METHOD

Abstract. Fundamental thermal mechanical phenomena arising in the process of metal cutting are difficult to give a systematic and interconnected theoretical and mathematical description. The phenomena various in essence and nature considered in the s tudies are so closely intertwined with each other that it is very difficult to describe their interaction. Based on the results of our research, it was revealed that eleven relatively independent theories that have not yet come to a holistic unity are focused on the top of the cutting edge. In such studies, it is necessary to systematize and relate the theory of chip formation, the mechanics of metal cutting, friction theories and wear during metalworking, the thermodynamics of cutting, and the theory of durability and reliability of cutting tools.

In this paper, the approaches of mathematical modeling of thermal mechanical processes of metal cutting, is based on the non-linear theory of elasticity of V.V. Novozhilov at that, the final deformation of the elementary volume of the considered three-dimensional body is accompanied by finite rotations and displacements but with small relative changes in geometric dimensions.

Key words: thermodynamics, thermal conductivity, cutting, deformation, friction, solids, stress, cutting tool, shavings, roughness, speed, shear.

Introduction. The mechanical processing of metals by cutting method is accompanied by thermodynamic processes. The source of heat when cutting metals is the work spent on the final deformation in the sheared layer and in the layers adjacent to the machined surface and the cutting surface as well as to overcome friction on the rear surfaces of the cutter. During the final deformation, the material points of the sample move relative to each other which are a source of additional heat generation [1-5].

It is known that the process of thermal mechanical cutting of solids is difficult to mathematically model due to the complexity of the process occurring there [3-5]. The various phenomena considered here are so closely intertwined with each other and their interaction is so complicated that eleven relatively independent theories that have not yet come to a holistic unity are focused on the cutter tip. These are the theory of chip formation, mechanics of metal cutting, the theory of friction and wear during metal working, the thermodynamics of cutting and the theory of resistance and reliability of cutting tools.

Here we propose a thermal mechanical theory of metal cutting based on the fundamental mechanisms of thermodynamics and nonlinear mechanics of a deformable solid. In this process, along the cutting line due to the occurrence of critical values of internal stresses at the tip of the cutting tool metal chips are detached from the base. In this case, after detaching, the chip in the form of a metal strip makes final movements [7-10].

Main part. The stress state during nonlinear deformation of an arbitrary three-dimensional elastic body under the action of the bulk system - X_i, and surface forces - S_i in the current coordinate system $O\xi_1\xi_2\xi_3$, is described by the Euler motion equation [7-10].

According to the theory of V.V. Novozhilov, nonlinear deformation of the elementary volume of the considered three-dimensional body is accompanied by finite rotations and displacements but with small relative changes in geometric dimensions. In these conditions, the actual (after deformation) curvilinear triple-orthogonal coordinate system $O\xi_1\xi_2\xi_3$ practically remains unchanged, i.e. the condition $\xi_i \approx x_i$ is fulfilled for them. Here $Ox_1x_2x_3$ is the initial coordinate system (before deformation). Then the second Piola-Kirchhoff tensor P_{ij} through the symmetric Cauchy tensor σ_{kj} in the initial coordinate system is expressed as follows [7]

$$P_{ij} = \left(\delta_{ik} + U_{i,k}\right)\sigma_{kj}, \tag{1}$$

where δ_{ij} are the Kronecker symbols.

Thus, the nonlinear deformation of a three-dimensional body, relative to the initial coordinate system $Ox_1x_2x_3$, is described by the following system of equations of Lagrangian motion

$$\left[\left(\delta_{ik} + U_{i,k}\right)\sigma_{kj}\right]_j + X_i - \rho\ddot{U}_i = 0 \tag{2}$$

under the initial conditions

$$U_i\big|_{t=0} = U_i^0, \qquad \dot{U}_i\big|_{t=0} = V_i^0, \tag{3}$$

and boundary conditions

$$U_i\big|_{\Sigma_1} = U_i^{\Sigma}, \quad \left(\delta_{ik} + U_{i,k}\right)\sigma_{kj} n_j\big|_{\Sigma_2} = S_i, \tag{4}$$

where U_i^{Σ} are the displacements $\Sigma=\Sigma_1+\Sigma_2$given on the part of the boundary, U_i^o, $V_i^o$are the coordinate functions characterizing the initial state of the body, n_j is the external normal and ρ is the density, δ_{ij} are the Kronecker symbols. Points above functions denote time derivatives. Derivatives by coordinate are denoted by a comma, i.e. tensor analysis operations take place. Here i, j, k∈(1,2,3).

For isotropic materials, according to the thermodynamic form of writing the determining Duhamel – Neumann relations [11-23] we have

$$\sigma_{ij} = \lambda\left(e_{kk} - \beta\vartheta\right)\delta_{ij} + 2\mu e_{ij}, \quad \theta = T - T_0, \tag{5}$$

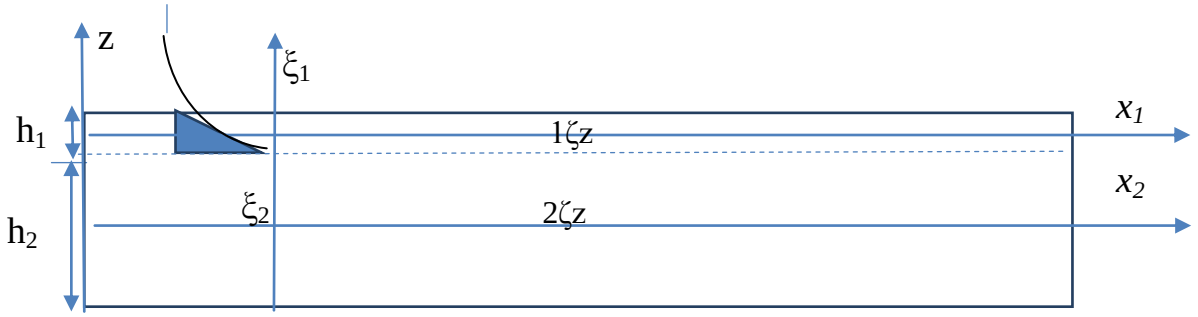
where $\lambda = \dfrac{E\nu}{(1-2\nu)(1+\nu)}$, $\mu = \dfrac{E}{2(1+\nu)}$, Lame coefficients, E - modulus of elasticity, ν - Poisson's ratio; T, T_0 - temperature of the current and initial state, β- characterize the influence of temperature stresses.

Based on the thermodynamic theory, the Fourier thermal conductivity has the following form [11]:

$$c_\varepsilon\dot{\vartheta} = \lambda_\varepsilon\Delta\vartheta - T\beta\dot{\varepsilon}_{kk}, \tag{6}$$

wherec_ε,λ_ε- coefficients of heat capacity and thermal conductivity with constant deformation.

Thus, we have the general task of the nonlinear thermodynamic theory of elasticity for thermal mechanical processing of metal parts by cutting method solving which we can study the stress-strain state of the objects under consideration, including metal strips and formed chips. Due to the difficulties encountered in solving nonlinear three-dimensional problems (1)-(9) in applied problems the mechanics of a deformable solid usually turn to two-dimensional problems.



The pattern of chips formation from the processed surface

In the problem under consideration, deformation of plate – 2 does not go beyond the framework of the linear theory of elasticity. The same is true for a metal strip - 1 before exposure to the cutting tool. Thus, we have linear physical and kinematic relations. After the impact of the cutter, at the time of chip formation, the metal strip undergoes final displacements, and the strip bending is accompanied by a predominance of deflection compared to the others, i.e. the condition $U_z>>U_i$ is satisfied.

Therefore, in expressions (1)-(6), when the plates are bent by nonlinear terms along the U_i displacement vector axial displacements they are usually neglected. At that, the nonlinear components of the derivative $U_z$with respect to the normal coordinate z are also taken to be negligible.

Then, for the components of the second Piola – Kirchhoff tensor and the Lagrange – Green strain tensor, we hae:

$$P_{ij}=\sigma_{ij},P_{3j}=\left(\delta_{3k}+U_{3,k}\right)\sigma_{kj},\varepsilon_{33}=U_{3,3},$$
$$\varepsilon_{ij}=\frac{1}{2}\left(U_{i,j}+U_{j,i}+U_{3,i}U_{3,j}\right),\ \varepsilon_{i3}=\frac{1}{2}(U_{i,3}+U_{3,i}),\quad \varepsilon_{33}=U_{3,3}, \tag{7}$$

Hereinafter, the indices i, j, k, l take the values (1), (2). Let the considered three-dimensional deformable body be a metal parallelepiped with a constant thickness $h=h1+h2$ on which the cutter affects (figure). At that, strip-1 with a thickness h_1 is located above the cutting tool, and strip-2 with a thickness h_2 below it. Cartesian coordinate systems $Ox_1x_2\xi_I,I=1,2$ are located in the middle plane of the considered bands.

These bands, until the moment of exposure $x_i>v_it$ of the cutter, are one whole composition, therefore, along the line of external influence $\xi_2 = h_2/2$ or $\xi_1=-h_1/2$, the continuity conditions for the components of the displacement vector, stress tensor, and temperature are satisfied.

$$U_i^{(1)}=U_i^{(2)},\ U_z^{(1)}=U_z^{(2)},\quad \sigma_{iz}^{(1)}=\sigma_{iz}^{(2)},\quad \sigma_{zz}^{(1)}=\sigma_{zz}^{(2)},\ \vartheta^{(1)}=\vartheta^{(2)},\left(\vartheta^{(1)}\right)'_{\xi}=\left(\vartheta^{(2)}\right)'_{\xi}, \tag{8}$$

After exposure to the cutter: $x_i\leq v_it$ on the upper plane of the lower strip $\xi_2= h_2/2$, the following boundary conditions

$$\sigma_{iz}^{(2)}=P_{\tau}\left[H(v_1t-x_1)H(v_2t-x_2)\right]_{,i},\quad \left(\vartheta^{(2)}\right)'_{\xi}=\gamma\left[1+\vartheta_r\frac{P_nv_i}{\lambda c}g(x_i,t)\right]\vartheta^{(2)},$$
$$U_z^{(2)}=0,\quad g(x_{\alpha},t)=H(v_{\alpha}t-x_{\alpha})H(x_{\alpha}+a_{\alpha}-v_{\alpha}t).\ \alpha=1,2 \tag{9}$$

where ϑr is the coefficient characterizing the influence of the surface roughness of the cutting tool and the processed sample during friction on the resulting temperature, which, depending on the materials used, is determined experimentally; γ is the coefficient characterizing the heat transfer of the sample material and the environment; c is the speed of sound propagation in the considered sample; $H(x)$ is the Heaviside function. v_i - the displacement speed of the cutter along the coordinate axes. Under these conditions, at the lower boundary $\xi_1=- h_1/2$ of the upper band, the following boundary conditions hold

$$U_z^{(1)}=v_it\,tg\eta_i+\alpha\vartheta^{(1)},\quad \sigma_{iz}^{(1)}=P_{\tau}\left[H(v_1t-x_1)H(v_2t-x_2)\right]_{,i},\quad \left(\vartheta^{(1)}\right)'_{\xi}=\gamma\vartheta^{(1)}. \tag{10}$$

In a rigidly clamped boundary near the $\xi_2 = -\dfrac{h_2}{2}$ lower strip, a heat exchange process takes place

$$U_i^{(2)} = 0,\ U_z^{(2)} = 0, \quad \left(\vartheta^{(2)}\right)'_{\xi} = \gamma\vartheta^{(2)}, \tag{11}$$

The upper plane $\xi_2 = h_2/2$ of the upper band is free from loads and there is a heat exchange process

$$\sigma_{iz}^{(1)} = 0, \quad \sigma_{zz}^{(1)} = 0, \quad \left(\vartheta^{(1)}\right)'_{\xi} = \gamma\vartheta^{(1)}, \tag{12}$$

Based on the nature of the problems under consideration, for the purpose of simplification, we proceed to the consideration of the corresponding two-dimensional ones, according to the non-classical theory of deformation of a nonlinear elastic parallelepiped [15,22]. The required components of the displacement vector are decomposed in a power series by the normal coordinate ζ:

$$\begin{cases} U_i^{(I)} = A_i^{(I)} + \xi B_i^{(I)} + \xi^2 C_i^{(I)} + \xi^3 D_i^{(I)} + \ldots, \\ U_z^{(I)} = a^{(I)} + \xi b^{(I)} + \xi^2 \theta^{(I)} + \ldots, \\ \vartheta^{(I)} = \vartheta_0^{(I)} + \xi\vartheta_1^{(I)} + \xi^2\vartheta_2^{(I)} + \ldots, \end{cases} \tag{13}$$

where $\Phi_1^{(I)}(\xi) = \dfrac{h_I^2}{12}\left[1 - 12\left(\dfrac{\xi}{h_I}\right)^2\right], \Phi_2^{(I)}(\xi) = \dfrac{1}{4}\left[1 - \dfrac{20}{3}\left(\dfrac{\xi}{h_I}\right)^2\right]\xi.$

$$\overline{\vartheta}^{(I)} = \frac{1}{h_I}\int_{-h_I/2}^{h_I/2}\vartheta^{(I)}d\xi, \quad \tilde{\vartheta}^{(I)} = \frac{1}{h_I}\int_{-h_I/2}^{h_I/2}\vartheta^{(I)}\xi d\xi,$$

$$u_i^{(I)} = \frac{1}{h_I}\int_{-h_I/2}^{h_I/2}U_i^{(I)}d\xi, \quad \psi_i^{(I)} = \frac{1}{h_I}\int_{-h_I/2}^{h_I/2}U_i^{(I)}\xi d\xi, \quad w^{(I)} = \frac{1}{h_I}\int_{-h_I/2}^{h_I/2}U_z^{(I)}d\xi, \quad V^{(I)} = \frac{1}{h_I}\int_{-h_I/2}^{h_I/2}U_z^{(I)}\xi d\xi,$$

where $C_i^{(I)}, D_i^{(I)}, \ldots, a^{(I)}, b^{(I)}, \theta^{(I)}$ are unknown functions of the coordinates x_1, x_2 and time t.

Taking into account (5)-(7), (13) for elastic isotropic plates the nonlinear components of the longitudinal stress tensor will have the following form:

$$\begin{aligned} \sigma_{ij} = \lambda\Big\{ & u_{k,k} + \xi\psi_{k,k} - \frac{1}{2}\Phi_1(\xi)C_{k,k} - \frac{3h^2}{5}\Phi_2(\xi)D_{k,k} - \beta\left(\overline{\vartheta}^{(I)} + \xi\tilde{\vartheta}^{(I)} - \Phi_{1`}^{(I)}(\xi)\vartheta_2^{(I)}\right) + \\ & + \left(V + 2\theta\xi\right) + \frac{1}{2}\left(w + V\xi - \Phi_1(\xi)\theta\right)_{,k}\left(w + V\xi - \Phi_1(\xi)\theta\right)_{,k}\Big\}\delta_{ij} + \\ & + \mu\Big\{u_{i,j} + u_{j,i} + \xi\left(\psi_{i,j} + \psi_{j,i}\right) - \frac{1}{2}\Phi_1(\xi)(C_{i,j} + C_{j,i}) - \\ & - \frac{3h^2}{5}\Phi_2(\xi)(D_{i,j} + D_{j,i}) + \left(w + V\xi - \Phi_1(\xi)\theta\right)_{,i}\left(w + V\xi - \Phi_1(\xi)\theta\right)_{,j}\Big\} \end{aligned} \tag{14}$$

$$\begin{aligned} \sigma_{zz} = \lambda\Big\{ & u_{k,k} + \xi\psi_{k,k} - \frac{1}{2}\Phi_1(\xi)C_{k,k} - \frac{3h^2}{5}\Phi_2(\xi)D_{k,k} - \beta\left(\overline{\vartheta}^{(I)} + \xi\tilde{\vartheta}^{(I)} - \Phi_{1`}^{(I)}(\xi)\vartheta_2^{(I)}\right) \\ & + \frac{1}{2}\left(w + V\xi - \Phi_1(\xi)\theta\right)_{,k}\left(w + V\xi - \Phi_1(\xi)\theta\right)_{,k}\Big\}\delta_{ij} + (\lambda + 2\mu)\left(V + 2\theta\xi\right) \end{aligned} \tag{15}$$

$$\sigma_{iz} = \mu\left\{\psi_i + \xi C_i - \frac{3h^2}{20}\left(1 - 20\left(\frac{\xi}{h}\right)^2\right)D_i + \left(w + V\xi - \Phi_1(\xi)\theta\right)_{,i}\right\} \tag{16}$$

It should be noted here, the line of impact of the cutter $x_{i=}\, v_i t$, ($\xi_2 = \frac{h_2}{2}$ или $\xi_1 = -\frac{h_1}{2}$) it has a significant feature, because along this line, due to the infinity of some components of the stress tensor, the separation and formation of chips begins. For chips, the deformations become finite, and in the other parts there is a linear stress-strain state. To take these features into account, the area under consideration is divided into 4 sections, separate equations of motion are solved in each area, and the continuity conditions for the components of the movement vector will be used along the lines of the section. For regions 1 and 2, unknown integral constants are determined from boundary conditions (8),(10),(12):

$$\begin{cases} h_1\vartheta_2^{(1)} = \dfrac{1}{1-\gamma\dfrac{h_1}{6}}\left(\gamma\overline{\vartheta}^{(1)} - \left(1-\dfrac{\gamma h_1}{2}\right)\tilde{\vartheta}^{(1)}\right), \;\; h_2\vartheta_2^{(2)} = -\dfrac{1}{1+\gamma\dfrac{h_2}{6}}\left(\gamma\overline{\vartheta}^{(2)} - \left(1+\dfrac{\gamma h_2}{2}\right)\tilde{\vartheta}^{(2)}\right), \\ h_1\theta^{(1)} = -V^{(1)} - \dfrac{\nu}{1-\nu}\left[u^{(1)}_{k,k} + h_1\psi^{(1)}_{k,k} + \dfrac{h_1^3}{10}D^{(1)}_{k,k} - \dfrac{\beta}{\gamma}\left(\tilde{\vartheta}^{(1)} + h_1\vartheta_2^{(1)}\right)\right], \\ h_2\theta^{(2)} = -6\left(\dfrac{w^{(2)}}{h_2} - \dfrac{1}{2}V^{(2)}\right), \;\; V^{(1)} = V^{(2)} + 3\left(\dfrac{w^{(1)}}{h_1} + \dfrac{w^{(2)}}{h_2}\right), \\ \tilde{\vartheta}^{(1)} = b_{11}\overline{\vartheta}^{(1)} + b_{12}\overline{\vartheta}^{(2)}, \quad \tilde{\vartheta}^{(2)} = b_{21}\overline{\vartheta}^{(1)} + b_{22}\overline{\vartheta}^{(2)}, \end{cases} \tag{17}$$

$$\begin{cases} h_2C_i^{(2)} = \dfrac{4}{9}\left[5\left(\psi_i^{(1)} + \dfrac{5}{2}\psi_i^{(2)}\right) + 3h_1V_{,i}^{(2)} + \dfrac{9}{2}h_1\left(\dfrac{w^{(1)}}{h_1} + \dfrac{w^{(2)}}{h_2}\right)_{,i} - 6\left(2\dfrac{u_i^{(1)}}{h_1} + \dfrac{u_i^{(2)}}{h_2}\right)\right], \\ h_1C_i^{(1)} = \dfrac{5}{9}\left[\left(\psi_i^{(1)} + 25\psi_i^{(2)}\right) + 6h_1V_{,i}^{(2)} + 9h_1\left(\dfrac{w^{(1)}}{h_1} + \dfrac{w^{(2)}}{h_2}\right)_{,i} - 24\dfrac{u_i^{(1)}}{h_1} + \dfrac{48}{5}\dfrac{u_i^{(2)}}{h_2}\right], \\ h_2^2D_i^{(2)} = \dfrac{20}{27}\left[10\psi_i^{(1)} + 23\psi_i^{(2)} + 6h_1V_{,i}^{(2)} + 9h_1\left(\dfrac{w^{(1)}}{h_1} + \dfrac{w^{(2)}}{h_2}\right)_{,i} - 6\left(4\dfrac{u_i^{(1)}}{h_1} + \dfrac{u_i^{(2)}}{h_2}\right)\right], \\ h_1^2D_i^{(1)} = \dfrac{10}{27}\left(\left[-18\psi_i^{(1)} + 25\psi_i^{(2)} + 6h_1V_{,i}^{(2)} + 9h_1\left(\dfrac{w^{(1)}}{h_1} + \dfrac{w^{(2)}}{h_2}\right)_{,i} - 24\dfrac{u_i^{(1)}}{h_1} + 6\dfrac{42}{5}\dfrac{u_i^{(2)}}{h_2}\right]\right), \end{cases} \tag{18}$$

$$b_{11} = \frac{\dfrac{3\gamma h_1}{6-\gamma h_1}a_{22} + \dfrac{6}{6-\gamma h_1}a_{12}}{a_{11}a_{22} - a_{21}a_{12}}, \; b_{12} = -\frac{\dfrac{3\gamma h_2}{6+\gamma h_2}a_{22} + \dfrac{6}{6+\gamma h_2}a_{12}}{a_{11}a_{22} - a_{21}a_{12}}, \; a_{11} = \frac{2(3-\gamma h_1)h_1}{6-\gamma h_1}, \; a_{12} = -\frac{2(3+\gamma h_2)h_2}{6+\gamma h_2},$$

$$b_{21} = -\frac{\dfrac{6_1}{6-\gamma h_1}a_{11} + \dfrac{3\gamma h_1}{6-\gamma h_1}a_{21}}{a_{11}a_{22} - a_{21}a_{12}}, \; b_{22} = \frac{\dfrac{3\gamma h_2}{6+\gamma h_2}a_{21} + \dfrac{6}{6+\gamma h_2}a_{11}}{a_{11}a_{22} - a_{21}a_{12}}, \; a_{21} = -\frac{4-\gamma h_1}{6-\gamma h_1}h_1, \; a_{22} = \frac{4+\gamma h_2}{6+\gamma h_2}h_2.$$

Here, to determine $V^{(2)}$, we will have the following partial differential equation with respect to the unknown

$$\begin{aligned} &h_1^2\Delta V^{(2)} + \frac{3}{2}h_1^2\Delta\left(\frac{w^{(1)}}{h_1} + \frac{w^{(2)}}{h_2}\right) + \frac{7}{18}h_1\psi_{i,i}^{(1)} + \frac{25}{6}h_1\psi_{i,i}^{(2)} - \frac{25}{6}\frac{u_{i,i}^{(1)}}{h_1} + \frac{41}{3}\frac{u_{i,i}^{(2)}}{h_2} \\ &-\beta\left(1 + \frac{\gamma h_1}{6-\gamma h_1}(1+2b_{11})\right)\overline{\vartheta}^{(1)} - \frac{2h_1}{6-\gamma h_1}\beta b_{12}\tilde{\vartheta}^{(1)} + 10\frac{1-\nu}{\nu}V^{(2)} - \frac{9}{2}\left(\frac{w^{(1)}}{h_1} - \frac{w^{(2)}}{h_2}\right) = 0, \end{aligned} \tag{19}$$

After exposure to the cutting tool, to determine unknown integral constants $C_i^{(3)}, D_i^{(3)}, \tilde{\vartheta}^{(3)}, \vartheta_2^{(3)}, V^{(3)}, \theta^{(3)}$ using boundary conditions (10),(12), as a result, we will have:

$$\begin{cases} h_1 C_i^{(1)} = -P_\tau \left[H(v_1 t - x_1)H(v_2 t - x_2)\right]_{,i} - h_1 V^{(1)}{}_{,i} \\ h_1^2 D_i^{(1)} = \dfrac{5P_\tau}{6\mu}\left[H(v_1 t - x_1)H(v_2 t - x_2)\right]_{,i} - \dfrac{5\alpha}{6\gamma}\left(\tilde{\vartheta}^{(1)} - h_1 \vartheta_2^{(1)}\right)_{,i} - \dfrac{5}{3}\psi_i^{(1)} \\ \tilde{\vartheta}^{(1)} = \dfrac{12\gamma}{12 - \gamma^2 h_1^2}\,\overline{\vartheta}^{(1)}, \quad \vartheta_2^{(1)} = \dfrac{6\gamma^2}{12 - \gamma^2 h_1^2}\,\overline{\vartheta}^{(1)} \\ h_1 \theta^{(1)} = 6\left[-\dfrac{w^{(1)}}{h_1} + \dfrac{1}{2}V^{(1)} + v_i t\, tg\eta_i + \dfrac{\alpha}{\gamma h_1}\left(\tilde{\vartheta}^{(1)} - h_1 \vartheta_2^{(1)}\right)\right], \end{cases} \tag{20}$$

Using the obtained expressions, from the boundary conditions (12) for the normal stress on the upper boundary of the formed chips, for the determination $V^{(3)}$ of neglecting the terms of the high order of smallness, we will have the following nonlinear partial differential:

$$\begin{aligned} & u_{k,k}^{(3)} + \frac{1}{2}W^{(3)}{}_{,k}\,W^{(3)}{}_{,k} + \frac{5h_1}{12}\psi_{k,k}^{(3)} - \frac{23}{24}\frac{P_\tau}{\mu}h_1 \Delta\left[H(v_1 t - x_1)H(v_2 t - x_2)\right] - h_1^2 \Delta V^{(3)} - \\ & \frac{6\gamma}{12 - \gamma^2 h_1^2}\left[2\left(\frac{1-\nu}{\nu}\frac{\alpha}{\gamma h_1} - \frac{\beta}{\gamma}\right) - \gamma h_1\left(\frac{1-\nu}{\nu}\frac{\alpha}{\gamma h_1} + \frac{\beta}{\gamma}\right)\right]\left(\frac{h_1}{24}\frac{\alpha}{\gamma}\Delta\overline{\vartheta}^{(3)} - \overline{\vartheta}^{(3)}\right) + \\ & \frac{1-\nu}{\nu}\left(4V^{(3)} - 6\frac{w^{(3)}}{h_1} + 6\frac{v_i t}{h_1}tg\eta_i\right) = 0, \end{aligned} \tag{21}$$

Now, for 4 plots, we will use the boundary conditions (9) and (11) to determine them, so we will have:

$$\begin{cases} h_2^2 D_i^{(4)} = \dfrac{6u_i^{(4)}}{5h_2} - \psi_i^{(4)} + \dfrac{2P_\tau}{5\mu}\left[H(v_1 t - x_1)H(v_2 t - x_2)\right]_{,i},\ h_2\theta^{(4)} = -\dfrac{6}{h_2}w^{(4)}, \\ h_2 C_i^{(4)} + = \dfrac{48}{25}\dfrac{P_\tau}{\mu}\left[H(v_1 t - x_1)H(v_2 t - x_2)\right]_{,i} - \dfrac{6u_i^{(4)}}{25h_2} - \dfrac{9}{5}\psi_i^{(4)}, \quad V^{(4)} = 0, \\ h_2\vartheta_2^{(4)} = -\dfrac{\dfrac{2}{2+\gamma h_2} - \left(1 + \dfrac{\gamma h_2}{2+\gamma h_2}\right)\left(1 + \vartheta_r \dfrac{P_n v_i}{\lambda c}g(x_i,t)\right)}{1 + \dfrac{1}{6}\dfrac{6+h_2\gamma}{2+\gamma h_2} - \left(1 + \dfrac{6+h_2\gamma}{2+\gamma h_2}\right)\gamma h_2\left(1 + \vartheta_r \dfrac{P_n v_i}{\lambda c}g(x_i,t)\right)}\gamma\overline{\vartheta}^{(4)} \\ \tilde{\vartheta}^{(4)} = \dfrac{2}{2+\gamma h_2}\left[1 - \dfrac{\dfrac{2}{2+\gamma h_2} - \left(1 + \dfrac{\gamma h_2}{2+\gamma h_2}\right)\left(1 + \vartheta_r \dfrac{P_n v_i}{\lambda c}g(x_i,t)\right)}{1 + \dfrac{1}{6}\dfrac{6+h_2\gamma}{2+\gamma h_2} - \left(1 + \dfrac{6+h_2\gamma}{2+\gamma h_2}\right)\gamma h_2\left(1 + \vartheta_r \dfrac{P_n v_i}{\lambda c}g(x_i,t)\right)}\left(1 + \dfrac{h_2\gamma}{6}\right)\right]\gamma\overline{\vartheta}^{(4)}, \end{cases} \tag{22}$$

The obtained analytical expressions for the components of the displacement vector and the Cauchy stress tensor in geometrically nonlinear form exactly satisfy the boundary conditions (9)-(12).

The components of the displacement vector - (19) and the symmetric stress tensor depend on unknown integral quantities $u_i^{(I)}, \psi_i^{(I)}, W^{(I)}, \overline{\vartheta}^{(I)}$ which are functions of the coordinates x_1, x_2 and t. In order to obtain a closed system of resolving equations for these unknowns, we introduce the following integral quantities from the components of the stress tensor: $N_{ij}^{(I)} = \int\limits_{-0.5h_I}^{0.5h_I} \sigma_{ij}^{(I)} d\xi$ - normal forces, $Q_i^{(I)} = \int\limits_{-0.5h_I}^{0.5h_I} \sigma_{iz}^{(I)} d\xi$ - shear forces, $M_{ij}^{(I)} = \int\limits_{-0.5h_I}^{0.5h_I} \sigma_{ij}^{(I)} \xi d\xi$ - internal bending moments. In the obtained integral expressions, substituting the components of the stress tensor, we will have

$$\begin{cases} N_{ij}^{(I)} = G^{(I)}\left\{\dfrac{2\nu}{1-2\nu}\left(u_{k,k}^{(I)} + V + \dfrac{1}{2}w_{,i}^{(I)}\,w_{,i}^{(I)}\right)\delta_{ij} + u_{i,j}^{(I)} + u_{j,i}^{(I)} + \dfrac{1}{2}w_{,i}^{(I)}\,w_{,j}^{(I)}\right\}, \\ M_{ij}^{(I)} = D^{(I)}\left\{\dfrac{2\nu}{1-2\nu}\left(\psi_{k,k}^{(I)} + 2\theta + \dfrac{1}{2}V_{,i}^{(I)}\,\theta_{,i}^{(I)}\right)\delta_{ij} + \psi_{i,j}^{(I)} + \psi_{j,i}^{(I)} + \dfrac{1}{2}V_{,i}^{(I)}\,\theta_{,j}^{(I)}\right\}, \\ Q_i^{(I)} = G^{(I)}k^2\left[\psi_i^{(I)} + \left(w^{(I)} - \dfrac{h^2}{30}\theta^{(I)}\right)_{,i}\right], \quad k^2 = \dfrac{5}{6} \end{cases} \tag{23}$$

In order to obtain the equations of elastic plate's motion, we perform the integration procedure (2) taking into account (3) -(5) and (7) over ξ in the interval *[-0.5h$_I$; 0.5h$_I$]:*

$$\begin{cases} N_{ij,j}^{(I)} + p_i^{(I)} - m\ddot{u}_i^{(I)} = 0 \\ M_{ij,j}^{(I)} - Q_i^{(I)} + m_i^{(I)} - \dfrac{h^2}{12}m\ddot{\psi}_{ii}^{(I)} = 0 \\ Q_{i,i}^{(I)} + (N_{ij}^{(I)}w_{,i}^{(I)})_{,i} + (M_{ij}^{(I)}V_{,i}^{(I)})_{,i} + S_z^{(I)} - m\ddot{w}^{(I)} = 0, \end{cases} \tag{24}$$

where

$$\begin{aligned} &p_i^{(1)} = -\sigma_{iz}^{(1)}(x_1, x_2, -\frac{h_1}{2}), \quad p_i^{(2)} = \sigma_{iz}^{(2)}(x_1, x_2, \frac{h_2}{2}) - \sigma_{iz}^{(2)}(x_1, x_2, -\frac{h_2}{2}), \\ &p_i^{(3)} = -P_\tau\left[H(v_1t - x_1)H(v_2t - x_2)\right]_{,i}, p_i^{(4)} = P_\tau\left[H(v_1t - x_1)H(v_2t - x_2)\right]_{,i} - \sigma_{iz}^{(4)}(x_1, x_2, -\frac{h_2}{2}), \\ &m_i^{(1)} = \frac{h_1}{2}\sigma_{iz}^{(1)}(x_1, x_2, -\frac{h_1}{2}), \quad m_i^{(2)} = \frac{h_2}{2}\left\{\sigma_{iz}^{(2)}(x_1, x_2, \frac{h_2}{2}) + \sigma_{iz}^{(2)}(x_1, x_2, -\frac{h_2}{2})\right\}, \\ &m_i^{(3)} = \frac{h_1}{2}P_\tau\left[H(v_1t - x_1)H(v_2t - x_2)\right]_{,i}, m_i^{(4)} = \frac{h_2}{2}\left\{P_\tau\left[H(v_1t - x_1)H(v_2t - x_2)\right]_{,i} + \sigma_{iz}^{(2)}(x_1, x_2, -\frac{h_2}{2})\right\}, \\ &S_z^{(1)} = -\sigma_{zz}^{(1)}(x_1, x_2, -\frac{h_1}{2}), \quad S_i^{(2)} = \sigma_{zz}^{(2)}(x_1, x_2, \frac{h_2}{2}) - \sigma_{zz}^{(2)}(x_1, x_2, -\frac{h_2}{2}), \\ &S_z^{(3)} = -\sigma_{zz}^{(3)}(x_1, x_2, -\frac{h_1}{2}), \quad S_i^{(4)} = \sigma_{zz}^{(4)}(x_1, x_2, \frac{h_2}{2}) - \sigma_{zz}^{(4)}(x_1, x_2, -\frac{h_2}{2}), \end{aligned} \tag{25}$$

Distributed external efforts and moments. $m=\rho h$ is the line armass, and the density – ρ in thick ness is considered constant. At the same time $h_3 = h_1$, $h_4 = h_2$

Similarly, integrating the thermal conductivity equation with the heat transfer process and the continuity condition at the interface of the bands under consideration, as well as with the expansion (19), we will have the thermal conductivity equation for each strip, in terms of integral quantities

$$c_\varepsilon\dot{\overline{\vartheta}}^{(I)} = \lambda_\varepsilon\Delta\overline{\vartheta}^{(I)} - T\beta\dot{u}_{k,k}^{(I)} + \tilde{\vartheta}^{(1)} + \frac{h_I}{2}\vartheta_2^{(1)} - \gamma\left(\overline{\vartheta}^{(1)} - \frac{h_1}{2}\tilde{\vartheta}^{(1)} + \frac{h_1^2}{6}\vartheta_2^{(1)}\right) \tag{26}$$

In this case, the equations of motion (24), taking into account (14)- (23) and (25) become closed with respect to the following integral quantities: $u_i^{(I)}, \psi_i^{(I)}, W^{(I)}, \overline{\vartheta}^{(I)}$.

In terms of integral quantities, the boundary conditions corresponding to various conditions are written as follows [22].

$$I. \quad \begin{cases} u_i^{(I-1)} = u_i^{(I)}, \ \psi_i^{(I-1)} = \psi_i^{(I)}, \ \ w^{(I-1)} = w^{(I)}, \ \ V^{(I-1)} = V^{(I)}, \ \ \vartheta^{(I-1)} = \vartheta^{(I)}, \\ N_{ij}^{(I-1)}n_j = N_{ij}^{(I)}n_j, \ M_{ij}^{(I-1)}n_j = M_{ij}^{(I)}n_j, \ \ Q_i^{(I-1)}n_i = Q_i^{(I)}n_i, \\ V^{(I-1)}{}_{,i}\,n_i = V^{(I)}{}_{,i}\,n_i, \ \ \vartheta^{(I-1)}{}_{,i}\,n_i = \vartheta^{(I)}{}_{,i}\,n_i. \end{cases}$$

$$I = 2, 4 \quad x_1 = v_1t, t > 0.$$

$$II. \ N_{ij}^{(I)}n_j\big|_\Sigma = 0, \ M_{ij}^{(I)}n_j\big|_\Sigma = 0, \ \ Q_i^{(I)}n_i\big|_\Sigma = 0, \ V^{(I)}{}_{,i}\,n_i\big|_\Sigma = 0, \ \vartheta^{(I)}{}_{,i}\,n_i\big|_\Sigma = \gamma\vartheta^{(I)},$$

$$I = \overline{1, 4} \quad x_1 = 0, l$$

It should be noted that the first type of boundary conditions correspond to a hard jamming of the edges of the bands under consideration, and the second type corresponds to a joint edge taking into account the thermal exchange process. Here, for prostate records, $v_2=0$ is assumed.

The initial conditions (3), taking into account (19), can be similarly written in terms of integral quantities.

Conclusions. Based on the results obtained, the **following conclusions** can be drawn:

1. The thermal mechanical formulation of the cutting objects problem on the basis of the fundamental thermodynamic nonlinear theory of elasticity is formulated;

2. The boundary conditions for the interaction of the cutting tool and the object under consideration (13) and (14) are formulated;

3. In the obtained formulas (13) of thermal transfer at the boundary, the possibility of the appearance of additional heat from the influence of the base of the cutting tool on the surface of the objects under consideration is taken into account;

4. The formulated thermal mechanical theory of cutting method allows us to solve the related problem of thermodynamics to determine the stress-strain state and the laws of temperature distribution in the formed cutting chips.

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МЕТАЛДАРДЫ КЕСУ КЕЗІНДЕ МЕХАНИКАЛЫҚ ӨҢДЕУДІҢ ТЕРМОДИНАМИКАЛЫҚ НЕГІЗДЕРІ

Аннотация. Металдарды кесу үдерісінде пайда болатын іргелі термомеханикалық құбылыстар жүйелі және өзара байланысы теориялық және математикалық сипаттауға қиын. Зерттеулерде қарастырылатын, мәні мен сипаты жағынан әртүрлі құбылыстар бір-бірімен тығыз байланысқандықтан, олардың өзара әрекетін сипаттау күрделі. Зерттеуліміздің нәтижелері бойынша кесетін жиектің шыңына әлі күнге дейін тұтас бірлікке келмеген он бір тәуелсіз теориялар тоғыстырылғаны анықталды. Осындай зерттеулерде жоңқа түзілу теориясын, металдарды кесу механикасын, металл өңдеу кезінде үйкеліс және тозу теориясын, кесу термодинамикасын, кесу құралдарының беріктігі мен сенімділігі теориясын жүйелеу және өзара байланыстыру қажет.

Металдарды кесу арқылы механикалық өңдеу термодинамикалық үдерістермен сүйемелденеді. Металл кесу кезінде жылу көзі кесілетін қабатта және өңделген беті мен кесу бетіне іргелес қабаттарда соңғы деформацияға, сондай-ақ кескіштің артқы беті бойынша үйкелуді еңсеруге кететін жұмыс болып саналады. Соңғы деформация үдерісінде үлгінің материалдық нүктелері бір-біріне қатысты қозғалады, бұл қосымша жылу түзудің көзі болып саналады. Кесу үдерісінде бөлінетін жылу оның пайда болу орындарына шоғырланбайды, ал термодинамика заңдарына сәйкес үлгінің көлемі бойынша жоғары температуралы нүктелерден төмен температуралы нүктелерге таралады. Механикалық жұмыстың 95% - ға жуығы металдарды кесу кезінде деформация мен үйкеліс жылуға өтеді. Сондықтан металдарды кесу кезінде жоңқалар мен байланыс беттері 500÷1000° аралығында қызады, бұл ретте бөлінетін жылу, негізінен жоңқа арқылы 50÷86% жұтылады, кескіш арқылы 10÷40%, өңделетін бұйым негізінде 3÷9%, шамамен 1% жылу қоршаған кеңістікке шығарылады.

Бұл жұмыста термодинамиканың іргелі заңдары және деформацияланатын қатты дененің сызықты емес механикасы негізінде металдарды кесудің термомеханикалық теориясы ұсынылады. Бұл үдерісте кесу құралы өткір ішкі кернеулердің сыни мәнінің пайда болуына байланысты кесу желісі бойынша металл жоңқасының түбінен үзіліп кетеді. Бұл ретте жоңқасы металл жолақ түрінде үзілгеннен кейін соңғы орын ауыстырады. Бұл жұмыста металдарды кесудің термомеханикалық үрдістерін математикалық модельдеу әдістері В.В. Новожиловтың сызықты емес серпімділік теориясына негізделеді. Үшөлшемді дененің қарапайым көлемінің соңғы деформациясы соңғы айналу және қозғалумен, алайда геометриялық өлшемдердің аз салыстырмалы өзгерістерімен бірге жүреді.

Алынған нәтижелер негізінде фундаментальды термодинамикалық сызықты емес серпімділік теориясы негізінде объектілерді кесу міндетін терммеханикалық қою жағдайы тұжырымдалды; кесетін аспап пен қарастырылатын объектінің өзара әрекеттесуі үшін шекаралық жағдайлар жасалды; d алынған шекарадағы жылу алмасу формулалары кесетін құрал негізінің қарастырылатын объектілердің беті туралы әсерінен қосымша жылудың пайда болу мүмкіндігі ескерілген; тұжырымдалған термомеханикалық кесу теориясы қалыптасқан кесу жоңқаларында температураның таралу заңдылықтары мен кернеулі-деформацияланған жағдайын анықтау бойынша термодинамиканың байланысты есебін шешуге мүмкіндік береді.

Кесу үдерістерін математикалық модельдеу мәселелерімен Қазақстан Республикасы білім және ғылым Министрлігі Ғылым Комитетінің гранттық қаржыландыру бойынша «Кесу үрдістерінің имитациялық модельдерін әзірлеу және олардың негізінде жабдықтардың тиімді параметрлері мен өңдеу режимдерін болжау» жобасы бойынша ғалымдар тобы айналысады.

Түйін сөздер: термодинамика, жылу өткізгіштік, кесу, деформация, үйкеліс, қатты дене, кернеу, кесу құралы, жоңқа, кедір-бұдырлық, жылдамдық, ығысу.

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ТЕРМОДИНАМИЧЕСКИЕ ОСНОВЫ МЕХАНИЧЕСКОЙ ОБРАБОТКИ МЕТАЛЛОВ РЕЗАНИЕМ

Аннотация. Фундаментальные термомеханические явления, возникающие в процессе резания металлов, трудно поддаются системному и взаимосвязанному теоретическому и математическому описанию. Различные по сути и характеру явления, рассматриваемые в исследованиях, столь тесно переплетены друг с другом, что очень сложно описать их взаимодействие. По результатам наших исследований выявлено, что на вершину режущей кромки сфокусировано одиннадцать относительно независимых теорий, не пришедших до сих пор к целостному единству. В подобных исследованиях необходимо систематизировать и взаимно увязать теорию стружкообразования, механику резания металлов, теории трения и износа при металлообработке, термодинамику резания, теории стойкости и надежности режущих инструментов.

Механическая обработка металлов резанием сопровождается термодинамическими процессами. Источником теплоты при резании металлов является работа, затрачиваемая на конечные деформации в срезаемом слое и в слоях, прилегающих к обработанной поверхности и поверхности резания, а также на преодоление трения по задним поверхностям резца. В процессе конечной деформации материальные точки образца перемещаются относительно друг друга, что является источником дополнительного теплообразования. Выделяющаяся в процессе резания теплота не сосредоточивается в местах ее образования, а согласно законам термодинамики распространяется по объему образца от точек с высшей температурой к точкам с низшей температурой. При резании металлов около 95% механической работы деформации и трения переходит в теплоту. Поэтому при резании металлов стружки и контактные поверхности нагреваются в интервале 500÷1000°, при этом выделяемая теплота, в основном поглощается стружкой – 50÷86%, резцом – 10÷40%, обрабатываемым изделием – 3÷9%, около 1% теплоты излучается в окружающее пространство.

В данной работе предлагается термомеханическая теория резания металлов на основе фундаментальных законов термодинамики и нелинейной механики деформируемого твердого тела. В данном процессе по линии резания, в связи с возникновением критических значений внутренних напряжений на острие режущего инструмента, происходит отрыв стружки металла от основания. При этом после отрыва стружка в виде металлической полосы совершает конечные перемещения. В данной работе подходы математического моделирования термомеханических процессов резания металлов основываются на нелинейной теории упругости В.В. Новожилова, причем конечное деформирование элементарного объема рассматриваемого трехмерного тела сопровождается конечными вращениями и перемещениями, но с малыми относительными изменениями геометрических размеров.

На основании полученных результатов сформулирована термомеханическая постановка задачи резания объектов на основе фундаментальной термодинамической нелинейной теории упругости; сформулированы граничные условия для взаимодействия режущего инструмента и рассматриваемого объекта; d полученных формулах теплообмена на границе учтена возможность возникновения дополнительной теплоты от воздействия основания режущего инструмента о поверхность рассматриваемых объектов; сформулированная термомеханическая теория резания позволяет решать связанную задачу термодинамики по определению напряженно-деформированного состояния и закономерностей распространения температуры в образовавшихся стружках резания.

Вопросами математического моделирования процессов резания занимается группа ученых по проекту AP05132157 «Разработка имитационных моделей процессов резания и прогнозирование на их основе оптимальных параметров инструмента и режимов обработки» по грантовому финансированию Комитета науки Министерства образования и науки Республики Казахстан для прогнозирования значений возникающих силовых и температурных явлений, величину износа инструмента, которая будет сопровождаться имитацией процесса резания.

Ключевые слова: термодинамика, теплопроводность, сдвиг, деформация, трение, твердые тела, напряжение, режущий инструмент, сколы, шероховатость, скорость, сдвиг.

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COMPARATIVE ANALYSIS OF STANDARD INDICATORS FOR NANOCARBON ASPHALT CONCRETE AND OTHER ASPHALT CONCRETES

Abstract. A comparative analysis of the standard indicators for a nanoasphalt concrete of the type B prepared with the use of a nanocarbon powder and the asphalt concretes of the type B and stone mastic asphalt concretes (SMA20) with modifiers and without them has been performed in the work. The bitumens of the grades BND 70/100, BND 100/130 and BND 130/200 have been used for preparing of the asphalt concretes. The bitumens of the grades BND 70/100 and BND 100/130 have been produced by the Pavlodar petrochemical plant, and the bitumen of the grade BND 130/200 has been manufactured by compounding of the bitumen of the grade BND 100/130 and the petroleum tar of the same plant in Kazakhstan Highway Research Institute. A nanopowder (150-200 nm) has been manufactured from a coal rock of the deposit "Saryadyr" of the "Corpoation "ON-Olzha" LLP (Akmola region) by three-stage size reduction sequentially in a mechanical dispergator (up to 2-3 mm), an aerodynamic mill (up to 20 mcm) and a reactor with a rotating electromagnetic field (150-200 nm).

To compare the standard indicators of 13 types of asphalt concretes have been prepared. The standard indicators of the asphalt concretes have been determined in a laboratory under the standard ST RK 1218-2003. The comparative analysis has been performed under the following 6 main standard indicators: a compression strength at the temperature of 50 ºC;a compression strength at the temperature of 20 ºC;a compression strength at the temperature of 0 ºC;the shear resistance (atfriction at the temperature of50 ºC);the crack resistance at the temperature of0 ºC; the water saturation.

It is found out that thenanoasphalt concrete under the considered standard indicators can substitute practically all the main types of the asphalt concretes used in a road construction in many countries of the world and in Kazakhstan. It has essentially high resistance to the shear, low temperature and fatigue failures, cyclic freezing and thawing.

Keywords:bitumens, carbon nanopowder, polymers, crumb rubber, asphalt concretes, stone mastic asphalt concretes, standard indicators.

1. Introduction. An asphalt concrete is one of the main road materials in the world. It is used, as a rule, for construction of the upper road surfacing layers – a pavement of highways. Therefore, it is exactly the pavement from the asphalt concrete which sustains the strongest weather-climatic and mechanical impacts during its full service life. The road asphalt concrete should have a complex of the required properties to become sufficiently resistant to the above impacts. As the multiyear experience shows the composition, the technology of preparing and construction of the asphalt concretes are constantly improved to have all the required properties. At present all over the world it is considered that it is possible to achieve the considerable increase of the operational characteristics of the road asphalt concretes by the modification of the bitumens with different polymers.

The works [1-4] show the possibility of the essential increase for the low temperature characteristics of the road bitumens by their modification with a nanocarbon powder. Based on the electromagnetic theory [5,6] and the quantum physics [7] a physic-chemical phenomenon has been explained for a group

chemical composition variation of the bitumen which stipulated the essential variation of the low temperature characteristics of the bitumen. The work [8] demonstrates the increased characteristics of ananoasphaltconcrete of the type B prepared with the use of the bitumen with the nanocarbon powder we obtained before.This article is a continuation of our above works, and it gives the results of the comparative analysis for the standard indicators of the nanoasphalt concrete of the type B and 12 other main types of asphalt concrete: 2 asphalt concretes of the type B, 5 asphalt concretes of the type B with the polymers and a crumb rubber, 5 types of stone mastic asphalt concretes (SMA 20) with polymers and without them.

2. Materials and methods.

2.1. Bitumens. In this work the road bitumens of three grades (BND 70/100, BND 100/130 and BND 130/200) satisfying the requirements of the standard ST RK 1373-2013 have been used for preparing of the asphalt concretes of 13 different types including thenanoasphalt concrete of the type B. In this work the polymers Elvaloy 4170, Calprene 501, Butonal NS 198, SBS L30-01 A and a crumb rubber have been used as the modifiers. The bitumens modified with the polymers satisfy the requirements of the standard ST RK 2534-2014. The detailed information about preparing of the bitumens modified with the polymers one can obtain in the work [9].

The nanopowder (150-200 nm) has been manufactured from a coal rock of the deposit “Saryadyr” (“Corpoation “ON-Olzha” LLP, Akmola region). First for the purpose of provision a homogeneous distribution of the nanopowder particles in the bitumen the nanocarbon powder has been dispersed in a kerosene under the impact of an ultrasound with the frequency of 20 kHz for 5 minutes at a room temperature. Then the dispersed solution (kerosene+nanopowder) has been added to the bitumen at the temperature of 160 ºCand constant mixing for 30 minutes.

2.2. Asphalt concretes. For the purpose of the determination of the standard indicators the next 13 types of asphalt concretes have been prepared and tested: a nanoasphalt concrete of the type B, 2 asphalt concretes of the type B, 5 asphalt concretes of the type B with polymers and a crumb rubber, 5 type of the stone mastic asphalt concretes (SMA 20) with the polymers and without them. The data about the prepared and tested asphalt concretes are given in the Table 1. The asphalt concrete mixes have been prepared in accordance with the requirements of the following relevant standards:

Data about the tested types of asphalt concretes

Serial number	Type of asphalt concrete	Grade of bitumen	Modifier	Content of modifier, %	Contracted notation
1	Dense fine-grained, type B	BND 70/100	–	–	B-70-100
2	Dense fine-grained, type B	BND 70/100	nanocarbon	2.0	B-70-100+nano
3	Dense fine-grained, type B	BND 100/130	–	–	B-100-130
4	Dense fine-grained, type B	BND 100/130	polymer Elvaloy 4170	1.4	B-100-130+Elvaloy
5	Dense fine-grained, type B	BND 100/130	polymer Calprene 501	4.0	B-100-130+Calprene
6	Dense fine-grained, type B	BND 100/130	polymer Butonal NS 198	3.0	B-100-130+Butonal
7	Dense fine-grained, type B	BND 100/130	Crumb rubber	10	B-100-130+CR10
8	Dense fine-grained, type B	BND 100/130	Crumb rubber	15	B-100-130+CR15
9	Stone mastic asphalt concrete-20	BND 100/130	–	–	SMA-100-130
10	Stone mastic asphalt concrete-20	BND 130/200	polymer Elvaloy 4170	1.7	SMA-130-200+Elvaloy
11	Stone mastic asphalt concrete-20	BND 130/200	polymer Calprene 501	6.0	SMA-130-200+Calprene
12	Stone mastic asphalt concrete-20	BND 130/200	polymer Butonal NS 198	3.5	SMA-130-200+Butonal
13	Stone mastic asphalt concrete-20	BND 130/200	polymer SBSL30-01 A	5.0	SMA-130-200+SBS

The asphalt concretes and thenanoasphalt concrete of the type B–ST RK 1225-2019; the polymer asphalt concretes of the type B – ST RK 1223-2019; the asphalt concretes of the type B with the crumb rubber – ST RK 2028-2010; the stone mastic asphalt concrete (SMA 20) – under GOST 31015-2002; the stone mastic asphalt concretes (SMA 20) with the polymers – ST RK 2373-2019.

3. Results and discussion

3.1. Compression strength at the temperature of 50 ºC. It is found out in our work [8] that the strength of the asphalt concrete of the type B with nanocarbon bitumen (content of the carbon nanopowder is 2%) at compression at the temperature of 50 ºC is higher for 29% than the strength of the conventional asphalt concrete of the type B. Now we can see (figure 1) that the strength of the nanoasphalt concrete of the type B at 50 ºC is higher than the average strength of the stone mastic asphalt concretes nearly for 60% and not lower than the minimum allowed strength of the polymer asphalt concretes of the type B.

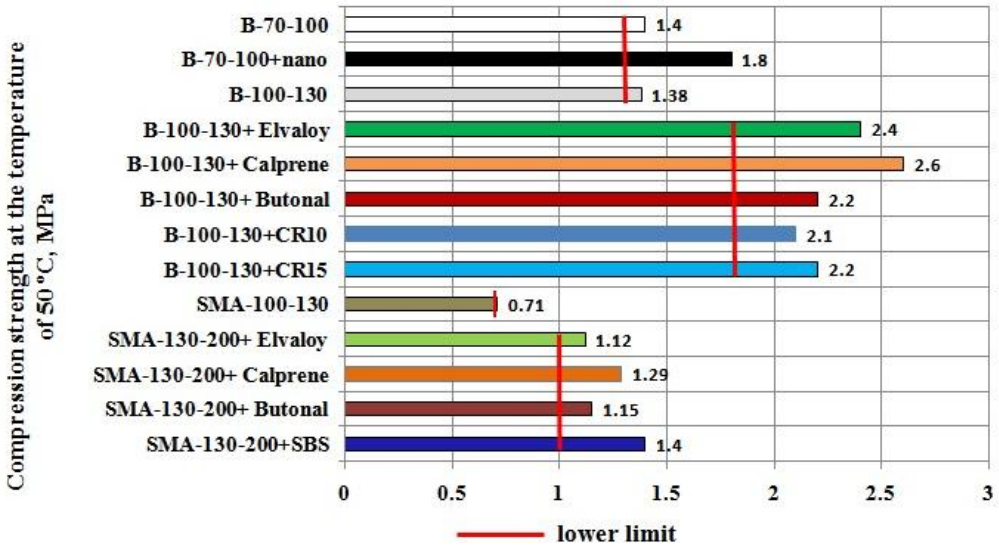

Figure 1 – Compression strength of the asphalt concretes at the temperature of 50ºC

3.2. Compression strength at the temperature of 20ºC. It is clearly seen (figure 2) that the values of this indicator for the compared asphalt concretes are varied within narrow limits (3.2-4.1 MPa), i.e. they havethe similar values. Meanwhile, thenanoasphalt concrete of the type B has the strength (3.5 MPa) essentially higher than the minimum allowed values for all the compared asphalt concretes. The minimum allowed value of the compression strength at the temperature of 20ºC for the asphalt concretes of the type B and the stone mastic asphalt concrete without a polymer is equal to 2.5 MPa, and it is equal to 2.8 MPa for the stone mastic asphalt concretes with the polymers. For example, the nanoasphalt concrete has the strength at the temperature of 20ºC higher than the minimum allowed value for the asphalt concretes of type B without polymers and for the stone mastic polymer asphalt concretes for 40% and 25% respectively.

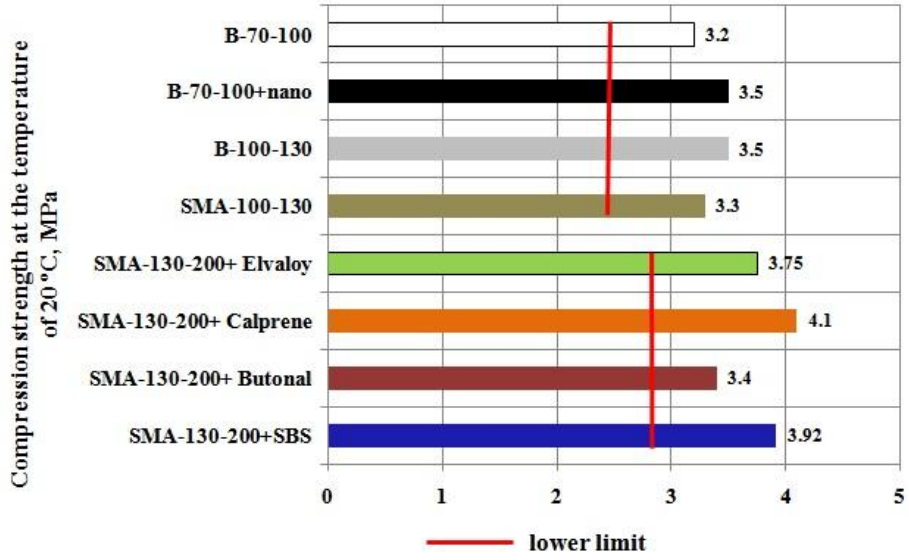

Figure 2 – Compression strength of the asphalt concretes at the temperature of 20ºC

3.3. Compression strength at the temperature of 0 ºC. It is found out in our work [8] that the strength at 0ºCfor the nanoasphalt concrete of the type B is nearly 2 times (44%) lower than for the conventional asphalt concrete of the type B. Now we can see (figure 3) that the nanoasphalt concrete reigns supreme under this indicator – its strength at 0ºC is nearly 2 times (more exactly 1.91 times) lower than the average strength of other compared asphalt concretes.

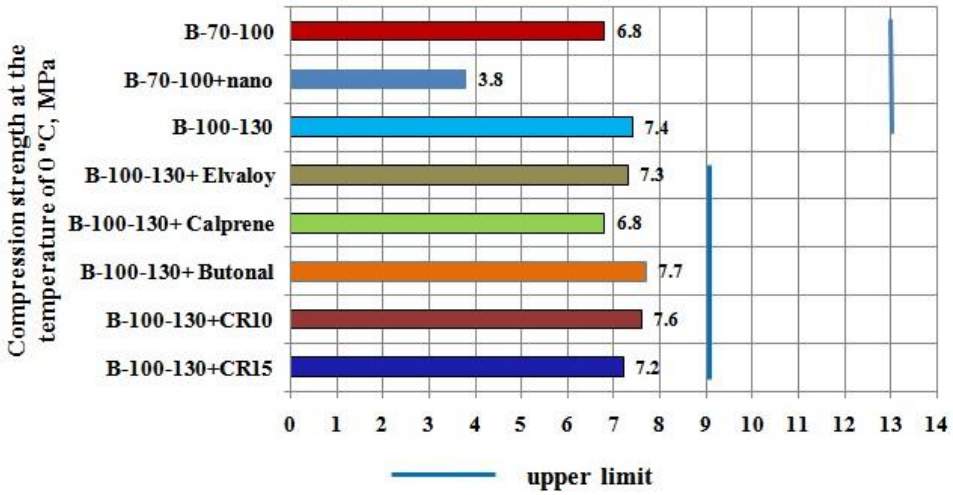

Figure 3 – Compression strength of the asphalt concretes at the temperature of 0ºC

3.4. Shear resistance. It is found out in our work [8] that the nanoasphalt concrete of the type B has the shear resistance for 43% higher than for the conventional asphalt concrete of the type B. And now it is clearly seen (figure 4) that under this indicator the nanoasphalt concrete is one of the best among the compared ones: its shear resistance is more for 48%, 25% and 2.04 times compared with the conventional asphalt concretes of the type B, the asphalt concretes of the type B with the polymers and the stone mastic asphalt concretes with the polymers and without them.

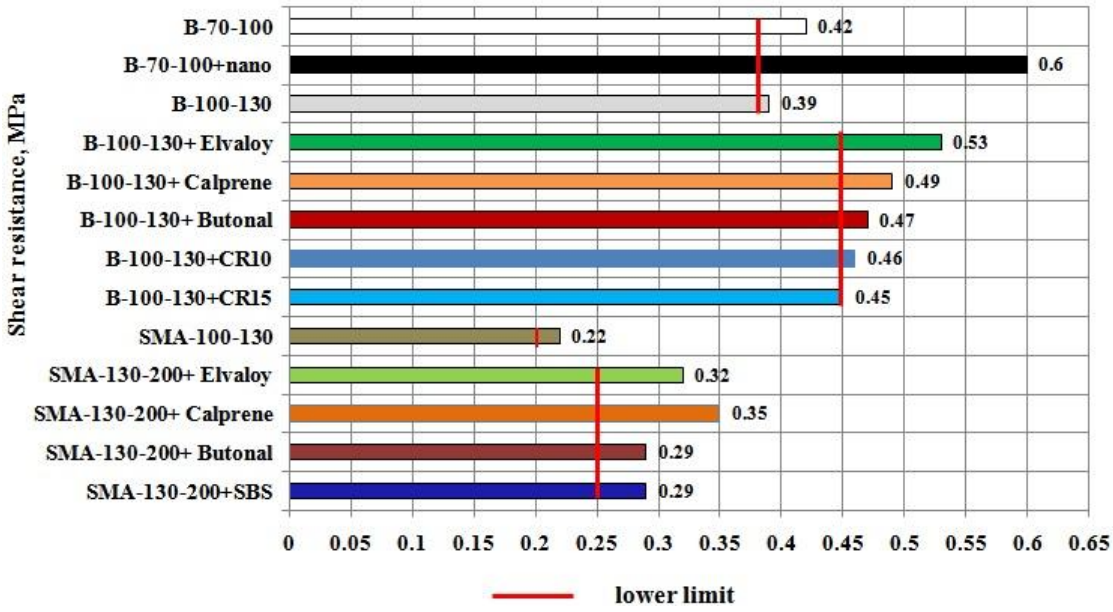

Figure 4 – Shear resistance of the asphalt concretes (at friction at the temperature of 50ºC)

3.5. Crack resistance at the temperature of 0ºC. It is seen from the figure 5 that the nanoasphalt concrete of the type B has the crack resistance considerably lower than the maximum allowed values for all the considered types of the asphalt concretes. This fact indicates that the nanoasphalt concrete according to the considered standard indicator can substitute practically all the main types of the asphalt concretes used in a road construction in many countries of the world including Kazakhstan.

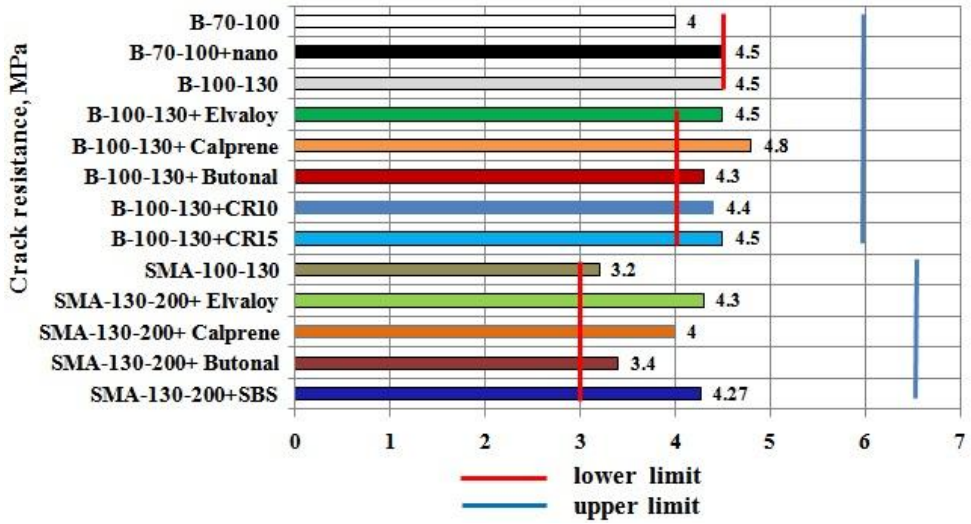

Figure 5. Crack resistance of the asphalt concretes at the temperature of 0ºC

3.6. Water saturation. It has been found out in our work [8] that the water saturation for the nanoasphalt concrete of the type B is for18% less than for the conventional asphalt concrete of the type B. And now it is seen (figure 6) that except for the asphalt concrete of the type B with the polymerCalprene the nanoasphalt concrete of the type Bis among those types of the asphalt concrete which have the least values of the water saturation (2.5-2.8%). It is also should be mentioned that the water saturation of the nanoasphalt concrete is lower than the maximum allowed values for all the considered types of the asphalt concrete.

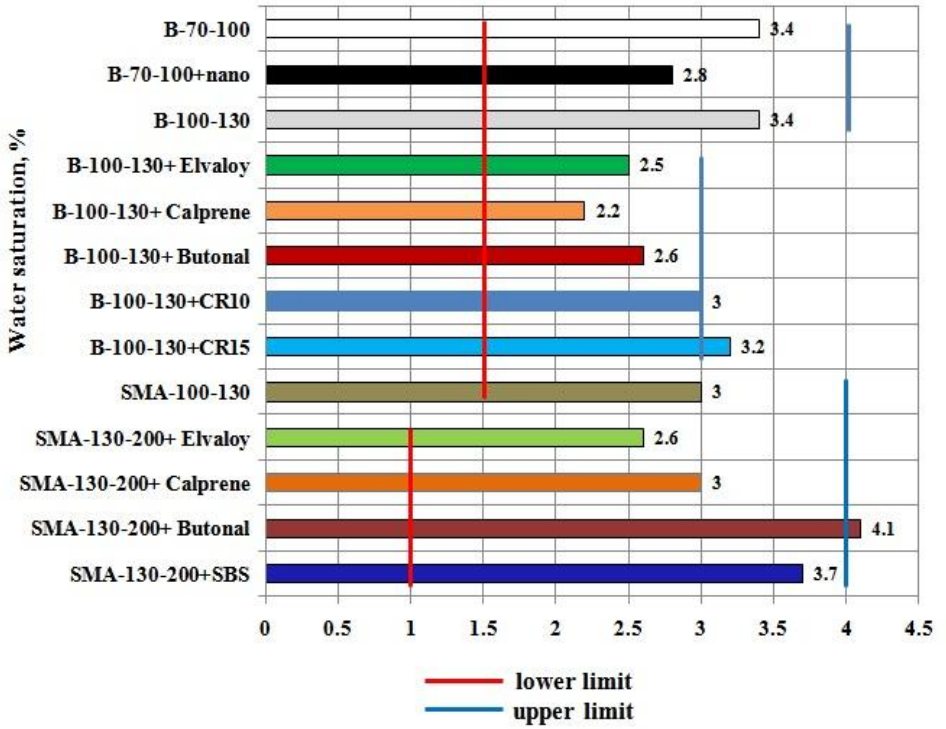

Figure 6 – Water saturation of the asphalt concretes

Conclusion. 1. The nanoasphalt concrete according to the considered standard indicators can substitute practically all the main types of the asphalt concretes used in a road construction in many countries of the world and in Kazakhstan.

2. The nanoasphalt concrete has the compression strength at the temperature of 0º Con average nearly 2 times higher than other types of the asphalt concretes, i.e. it has essentially high low temperature and fatigue strengths.

3. The nanoasphalt concrete proved to be the most shear resistant among the considered types of the asphalt concretes: its shear resistance is more for 25-204 % than for other asphalt concretes.

4. The nanoasphalt concrete is among the group of the asphalt concretes with the least water saturation values, i.e. after appropriate additional tests it may prove to be one of the most frost resistant types of the asphalt concretes.

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НАНОКӨМІРТЕК АСФАЛЬТБЕТОН МЕН БАСҚА АСФАЛЬТБЕТОНДАРДЫҢ СТАНДАРТТЫҚ КӨРСЕТКІШТЕРІН САЛЫСТЫРМАЛЫ ТАЛДАУ

Аннотация. Жұмыста нанокөміртек ұнтағы негізінде дайындалған Б типті наноасфальтбетон, модификатормен және онсыз Б типті асфальтбетон және шағыл тас-мастикалық асфальтбетондардың стандарттық көрсеткіштерін салыстырмалы талдау жасалған. Асфальтбетондарды дайындауға МЖБ 70/100, МЖБ 100/130 және МЖБ 130/200 маркалы битумдар пайдаланылды. МЖБ 70/100 және МЖБ 100/130 маркалы битумдар Павлодар мұнай-химия зауытында, ал МЖБ 130/200 маркалы битумы Қазақстан жол ғылыми-зерттеу институтында МЖБ 100/130 маркалы битум мен сол зауыттың гудронын араластыру негізінде алынды. Наноұнтақ (150-200 нм) «ОН-Олжа» ЖШС-нің (Ақмола облысы) «Сарадыр» кенорнының көмір жынысын механикалық диспергаторда (2-3 мм-ге дейін), аэродинамикалық диірменде (20 мкм-ге дейін) және айналмалы электр-магниттік өрісті реакторда үшсатылы тізбектей ұнтақтау жолымен алынды.

Стандарттық көрсеткіштерін салыстыру үшін асфальтбетонның 13 түрі дайындалып, сынақтан өткізілді. Зертханада ҚР СТ 1218-2003 стандарты бойынша асфальтбетондардың стандарттық көрсеткіштері анықталды. Салыстырмалы талдау келесі 6 негізгі стандарттық көрсеткіштер бойынша жасалды: 50°С температурадағы сығу беріктігі; 20°С температурадағы сығу беріктігі; 0°С температурадағы сығу беріктігі; ығысуға тұрақтылық (50°С температурадағы ілігісу бойынша); 0°С температурадағы жарылуға тұрақтылық; суға қанығу.

Қарастырылған стандарттық көрсеткіштер бойынша наноасфальтбетонның әлемнің көптеген елдерінде және Қазақстанда жол құрылысында қолданылатын асфальтбетондардың барлық негізгі түрлерін алмастыра алатындығы анықталды. Оның ығысуға, төменгі температуралық және шаршау бұзылысына, циклдік тоңу мен еруге тұрақтылығы айтарлықтай жоғары.

Түйін сөздер: битумдар, көміртек наноұнтағы, полимерлер, резеңке ұнтағы, асфальтбетондар, шағыл тас-мастикалық асфальтбетондар, стандарттық көрсеткіштер.

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СРАВНИТЕЛЬНЫЙ АНАЛИЗ СТАНДАРТНЫХ ПОКАЗАТЕЛЕЙ НАНОУГЛЕРОДНОГО АСФАЛЬТОБЕТОНА И ДРУГИХ АСФАЛЬТОБЕТОНОВ

Аннотация. В настоящей работе выполнен сравнительный анализ стандартных показателей наноасфальтобетона типа Б, приготовленного с использованием наноуглеродного порошка и асфальтобетонов типа Б и щебеночно-мастичных асфальтобетонов (ЩМАС-20) с модификаторами и без них. Для приготовления асфальтобетонов использовались битумы марок БНД 70/100, БНД 100/130 и БНД 130/200. Битумы марок БНД 70/100 и БНД 100/130 были произведены Павлодарским нефтехимическим заводов, а битум марки БНД 130/200 был получен путем компаундирования битума марки БНД 100/130 и гудрона из того же завода в Казахстанском дорожном научно-исследовательском институте. Нанопорошок (150-200 нм) получен из

угольной породы месторождения «Сарыадыр» ТОО «Корпорация «ОН-Олжа» (Акмолинская область) путем трехстадийного измельчения последовательно в механическом диспергаторе (до 2-3 мм), аэродинамической мельнице (до 20 мкм) и реакторе с вращающимся электромагнитным полем (150-200 нм).

Для сравнения стандартных показателей были приготовлены и испытаны 13 видов асфальтобетонов. В лаборатории по стандарту СТ РК 1218-2003 были определены стандартные показатели асфальтобетонов. Сравнительный анализ был выполнен по следующим 6 основным стандартным показателям: прочность при сжатии при температуре 50 ºС; прочность при сжатии при температуре 20 ºС; прочность при сжатии при температуре 0 ºС; сдвигоустойчивость (по сцеплению при температуре 50 ºС); трещиностойкость при температуре 0 ºС; водонасыщение.

Установлено, что наноасфальтобетон по рассмотренным стандартным показателям может заменить практически все основные виды асфальтобетонов, применяемых в дорожном строительстве во многих странах мира и в Казахстане. Он имеет существенно высокую устойчивость к сдвигу, низкотемпературному и усталостному разрушению, циклическому замораживанию и оттаиванию.

Ключевые слова: битумы, углеродный нанопорошок, полимеры, резиновая крошка, асфальтобетоны, щебеночно-мастичные асфальтобетоны, стандартные показатели.

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INFLUENCE OF AN INSTALLATION ANGLE OF THE CONVEYOR LIFT ON THE VOLUMES OF MINING AND PREPARING WORK AT QUARRIES AT THE CYCLIC-FLOW TECHNOLOGY OF ORE MINING

Abstract. Determination of the effect of the installation parameters of the conveyor hoist on the volumes of mining operations in the open-pit mine at cyclic-flow method for the ore mining. Justification of application of various technological schemes of cyclic-flow method (CFM) depending on the duration of work at the concentration horizon of crushing and loading points, as well as rational schemes of opening the open-pit mine.

To achieve the purpose of this paper we have used the integrated approach, including the analysis of scientific papers to identify problematic aspects of the applicability of the cyclic-flow method in domestic open-pit mines, the analytical studies to identify the relationship between the volumes of mining operations and the technological parameters for mining the open-pit fields, the method of technical and economic comparison to justify rational schemes for opening the open-pit fields.

We have scientifically established the areas of expedient application of steeply inclined conveyors in the technological CFM schemes in comparison with usual belt conveyors which are expedient to use at a height of rock mass hoisting of 100-200 m and more and at an annual output of 5-10 million tons.

We have determined the areas of preferable application of steeply inclined conveyors in the technological CFM schemes in comparison with usual belt conveyors. It is expedient to use the steeply inclined conveyors in the CFM complexes with an annual output 5-10 million tons at a height of rock mass hoisting of 100-200 m and more. When increasing the volumes of movement by the CFM complexes up to 20-30 million tons per year, it is expedient to use the steeply inclined conveyors at a height of rock mass hoisting of 200-300 m and more. In these conditions, with practically equal operating costs, the specific capital costs of the CFM complexes with steeply inclined conveyors are lower by 6-20 %.

As a result of technical and economic calculations, we have confirmed high efficiency of application of technological schemes with steeply inclined conveyor hoisting and semistationary crushing and loading devices at open-pit mines with high annual output. The results are useful for the organizations engineering the mining enterprises with open pit mining.

Key words: cyclical-flow technology, deep quarries, mobile crushing and reloading plants, concentration horizon, mining preparatory work.

Introduction. Problems and its connection with scientific and practical tasks. Application of the cyclical-and-flow method (CFM) in conditions of constant deepening of open-pit mines allows to reach high concentration of operations, to improve indicators of use of mining transport equipment, to provide high degree of automation of technological processes and to increase work efficiency of the open-pit mine as a whole.

In recent years, the use of the CFM in open-pit mines as energy-and resource-saving mining technologies continues to be relevant. A sufficient number of publications have been devoted to the

questions of possibility and expediency of using and development of the CFM complexes at the open-pit mines [1-8], as well as to the problem of increasing the output through the use of rational design and layout schemes of the CFM complex elements, reducing the costs of the CFM complexes by reducing the number of dump trucks in the cyclical link of the CFM.

The performed studies have showed that specific energy consumption of the cyclic-flow method used in the open-pit mines of the Commonwealth of Independent States is lower by 14-16 % compared to the cyclic technology. Distribution of energy consumption by the main technological CFM processes is on average the following: transportation of rock mass 75-80 %, crushing 8-10 %, excavation 16-18 % [9,21].

However, the possibilities of the cyclic-flow method used in the open-pit mines of the Commonwealth of Independent States have not been fully realized. The main disadvantages of the applied CFM schemes include the stationary nature of crushing and conveyor complexes, whose use contradicts the dynamics of mining operations (rate of progress in depth being 7-15 m/year) and the conditions for the formation of technological cargo flows. The stationary nature of the CFM facilities determines the large volume of capital mining and construction and installation works (up to 75 % of the total cost of the complexes) and, as a result, the construction time for such complexes is at least 3-5 years. The service life of the crushing and loading point at one concentration horizon is at least 8-10 years. This determines the irrational working conditions of gathering vehicles: the actual distance of transportation of the rock mass at the site from the excavator face to the crushing and loading point (CLP) reaches 3 km or more. The rate of progress in depth and the lengthening of the inclined conveyor result in considerable "throwing" costs connected with liquidation of the earlier operating CLP as its stationary nature allows to dismantle for the further use only a mechanical part (crusher and feeders) that makes no more than 28 % of the total CLP cost.

Analysis of previous studies and publications on the problem. The conditions for the formation of the working area of the deep open-pit mines and the space-time distribution of the rock mass volumes necessitate the use of such crushing and loading devices (CLD) in the technological CMM schemes, whose design ensures their periodic movement in the open-pit space as the open-pit mine deepens. Such the CLDs, which provide high flexibility of the method in changing the mining conditions of the lower horizons of deep open-pit mines, include the semistationary crushing and loading devices of block-modular design with output of 600, 1000 and 1350 m^3/h (up to 6-12 million tons of ore per year). The choice of the CLD type, the frequency and the step of its transfer are established on the basis of the results of optimization of technological cargo flows over a long mining period. The most effective use of the CLDs is in combination with open-type belt conveyors with an angle of inclination from 15-16° to 35-45° [10-11].

Scientific works of academician of RAS N. N. Mel'nikov and M. S. Chetverik were devoted to the problems of opening the deep horizons of the open-pit mines and locating the CLPs at concentration horizons. However, at present there is no verified and proven system of opening schemes with justification of the CLD operation term at concentration horizons before its subsequent moving to the lower horizon [12-14].

In addition to the considered technical solutions aimed at improving the efficiency of the CMM through the use of more advanced and mobile equipment, the correct location of the crushing and loading device at the concentration horizon and the scheme of opening the concentration horizons are essential.

When locating the belt conveyor hoists in the open-pit mines (trenches and semitrenches) at the open pit walls with the crushing and conveying complexes currently in operation, the crushing and loading devices are adjoined directly to the hoists. Such location of these units and their sites have required the mining and preparation works related to the spread of the open pit walls and the excavation of additional volume of overburden, or keeping the permanent pillars of rocks. Additional mining operations have led to an increase in the volume of overburden excavation in the open-pit mine, and a part of the project volume of mineral extraction has been kept in permanent pillars of rocks.

The analysis of the methods for formation of sites for the crushing and loading devices of the CFM at the iron ore open-pit mines of Ukraine has shown that when using the cone crusher KKD-1500 at the stationary CLP and locating the belt conveyor hoist in the trench the sizes of the site for the CLP are large. They vary from 210×100 m in the Poltavskiy open-pit mine to 360×260 m in the Annovskiy open-pit mine at the Severny MPS. When opening the horizons for locating such the points by inclined shafts, the sizes of sites change from 180×160 m at the open-pit mine 2-bis of the Novo-Krivorozhskiy MPS to 480×280 m

at the open-pit mine of the Yuzhny MPS. When locating the conveyor hoist in the inclined shaft and crosscuts, the size of the sites varies from 100×70 m at the Inguletskiy open-pit mine to 200×140 m at the Pervomayskiy open-pit mine of the Severny MPS. Table 1 shows the volumes of overburden excavation during the mining operations for the CLD site with the size of 200×100 m depending on the depth of its laying at the open pit wall.

Table 1 – Overburden excavation volumes for the crushing and loading device site

Depth of laying of the CLD site, m	Volume of overburden excavation for the CLD site, mln. m^3	
	With preliminary spread of the final open pit wall	At permanent pillar of rocks in open-pit mine outline
100	3.4	2.0
200	9.6	4.0
300	18.6	6.0
400	30.4	8.0
500	40.5	10.0

To open the horizons of the CLD location at the iron-ore open-pit mines of Ukraine, a scheme was widely used with the installation of a conveyor hoist in inclined shaft and crosscuts located beyond the final outline of the open-pit mine. Crosscuts open up the horizons of the location of the CLD. The conveyors move rock mass by the crosscuts from the crushing and loading devices located at the temporary pillars of rocks (temporary nonworking sites of working open pit wall), with reloading to the stationary conveyor in the inclined shaft. With the rate of progress in depth, the inclined shaft and the conveyor hoist in it are lengthened and new crosscut is extended with the installation of the conveyor in it to new concentration horizon and new CLP is built at the temporary pillar of rocks. The old CLP is dismantled and the pillar is developed under it. Such system of opening the concentration horizons meets the requirements of blast works in the open-pit mine. Significant disadvantages of this opening system are the high cost of underground mines and the long construction time of the CFM facilities. This does not allow to fully realize the advantages of the CFM and significantly reduces its competitiveness. The cost of opening excavations for installation of the belt conveyor hoists in them is several times less than the cost of construction of underground excavations for installation of hoists. But the open location of the hoists will be effective only when there is no need to excavate large additional volumes of overburden from the spread of the open pit wall in order to form the base of the conveyor excavation at the final open pit wall. When using the known methods of construction of the mine gallery with the hoist the base of the conveyor excavation locates also a strip with sites for the installation of the construction crane and a road for the movement of the tractor trolley, which delivers the construction components of the gallery and the hoist equipment to the site of installation, and to move the crane from site to site. At the Annovskiy open-pit mine of the Severny MPS of Ukraine the width of the base of the semitrench formed at an angle of 15° for a gallery 9.4 m wide is 36 m. The gallery locates two belt conveyor hoists with a belt width of 2000 mm. In addition to the gallery with hoists, the base of the semitrench includes a strip with sites for the construction crane and a road for the tractor trolley. The formation of such a base of the semitrench down to a depth of 154 m with a site for loading between the conveyor lines has required the spread of the final open pit wall with the excavation of additional overburden with a volume of 3.5 million m^3.

Study methodology. The studies have been carried out using an integrated approach, including the analysis of scientific works to identify the problematic aspects of the applicability of cyclical-and-flow method in domestic open-pit mines. Analytical studies allowed to reveal interrelationships between the volumes of mining operations and the technological parameters of development of the open-pit fields. Rational schemes for opening the open-pit fields are justified by the method of technical and economic comparison.

For calculations the following initial data have been accepted: angle of inclination of the conveyor hoist being 16º, angle of inclination of the open pit wall in final position being 37º. The output of the crushing and conveying complex is 18 million tons per year. The costs for the conveyor track were determined for a depth of 120, 240, 360 and 480 m [15-16].

The semitrench and trench forms of excavation for the belt conveyor hoist differ from each other in that the part of the base of the semitrench in width is located on an inclined safety berm, replacing sections of the horizontal safety berms of the open-pit mine along the hoist route. The semitrench can only be formed on a straight section of the open pit wall. On the open pit wall, which includes convex and concave sections, there can be formed an excavation for a belt conveyor, which, in order to excavate the minimum volume of overburden, includes the trench and semi-trench sections.

Figure 1 shows the dependences of the volumes of the spread of the open pit wall for the trench on the width of its base for the belt conveyor hoist with a belt width of 2000 mm, being obtained by analytical methods and graphical modeling. It is shown that with increasing the width of the trench base from 15 to 40 meters the volume of mining operations with depth increases from 4 to 10 million m^3.

Figure 2 shows the dependence of the volume on the spread of the open pit wall for the trench for the belt conveyor hoist (1) and the reduced costs for the conveyor track when locating the conveyor hoist in the trench and inclined shaft and crosscuts.

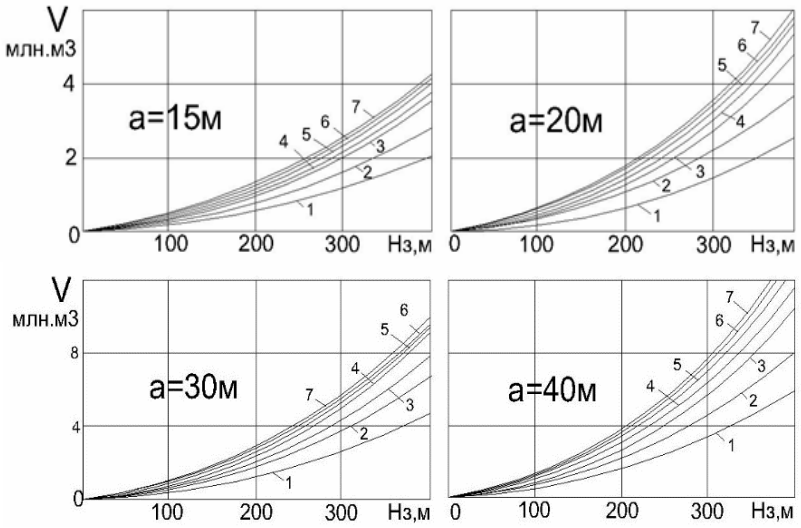

Figure 1 – Dependence of the volume of mining operations for the trench of the belt conveyor hoist (V) on the depth of its laying (Hз) with different width of the base of the trench (a) and inclination angles of the open pit wall: 1 - 20°; 2 - 25°; 3 - 30°; 4 - 35°; 5 - 40°; 6 - 45°; 7 -50°

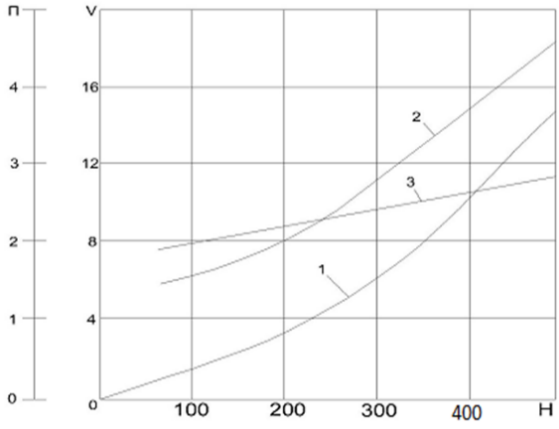

Figure 2 – Dependences of the volume on the spread of the open pit wall (V, mln. m^3) for the trench for the belt conveyor hoist (1) and the reduced costs for the conveyor track (P, mln. rubles) when locating the hoist in the trench (2) and the inclined shaft and crosscuts (3) from the depth of the trench (H, m)

It follows from an analysis of the diagrams that it is more advantageous to locate the belt conveyor hoist down to a depth of 250 m in the trench. At greater depth of trenching the costs for the conveyor hoisting essentially increase in comparison with the costs at locating the hoists in underground excavations. The main reason for the increase in costs is the increase with the depth of the additional

volume of the overburden excavation from the spread of the open pit wall for the trench. At lower angle of inclination of the open pit wall in the final position, the volume of the spread for the trench at the same depth of its laying will be smaller, and the rational area of use of the belt hoist with its location in the trench by the depth of the open-pit mine increases. Hence it is possible to draw a conclusion that the area of application of the trenches (semitrenches), for locating the belt conveyor hoists and construction and transport communications in them and in the open-pit mines developing steep deposits is opening of the first concentration horizons by depth of the open-pit mines. With this method of construction of the conveyor hoists in the galleries at the final open pit walls, opening the next in depth concentration horizons by the inclined shafts put down behind the final outlines of the open-pit mines and the crosscuts from the shaft for the crushers of the crushing and loading points in the open-pit mine will be economically more profitable. However, with this location of the conveyor hoist the costs of the crushing and conveying complex will be very high.

In order to reduce the volume of the mining operations for the trench of the internal belt conveyor hoist, part of the trench base by its width can be located at the inclined safety berm, replacing the horizontal safety berm sections along the hoist route. In this case, the opening excavation takes the form of the semitrench. The wall excavation width for the semitrench compared to the trench is reduced by the width of the safety berm of the open-pit mine. Table 2 shows the volumes of overburden excavation during the mining and capital works for the trench and semitrench of the belt conveyor hoist at the final open pit wall. Accepted: the angle of inclination of the open pit wall is 35º, the width of the base of the mine is 30 m and the angle of inclination is 16º.

Table 2 – Volumes of mining and capital works for opening excavations of belt conveyor hoist

Depth of pit, m	Overburden excavation volume, mln. m^3	
	for trench	for semitrench
100	0.64	0.40
200	2.13	1.41
300	4.80	3.03
400	8.11	5.27
500	12.53	8.12

Results and discussions. The established analytical dependencies for determining the volume of mining operations for the trench of the conveyor hoist have allowed to establish that when laying the trench with the base width of 30 m down to a depth of 240-400 m, these volumes will be from 2 to 10 mln. m^3 with a change of inclination angle of the open pit wall from 20º to 50º.

On the basis of graphic modeling of opening excavations it is established that on a straight line section of open pit wall the smallest volume of mining operations is provided when locating the conveyor hoist in the semitrench. Part of the base of the semitrench in its width is an inclined safety berm, replacing parts of the horizontal safety berm along the hoist route. The width of the spread of the open pit wall in comparison with the trench decreases by the width of the safety berm of the open-pit mine.

When locating the belt conveyor hoist in the opening excavation at the final open pit wall, the rational technological scheme of a crushing and conveyor complex corresponds to the technological scheme of a complex with locating the hoist in the inclined shaft and cross cuts. According to this scheme, the conveyor hoist at the final open pit wall is connected to the crushing and loading points in the temporary pillars of rocks through the transfer conveyors. Their length corresponds to the safe distance to the conveyor hoist according to the condition of blast works . In addition to the possibility of developing the temporary pillars of rocks under the crushing and loading points, another advantage of such a scheme, in comparison with locating the crushing and loading points at the final open pit walls, is the reduction in the distance of transportation by gathering vehicles. Dump trucks enter the unloading sites directly from the working area of the open-pit mine, bypassing the final open pit wall.

The rational scheme of opening when locating the belt conveyor hoist at the final open pit wall can be realized only with a single-wall mining system. Only in this case, the stationary and transfer conveyors can be located at the final open pit wall, and the crushing and transfer points can be located in the temporary pillars of the working open pit wall. Locating the crushing and loading points in the temporary pillars of rocks excludes additional overburden from mining operations for the sites of these points, as opposed to locating them in sections of the final open pit wall.

The main reason for the large volumes of overburden for the opening excavation of the belt conveyor hoist is the method of constructing a gallery with a hoist, which requires the formation of a construction and transport communication on the basis of the excavation, including the sites for the installation of the construction crane and the road for its movement and movement of the tractor trolley with cargo. The Institute of Mining of the Ural Branch of RAS has developed the methods of construction of conveyor hoists at the final open pit wall, which allows to reduce the volume of mining operations from the spread of the open pit wall. They are based on the principle of combining the conveyor and the construction and transport communications with the horizontal and inclined safety berms of the open-pit mine. When using one of these methods, the construction and transport communication is located on a temporary rock fill, and the conveyor hoist being located in the semitrench, which is an inclined safety berm of the open-pit mine. After the construction of the gallery with the hoist, the temporary rock fill is levelled simultaneously with setting the working benches of the open-pit mine to the final outline. It is established that there is a possibility to build the belt conveyor hoist without the spread of the open pit wall when locating the construction and transport communications at the inclined safety berm of the open-pit mine and the conveyor hoist in the gallery on supports above the side slopes of the semitrench. In another method, the construction and transport communication and the conveyor hoist are located at the adjacent inclined safety berms of the open-pit mine, being separated by the bench slope.

The belt conveyor hoist consists of individual conveyors, between which the transfer units being arranged. In order to build and maintain the conveyor lines, the vehicle mounts should be arranged from the main ramp in the open-pit mine to the sites of transfer units. The mounts require the preliminary mining operations with the spread of the open pit wall or keeping the permanent pillars of rocks. Additional mounts can be excluded if the routes of the hoist and the main ramp are linked to each other in such a way that the sites of transfer units between the conveyor lines are connected to the turn sites of the ramp.

The main direction for improvement of crushing and conveyor complexes in open-pit mines is the use of mobile crushing and loading points instead of stationary crushing and loading devices [17-19]. Moving the mobile crushing and loading device (MCLD) as the operations in the open-pit mine develop and its location at the deeper horizons allows to reduce the distance for transportation of rock mass by the gathering vehicles. Moving the MCLD along the stationary belt conveyor hoist is not rational, because of the need to form permanent sites at the final open pit wall to move it with the excavation of additional volume of overburden. For the effective use of the MCLD, the temporary belt hoisting conveyor can be used to be located in the excavation, which is a combination of the trench and the semitrench. The excavation is formed at the temporary pillar of rocks by the border of working and final open pit walls. The rock mass is transferred from this conveyor to the transfer conveyor located at the final open pit wall to the stationary conveyor hoist. The installation is adjacent directly to the temporary conveyor, and it will be moved along it with the rate of progress in depth, reducing the transportation distance by the gathering vehicles (figure 3).

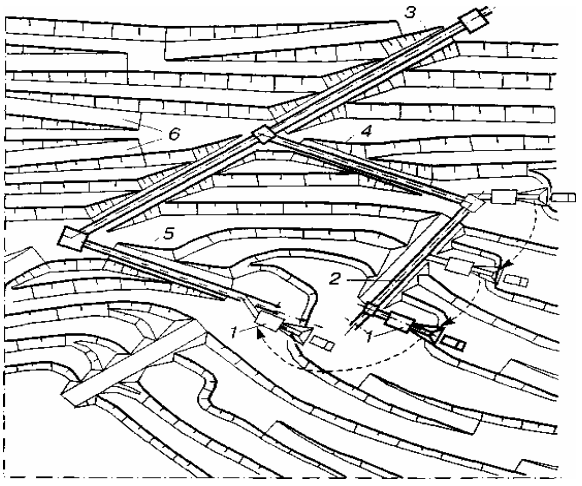

Figure 3 – Crushing and conveyor complex at open pit wall: 1 — MCLD; 2 — temporary hoisting conveyor; 3 — stationary conveyor hoist; 4, 5 — transfer conveyors; 6 — main vehicle ramp

If it is necessary to extract the rock mass from all the open-pit mine horizons, which are crossed by the hoisting conveyor along which the MCLD is moved, it is rational to use several units of lower output instead of one unit of high output. They are spread in height along the conveyor. When loading the belt hoisting conveyor at several points, the lower part of the conveyor belt will be always not fully loaded. In this case, a conveyor system can be used, which consists of several smaller conveyors with different outputs and lengths, installed one above the other and loaded by different MCLD located at different depths of the open-pit wall. Such an installation allows to reduce the metal consumption of the conveyor hoist and the volume of rock mass spilled from the idle flight of the conveyor belt.

The results of comparing the volumes of mining and capital works at the installation of belt conveyors in underground and opening excavations with the installation of a steeply inclined conveyor (SIC) allow to make a conclusion about the undeniable advantages of the latter. The systems of cyclic-flow method with use of steeply inclined belt conveyors and semistationary crushing and loading devices of block-modular design providing fast installation and dismantling of the complexes meet the most requirements of development of deep open-pit mines. Technical and economic calculations and data on foreign firms indicate high efficiency and prospects of the CFM systems with the SIC. One of the main conclusions that can be drawn from the experience of the SIC in the Muruntauskiy open-pit mine for 8 years, with an annual output of 18 million tons of ore is the operation of a unique facility installed at the open pit wall without any mining and capital works, except for the installation of the SIC supports on the concrete base [20].

When using the SIC, it is possible to create any (including complex) configuration of conveyor line routes with a minimum number of loading devices. The SICs allow to locate them at angles of the slope of the open pit walls and to combine inclined sections of the conveyor line with flat sections without loading devices. The angle of inclination of the conveyor line can be changed along the route length up to 90°. All this allows to transport the rock mass by the shortest distances, having essentially reduced the length of the conveyor lines in comparison with traditional conveyors, and to minimize the mining and capital works, having refused to lay special trenches and shaft sinking in open-pit mines [21].

Conclusions. The studies in the Institute of Mining of Ural Branch of RAS have determined the areas of preferable application of steeply inclined conveyors in the technological CFM schemes in comparison with usual belt conveyors. It is expedient to use the steeply inclined conveyors in the CFM complexes with an annual output 5-10 million tons at a height of rock mass hoisting of 100-200 m and more. In these conditions, with lower (down to 15-20 %) costs, the specific capital costs of the CFM complexes with steeply inclined conveyors are significantly (by 6-20 %) lower. When increasing the volumes of movement by the CFM complexes up to 20-30 million tons per year, it is expedient to use the steeply inclined conveyors at a height of rock mass hoisting of 200-300 m and more. In these conditions, with practically equal operating costs, the specific capital costs of the CFM complexes with steeply inclined conveyors are lower by 6-20 %.

2. Application of the scheme of opening the concentration horizons for locating the CLP, providing the maximum co-locating of the CLD sites with the temporary nonworking sites of open pit walls, and the bases of conveyor excavations, the construction sites and the mounts to them with the inclined and horizontal safety berms will reduce the volume of mining operations.

3. On the basis of graphic modeling of opening excavations it is established that on a straight line section of open pit wall the smallest volume of mining operations is provided when locating the conveyor hoist in the semitrench.

4. When choosing a scheme for opening and developing the deep horizons for open-pit mines at the CFM, it is necessary to take into account the costs of additional overburden from the spread of the open pit wall for a steep trench and the unloading sites of the CLP.

5. In the future, the development of cyclic-flow method in deep open-pit mines should be based on the use of steeply inclined conveyors installed on concrete supports, which will significantly reduce the volume of mining operations as well as reduce construction time and increase the efficiency of the CFM as a whole.

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ҮЗІЛМЕЛІ-ТОЛАССЫЗ ТЕХНОЛОГИЯ АРҚЫЛЫ КЕН ҚАЗУДА КОНВЕЙЕРЛІ КӨТЕРГІ ОРНАТУ БҰРЫШЫНЫҢ АРШЫҚТАҒЫ ТАУ-КЕН ДАЯРЛАУ ЖҰМЫС КӨЛЕМІНЕ ӘСЕРІ

Аннотация. Зерттеу мақсаты – кен өндірудің циклдік-ағынды технологиясы кезінде аршықтағы тау-кен дайындау жұмыстарының көлеміне конвейерлік көтергішті орнату параметрлерінің әсерін анықтау. Ашық қазу жұмысы тереңдету жағдайында ұдайы үзілмелі-толассыз технология пайдалануы, өндірістің жоғары деңгейде шоғырлануына, тау-кен тасымалдау жабдықтарының пайдалану көрсеткіштерін жоғарылатуға мүмкіндік береді, технологиялық үдерістердің жоғары автоматтандыру дәрежесін қамтамасыз ету арқылы және жалпы аршық жұмысының тиімділігін жоғарылатады.

Жүзеге асырылған зерттеу нәтижелері бойынша ТМД елдерінің үзілмелі-толассыз технология пайдаланатын аршықтарда үлесті энергия қолдану мөлшері үзілмелі технология пайдаланатын аршықтардан 14-16%-ға төмен көрсеткішті байқатты. Үзілмелі-толассыз технологияның негізгі технологиялық үдерістеріне келетін энергия қолдану мөлшері келісідей: кен массасын тасымалдауға 75-80%, ұсатуға 8-10%, экскава-циялауға 16-18%.

Зерттеу нәтижесінде құрастырылған график бойынша аршық тереңдігі 250 м-ден терең болмаса конвейерлі көтергіні траншеяда орналастыру тиімділігі анықталды. Аршық тереңдеген сайын ордың ұзындығы мен тау-кен даярлау жұмыстарының көлемі де артады. Шығынның ұлғаюының негізгі себебі – траншеяға карьер бортын таратудан аршылған жыныстарды қазудың қосымша көлемінің тереңдігі арқылы өсу. Аршықтың тереңдігіне сәйкес карьер бортының еңкіш бұрышы азайтылған шамада болған жағдайда және сол тереңдікке сәйкес орды үңгілеу үшін қажетті көлем де азаяды, ал аршықтың тереңдеуіне сәйкес конвейерлі көтергіні қолдану мүмкіндігі жоғарылайды.

Ішкі салынған таспалы конвейерлік көтергіштің траншея астындағы тау-кен-дайындық жұмыстарының көлемін азайту мақсатында траншея негізінің бір бөлігі оның ені бойынша көтергіштің трассасымен көлденең сақтандырғыш бермалардың учаскелерін ауыстыратын көлбеу сақтандырғыш бермада орналасуы мүмкін. Бұл жағдайда ашу кен қазба пішіні жартылай траншеяға ұқсас болады. Аршық жағдайын жартылай траншеяның орналасу жағдайын қамтамасыз ететін шамаға жылжыту траншея орналасуымен салыстырғанда ол аршықтың сақтандырғыш алаңының еніне тең мөлшерге азаяды.

Тік еңкішті конвейерлерді қолдану қайта тиеу қондырғылар санын азайтуға және кез келген пішіндеме мен және орнату бұрыш бойынша конвейерлерді пайдалану мүмкіндігін береді. Тік еңкішті конвейерлерді аршық жағдайының еңкіш бұрышы бойынша орнатуға мүмкіндік береді, сонымен қатар конвейерлі трассаларының жайпақ және көлбеу бөліктерін қайта тиеу қондырғыларсыз тіркестіреуге жағдай тудырады.

Конвейерлі көтергінің еңкею бұрышын трассаның ұзындығы бойынша 90°-қа дейін өзгертуге болады. Мұның бәрі конвейерлер желісінің ұзындығын әдеттегі конвейерлермен салыстырғанда ең қысқа қашықтық бойынша кен массасын тасымалдауға мүмкіндік береді және траншея мен оқпанды үңгілемей-ақ тау-кен күрделі жұмыс көлемі күрт азаяды.

Ұсату-қайта тиеу қондырғыларының жинақтаушы көкжиекте жұмыс ұзақтығына байланысты үзілмелі-толассыз технологияның түрлі технология тәсімдерін қолдануды негіздеу және аршықтың тиімді ашу тәсімін дәлелдеу.

Әдістеме. Қойылған мақсатқа жету үшін жұмыста ғылыми еңбектерді талдауды қоса алғанда аршықтарда үзілмелі-толассыз технология қолданудың өзекті мәселелерін айқындау, аналитикалық зерттеулер тау-кен даярлау жұмысының көлемі мен аршық қазудың технологиялық параметрлерінің өзара байланысын анықтау, техника-экономикалық салыстыру әдістемесі – аршық алаңдарын тиімді ашу тәсілін дәлелдеу барысында кешенді әдіс қолданылды.

Нәтижелер. Үзілмелі-толассыз технология тәсімдерінде тік еңкішті конвейерлерді қолданудың ғылыми бағыттары әдеттегі таспалы конвейерлермен салыстырылып негізделген, оларды кен массасының көтеру биіктігі 100-200 м немесе одан жоғары болғанда және аршықтың жылдық өнімділігі 5-10 млн.т. болған жағдайда қолданған жөн.

Ғылыми жаналығы. Тік еңкішті конвейерлі үзілмелі-толассыз технология тәсімдерін әдеттегі таспалы конвейерлермен салыстырғанда олардың артықшылығын пайдалану аймағы анықталды. Жылдық өнімділігі 5-10 млн.т. үзілмелі-толассыз технологиялық кешенде тік еңкішті конвейерлерді кен массасының көтеру биіктігі 100-200 м-ге тең не одан жоғары болғанда қолданған тиімді. Үзілмелі-толассыз технологиямен тасымалданатын көлем жылына 20-30 млн.т.-дан жоғары болған жағдайда, ал көтеру биіктігі 200-300 м немесе

одан жоғары болғанда тік еңкішті конвейерлерді қолдану тиімділігі жоғарылайды. Бұл жағдайда пайдалану шығын көлемі тең болғанда тік еңкішті конвейерлерлі үзілмелі-толассыз технология кешендерінің үлесті күрделі шығыны 6-20%-ға төмен болады.

Тәжірибелік маңыздылығы. Жылдық өнімділігі жоғары аршықтарда техникалық-экономикалық есептеу нәтижесінде құрамында жылжымалы ұсату-қайта тиеу құрылғылармен жабдықталған тік еңкішті конвейерлерлі технологиялық тәсімдерінің жоғары қолдану тиімділігі дәлелденген. Нәтижелер ашық тәсілмен кен қазатын тау-кен кәсіпорындарын жобалайтын мекемелерге пайдалы болады.

Түйін сөздер: үзілмелі-толассыз технология, терең аршық мобильді ұсақтау және қайта-тиеу қондырғылары, тік еңкішті конвейер, жинақтаушы көкжиек, тау-кен даярлау жұмысы.

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ВЛИЯНИЕ УГЛА УСТАНОВКИ КОНВЕЙЕРНОГО ПОДЪЁМНИКА НА ОБЪЁМЫ ГОРНО-ПОДГОТОВИТЕЛЬНЫХ РАБОТ НА КАРЬЕРАХ ПРИ ЦИКЛИЧНО-ПОТОЧНОЙ ТЕХНОЛОГИИ ДОБЫЧИ РУД

Аннотация. Целью исследования является устанавление влияния параметров установки конвейерного подъёмника на объёмы горно-подготовительных работ в карьере при циклично-поточной технологии добычи руд. Применение циклично-поточной технологии в условиях постоянного углубления открытых разработок позволяет достичь высокой концентрации производства, улучшить показатели использования горно-транспортного оборудования, обеспечить высокую степень автоматизации технологических процессов и повысить эффективность работы карьера в целом.

Выполненные исследования показали, что удельное энергопотребление применяемой на карьерах СНГ циклично-поточной технологии по сравнению с цикличной технологией ниже на 14-16%. Распределение энергопотребления по основным технологическим процессам ЦПТ в среднем составляет: транспортирование горной массы 75-80 %, дробление 8-10 %, экскавация 16-18 %.

Из анализа графиков исследований следует, что до глубины 250 м ленточный конвейерный подъемник более выгодно размещать в траншее. При большей глубине заложения траншеи затраты на конвейерный подъём резко возрастают. Основной причиной увеличения затрат является возрастание с глубиной дополнительного объема выемки вскрышных пород от разноса борта карьера под траншею. При меньшем угле наклона борта карьера в конечном положении объем разноса под траншею при одной и той же глубине ее заложения будет меньше и рациональная область использования ленточного подъемника с его размещением в траншее по глубине карьера увеличивается.

С целью уменьшения объёма горно-подготовительных работ под траншею ленточного конвейерного подъёмника внутреннего заложения часть основания траншеи по его ширине может быть расположена на наклонной предохранительной берме, заменяющей по трассе подъёмника участки горизонтальных предохранительных берм. В этом случае вскрывающая выработка приобретает форму полутраншеи. Ширина разноса борта под полутраншею в сравнении с траншеей уменьшается на ширину предохранительной бермы карьера.

При применении КНК открывается возможность создания любой, в том числе сложной конфигурации трасс конвейерных линий с минимальным количеством перегрузочных устройств. КНК позволяют располагать их под углами откосов бортов карьеров и сочетать наклонные участки конвейерной трассы с пологими участками без перегрузочных устройств. Угол наклона конвейерной линии может изменяться по длине трассы вплоть до 90°. Все это позволяет транспортировать горную массу по кратчайшим расстояниям, существенно сократив длину конвейерных линий по сравнению с традиционными конвейерами, и свести до минимума горно-капитальные работы, отказавшись от прокладки на карьерах специальных траншей и проходки стволов.

Обоснование применения различных технологических схем циклично-поточной технологии в зависимости от продолжительности работы на концентрационном горизонте дробильно-перегрузочных пунктов, а также рациональных схем вскрытия карьера.

Методика. Для достижения поставленной цели в работе использован комплексный подход, включающий анализ научных трудов – для выявления проблемных аспектов применимости циклично-поточной технологии на карьерах, аналитические исследования – для выявления взаимосвязи объемов горно-подготовительных работ и технологических параметров разработки карьеров, метод технико-экономического сравнения – для обоснования рациональных схем вскрытия карьерных полей.

Результаты. Научно обоснованы области целесообразного применения в технологических схемах ЦПТ крутонаклонных конвейеров в сравнении с обычными ленточными конвейерами, которые целесообразно использовать при высоте подъема горной массы 100-200 м и более и годовой производительности 5-10 млн. т.

Научная новизна. Установлены области предпочтительного применения в технологических схемах ЦПТ крутонаклонных конвейеров в сравнении с обычными ленточными конвейерами. В комплексах ЦПТ с годовой производительностью 5-10 млн. т. крутонаклонные конвейеры целесообразно использовать при высоте подъема горной массы 100-200 м и более. С увеличением объемов перемещения комплексами ЦПТ до 20-30 млн. т в год крутонаклонные конвейеры целесообразно применять при подъеме горной массы на высоту 200-300 м и более. В этих условиях при практически равных эксплуатационных расходах, удельные капитальные затраты на комплексы ЦПТ с крутонаклонными конвейерами ниже на 6-20 %.

Практическая значимость. В результате проведенных технико-экономических расчётов подтверждена высокая эффективность применения технологических схем с крутонаклонным конвейерным подъёмом и полустационарными дробильно-перегрузочными устройствами на карьерах с большой годовой производительностью. Результаты являются полезными для организаций, проектирующие горные предприятия с открытым способом разработки.

Ключевые слова: циклично-поточная технология, глубокие карьеры, мобильные дробильно-перегрузочные установки, концентрационный горизонт, горно-подготовительные работы.

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SORPTION CHARACTERISTICS OF ZEOLITE AND BENTONITE NATURAL ADSORBENTS MODIFIED COMPLEX

Abstract. The main objective of our study is to obtain a complex compound from natural adsorbents to purify wastewater with simultaneous sorption of chemical and microbiological substances contained therein, which contribute to disinfection and softening of water, increasing the degree of treated water saturation with calcium, magnesium salts and trace elements, while not requiring the use of sophisticated equipment. The technical result is to create a complex of adsorbents with the sorbing ability of chemical and microbiological pollution, disinfecting and softening water, enriching it with calcium ions, magnesium, sodium, potassium, as well as trace elements.

Key words: water, purification, sorption, natural adsorbents, aluminosilicates, heavy metals.

Introduction. Currently, water purification is becoming one of the most common technological processes in the world, including Kazakhstan. This determines the particular relevance of the issue of reducing the cost of cleaning drinking water, and sewage [1]. In this regard, a very promising seems the application of natural sorbents, deposits of which are available in Kazakhstan. In the literature appears more and more with about the effectiveness of natural sorbents for disperse impurities, heavy metals, oil and oil products, surface active agents, dyes, radioactive contaminants and others [2].

The study was intended to determine the methods of a promising approach, the creation of new types of modified complex sorbents and an experimental evaluation of the effective use of a modified complex of natural mineral sorbents, based on zeolite and bentonite, for the purification and conditioning of drinking water and the purification of wastewater.

Technical characteristics of the studied adsorbents:

Bentonite (Mukrynskoye field of Almaty region) - natural clay mineral, hydroaluminosilicate, has the property of swelling during hydration (14-16 times). In a confined space for free swelling in the presence of water, a dense gel is formed that prevents further penetration of moisture. This property, as well as non-toxicity and chemical resistance, makes it indispensable in industrial production, construction and many other fields of application.

Natural bedding bentonites usually have a pH of 6-9.5 (for 5% aqueous suspension after settling for 1 hour) and contain less than 2% sodium carbonate; the total content of interchangeable sodium and calcium does not exceed 80 me/100. There are two types of bentonites:

- Calcium, with a low degree of swelling;
- sodium, with a high degree of swelling (swelling rate less than 7 ml/g or more than 12 ml/g).

Chemical formula: AI_2 $[Si_4O_{10}]$ $(OH)_2$ * nH_2O.

Chemical composition: SiO_2 - 58.25%; AI_2O_3 - 14.27%; Fe_2O_3 - 4.37%; FeO - 0.5%; Ti_2O - 0.36%; CaO - 2.07%; MgO - 3.67%; P_2O_5 - 0.18%; S - 0.14%; K_2O - 1.2%; Na_2O - 2.25%; PPP - 12.19%.

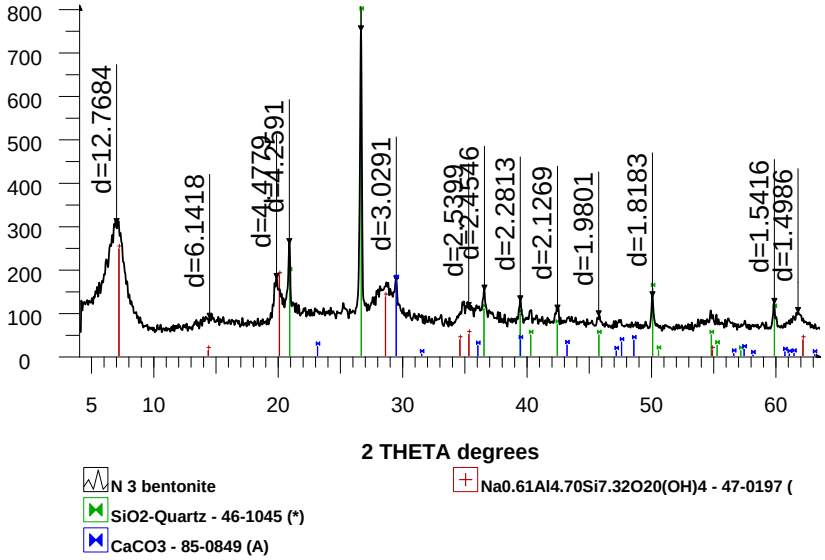


Figure 1 – Radiograph of a sample of bentonite-montmorillonite (Mukrynskoye field of Almaty region)

Zeolites (Maytobinskoye deposit of Almaty region) - a large group of minerals with similar composition and properties; aqueous calcium and sodium aluminosilicates of the subclass of frame silicates, with glass or pearlescent gloss, known for their ability to give and reabsorb water depending on temperature and humidity. The most common representatives of the group of zeolites - natrolit, shabazit, geylandit, stilbite (desmin), mordenite, thomsonite, lomontite.

The crystal structure of natural zeolites is formed by the tetrahedral groups $SiO_{2/4}$ and $AlO_{2/4}$, united by common vertices in a three-dimensional framework, permeated with cavities and channels (windows) of 2-15 angstroms[3]. The open frame-cavity structure of zeolites [AlSi] O_4^- has a negative charge, compensated by counterions (metal cations, ammonium, alkyl ammonium and other ions, introduced by the mechanism of ion exchange) and easily dehydrating water molecules.

Chemical formula: Zeolite-clinoptilolite, described by the idealized formula $(KNa,)_4\ CaAl_6Si_{30}O_{72} * 24H_2O$ - is a crystalline aqueous aluminosilicate.

Chemical composition: AI_2O_3 - 12.9-13.2%; K_2O - 4.0-4.8%; CaO - 1.8-2.4%; V - 0.001%; Cu - 0.001%; Rb - 0.001%; SiO_2 - 66.2-78.3%; Na_2O - 1.8-2.2%; Fe_2O_3 - 0.8-1.2%; Mn - 0.001%; Be - 0.001%; As - 0.03%.

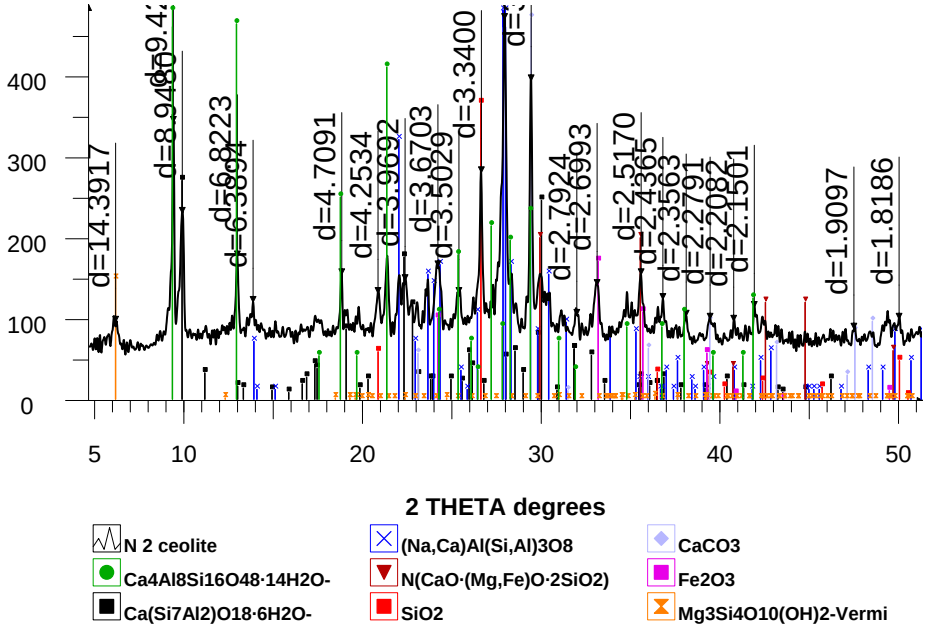


Figure 2 – Zeolite radiograph (mine I Maytobe Almaty region)

Materials and research methods. A sorbent based on zeolites modified by ion exchange of silver ions is known for absorption of radioiodine and/or radiocaesium. After ion-exchange modification, the sorbent is additionally treated with acetylene in a gaseous or liquid medium so that its carbon content in carbon is 0.4 - 2,0 wt. The sorbent is designed specifically for purifying water from strong contamination with radionucleotides, it is effective to purify drinking water, but it does not enrich water with calcium, magnesium salts, as well as with trace amounts of elements from side groups of the Periodic System[4,5].

The technical result is achieved by the fact that the proposed sorbent of the following composition, chemical formula: Zeolite-clinoptilolite, chemical formula: $(KNa)_4\ CaAl_6Si_{30}O_{72} * 24H_2O$ is a crystalline aqueous aluminosilicate, chemical composition: AI_2O_3 - 12.9-13.2%; K_2O - 4.0-4.8%; CaO - 1.8-2.4%; V - 0.001%; Cu - 0.001%; Rb - 0.001%; SiO_2 - 66.2-78.3%; Na_2O - 1.8-2.2%; Fe_2O_3 - 0.8-1.2%; Mn - 0.001%; Be - 0.001%; As - 0.03% and Bentonite- hydroaluminosilicate, chemical formula: $AI_2\ [Si_4O_{10}\ (OH)_2 * nH_2\ O$, the chemical composition: SiO_2 - 58.25%; AI_2O_3 - 14.27%; Fe_2O_3 - 4.37%; FeO - 0.5%; Ti_2O - 0.36%; CaO - 2.07%; MgO - 3.67%; P_2O_5 - 0.18%; S - 0.14%; K_2O - 1.2%; Na_2O - 2.25%; PPP - 12.19% .

To test the effectiveness of the complex, natural adsorbents were taken in different percentages, agglomerate was obtained: 1) zeolite (60%) and bentonite (40%), 2) zeolite (50%) and bentonite (50%), 3) zeolite (40%) and bentonite (60%). Subsequently, capsules 10 mm wide, 15mm long were made from the mixture obtained, acid activation was performed using 15 % H_2SO_4 taken in an amount of 50 % of the air-dry sample, the duration of treatment was 4 hours. In a muffle furnace at a temperature of 400 degrees, heat treatment was carried out to increase the total porosity.

Determination of the sorbent porosity.

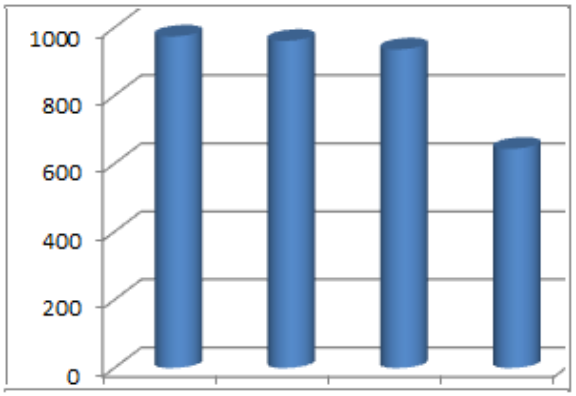
One of the most important characteristics of the adsorbent is the determination of its porosity, which in general depends on its deposit. It is characterized by the total volume of all voids (pores) in the rock [6].

Determination of the porosity of the sorbent was carried out according to the following method. The samples were boiled in a glass with distilled water for 1.5–2.0 hours and then weighed [7].

Sample density, water absorption and porosity were calculated according to table 1, where: m_0 - the mass of the samples with suspension in water, g; m_1 - weight of wet samples, g; m_2 - weight of dry samples g; m_3 - suspension weight year.

Table 1 – Incoming data for calculation (modified complex of bentonite and zeolite)

No experience	Material name	m_0, g	m_1, g	m_2, g	m_3, g
1	Zeolite complex (60%) and bentonite (40%)	10,0018	31.4312	19.0645	0.5923
2	Complex zeolite (50%) and bentonite (50%)	9.6453	29.2576	16.7312	0.4627
3	Zeolite complex (40%) and bentonite (60%)	9,9459	31.2057	18,1124	0.4134



Heavy metals, mg/dm^3	974	961	936	644
	Waste water	Zeolite (60%) Bentonite (40%)	Zeolite (50%) Bentonite (50%)	Zeolite (40%) Bentonite (60%)

The results of the laboratory research on change of heavy metals in wastewater by modified complex of natural adsorbents consisting of bentonite, zeolite in different percentages.

The limits of the relative total error of result, which is admitted, is equal to 2.0; at confidence probability is 0,95. The results of the research are given in table 2.

Table 2 – Determination of porosity of bentonite and zeolite complex

Sample number	The name of material	Sample weight, g	Water adsorption, %	Density, %	Porosity, %
1	Zeolite (60%) and bentonite (40%) complex	21,2145	76.0690	43.8490	73.45
2	Zeolite (50%) and bentonite (50%) complex	20,7124	77.7860	44,7296	73.91
3	Zeolite (40%) and bentonite (60%) complex	19,9437	82,3320	45.6125	80,51

Determination of adsorption capacity according to methyl orange and iodine.

To determine the adsorption according to methyl orange we have chosen the method, introduced at State Standard 4453–74.

For this purpose, the sample of coal was placed in a conical flask with capacity of 100 cm^3, added 25 cm^3 of methyl orange solution. After that, optical density was determined using a photoelectric colorimeter.

As a control solution we used distilled water. From the received optical densities on the base of calibrating graph we determined residual concentration of the pigment.

Adsorption activity was calculated by the formula 1 [5,8]:

$$X = \frac{(C_1 - C_2 K) \cdot 0.025}{m} \quad (1)$$

where C_1 - concentration of the original dye solution, mg/dm^3; C_2 - concentration of the dye solution after interacting with tripoli powder, mg/dm^3; K - dilution factor; m - weight of the coal sample, g; 0.025 - the volume of methyl orange solution, dm^3 .

The results of the research of the adsorption capacity are given in table 3.

Table 3 – The results of the experiment to determine the adsorption capacity according to methyl orange

Sample	Adsorption capacity according to MO			
	Weight of the sample, g	Concentration, mg / dm^3		Adsorption capacity according to MO, mmol / g
		original	residual	
1. Zeolite (60%) and bentonite (40%) complex	0.1	1500	0,600	0.6880
2. Zeolite (50%) and bentonite (50%) complex	0.1	1500	0,800	0.5351
3. Zeolite (40%) and bentonite (60%) complex	0.1	1500	0.750	0.6291

Determination of the adsorption capacity of tripoli by iodine was realized in accordance with the State Standard 4453–74. Iodine number is an approximate measure of the ability of a substance to adsorb small molecules, which depends on the size of the surface area. The processing of the result was carried out according to formula 2 [4,8]:

$$X = \frac{(V_1 - V_2) \cdot 0.0127 \cdot 100 \cdot 1000}{10 \cdot m} \quad (2)$$

where V_1 - the volume of sodium thiosulfate solution (0.1 n), which was used for titration of 10 cm^3 of iodine solution in potassium iodide, cm^3; V_2 - the volume of sodium thiosulfate solution (0.1 n), which was used for titration of 10 cm^3 of iodine solution in potassium iodide, after processing it with bentonite and zeolite complex, cm^3; 0,0127 - the mass of iodine, which corresponds to 1 cm^3 of sodium thiosulfate

solution, g; 100 - the volume of iodine solution in potassium iodide, which is needed for bentonite and zeolite complex, cm^3 ; m - the mass of the sample of bentonite and zeolite complex, 1.00g.

The results of calculation of the iodine number of the bentonite and zeolite complex are given in table 4.

Table 4 – The results of the experiment to determine the iodine number of the bentonite and zeolite complex

Sample	Iodine adsorption capacity			
	Weight of the sample, g	The amount of thiosulfate for titration, cm^3		Iodine adsorption capacity, mmol/g
		Iodine	Bentonite and zeolite complex	
1. Zeolite (60%) and bentonite (40%) complex	0.5	16,10	12.60	10.16
2. Zeolite (50%) and bentonite (50%) complex	0.5	16,10	12.40	12.70
3. Zeolite (40%) and bentonite (60%) complex	0.5	16,10	12.52	11.80

Since bacterial spores are much more resistant to disinfecting agents than E.coli cells, the absence of the latter in water does not guarantee absence of the spores. The indicator, showing presence of bacterial spores in water was anaerobic spore-forming organism C. perfringens and aerobic spore-forming bacterium B. subtilis. These bacteria differ in location of spores in a cell. Since their spores are able to exist in water for much longer than coliform bacteria, they are resistant to disinfection and therefore serve as indicators of long-term contamination and defects in filtering techniques at waterworks.

Tables 5-7 show the results of studying the effectiveness of NMS (natural mineral sorbents) regarding removal of E. coli cells from water, as well as B. subtilis and C.perfringens spores.

The results shown in tables 5-7 indicate that NMS effectively remove microbial contamination from water at the concentration of bacterial suspension (1.2÷3.5) $x10^3$ cells/ml.

At increasing the concentration of the bacterial suspension significantly [up to (3.1÷3.2) $x10^4$ cells/ml] in the filtrate inoculations you can find bacteria colonies. At the same time, their number decreases in comparison with the initial by (4÷5)$x10^3$ times - for the filter. The effectiveness of reducing microbial contamination with zeolite is significantly lower than in control, and is (2÷2.8) $x10^3$ times [9].

Table 5 – The number of microorganisms E.coli (X±x) in water before and after filtration through filters (n = 5)

The number of microorganisms, cells/ml			
Initial	Filter type		
	Coal filter	Zeolite filter	Filter- zeolite, bentonite complex.
(1.2 ± 0.1) $x10^3$	0	0	0
(3,5 ± 0,2)) $x10^3$	0	0	0
(3.2 ± 0.2) $x10^3$	(1.5 ± 0.3) $x10^3$	(0.7 ± 0.05) $x10^3$	(0.6 ± 0.03) $x10^3$

Table 6 – The number of microorganisms B. subtilis (X±x) in water before and after filtration through filters (n = 5)

The number of microorganisms, cells / ml		
Initial	Filter type	
	Carbon filter	Filter - zeolite, bentonite complex
(1.5 ± 0.1) $x10^3$	(1.5 ± 0.1) * $x10^1$	(0.7 ± 0.02) $x10^1$
(3.4 ± 0.2) x $x10^3$	(1,8 ± 0.1) * $x10^2$	(1,1 ± 0.02) $x10^2$
(3.2 ± 0.1) $x10^4$	(4,5 ± 0.1) * $x10^2$	(2,3 ± 0.02) $x10^2$

It should be noted that in practice in distribution networks, as well as at water withdrawal from a natural water source, we face less severe microbiological pollution. Installations designed for water disinfection in the field and built on the principle of ultraviolet bactericide irradiation are designed for coli index of not more than 5×10^3 cells/l [10].

Determination of toxicity of water samples containing chemical toxicants (phenol, copper sulphate) before and after passing through NMS filters was performed using Daphnia magna and microalgae Chlorella vulgaris.

The data in table 7 show that water before passing through NMS filters had a toxic effect on the Daphnia magna (the percentage of daphnia death in both cases exceeded 50%). After passing water through NMS filters there was no toxic effect on daphnia in all cases, and the percentage of their deaths hardly differed from the control one, except for the variant with bentonite at concentration of 1.5 mg/l, when the percentage death was 11%.

Table 7 – The effect of NMS on the death of Daphnia magna (% to the control one) in water samples containing toxicants (n = 5)

Toxicant content mg/l	Original water	Zeolite	Bentonite
10.0 $CuSO_4$	85.5 ± 5.0	4.0 ± 0.2	3.0 ± 0.2
5.0	59.0 ± 3.0	3.0 ± 0.1	3.0 ± 0.2
1.5	73.0 ± 2.5	11.0 ± 0.5	4.0 ± 0.3
0.05	57.0 ± 1.5	3.0 ± 0.2	3.0 ± 0.1

Notes: 1. In the control (cultivation water), no death was noted;

2. The duration of cultivation Daphnia magna in water samples is 96 hours;

3. After passing through the filters, the water pH in all variants of the experiment was in the limits of 7.0 ÷ 7.2. The water was aerated for 1 hour.

Some indicators of the quality of tap water (Taldykorgan city) before and after filtering through filter complex, containing the complex NMS studied in the work (bentonite and zeolite).

Conclusions. The received results testify that after passing tap water through the filter zeolite and bentonite complex the composition of water had significant changes. Its organoleptic characteristics significantly improved, in particular, they began to comply with the Sanitary Regulations and Standards in smell and taste of water.

The iron content in water decreased by 9.5 times and began to comply with the Sanitary Regulations and Standards requirements.

In the filtered water pH, the content of calcium, magnesium, silicon, hydrocarbonate ions, as well as the total hardness and dry residue increased. This fact should be assessed positively, since it is known that tap water is distinguished by low content of these essential elements, increased softness and total low salt content.

Based on the analysis of technical and economic indicators for this experimental study we selected material of the domestic resource base, mineral sorbents of different nature: zeolite and bentonite. Experimentally we selected conditions for NMS activation. Most significantly (by 35-57%) PMS activity increased after acid processing with a mixture of 10% sulfuric acid (1: 1).

The results of the conducted sanitary-microbiological studies have shown that NMS have pronounced sorption properties against bacteria E.coli strain K12, as well as the spores B.subtilis and C.perfringes. All studied NMS and their combination in the filter of zeolite and bentonite complex effectively remove microbial contamination from water at the initial concentration $(1.2 \div 3.5) \times 10^3$ cells/ml.

Since the work has not been completed yet, it is planned to conduct further studies and to offer improvements of adsorption characteristics of the complex of natural adsorbents for water purification from harmful impurities.

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ЦЕОЛИТ ЖӘНЕ БЕНТОНИТ ТАБИҒИ АДСОРБЕНТТЕРІНЕН ЖАСАЛҒАН МОДИФИКАЦИЯЛАНҒАН КЕШЕННІҢ СОРБЦИЯЛЫҚ СИПАТТАМАЛАРЫ

Аннотация. Мақалада авторлар ауызсу және ластанған сарқынды ақаба суды жоғары дәрежеде тазартуға қол жеткізуге мүмкіндік беретін бентонит, цеолит және диатомит негізіндегі құрамдастырылған табиғи адсорбенттер кешенін алудың тиімді технологиясын жасауға тырысты, өйткені зиянды қосылыстармен ластау үрдісі жоғары болатын сулы ортада жоғары көптеген ластаушы заттардың соңғы нәтижесі болып саналады. Осыған байланысты табиғи судың ластануы, оны су құбыры станцияларында қанағаттанғысыз тазартумен, таратушы желілерде екінші рет ластану арқылы анықталатын ауызсу сапасының проблемасы бар. Осыған орай су құбырлары бекеттерінде сапасыз тазартудан табиғи сулардың тарату желілерінде екінші рет ластануы салдарынан ауызсу сапасының мәселелері туындайды.

Зерттеудің мақсаты – суды тазалау және кондициялау үшін табиғи минералды сорбенттерді пайдалану тиімділігін іс жүзінде тәжірибелік бағалау.

Зерттеудің негізгі міндеті күрделі жабдықты пайдалануды талап етпейтін табиғи адсорбенттерден суды тазарту үшін кешенді қосылыстар алу, сонымен қатар сорбциямен бірге құрамында химиялық және микробиологиялық ластану жағдайы кездеседі, суды залалсыздандыруға және жұмсартуға ықпал ететін, өңделген судың кальций, магний тұздарымен және микроэлементтермен қанығу деңгейін арттыру болып саналады.

Жұмыста цеолит, бентонит сазы және Жетісу (Жоңғар) Алатауының аласа таулы бөліктерінде кездесетін цеолит, бентонит диатомит негізінде алынған табиғи минералды сорбенттерді ауызсуды тазарту және кондициалау және сарқынды ақаба суларды сульфаттардан, гидрокарбонаттардан, нитраттардан, ауыр металл иондарынан және басқа да зиянды қоспалардан тазартудың тиімділігін зерттеу нәтижелері ұсынылған.

Табиғи сорбенттердің физикалық-химиялық, минералогиялық құрамы және алынған құрама сорбенттердің адсорбциясының тиімділігі зерттелді, сорбенттің құрамына және алдын ала температуралық модификация әсеріне байланысты сорбциялық белсенділік артты.

INCA Energy-350 «(Oxford Instruments) микроталдау жүйесі бар EVO 50 XVP» (Carl Zeiss) сканерлейтін электронды микарскоппен рентгендік фазалық талдаулар негізінде Алматы облысы аумағындағы Жетісу Алатауының аласа таулы бөлігінде кездесетін Майтөбе кен орнының цеолит және Мукрин кен орындарынан өндірілетін бентониттің физикалық-химиялық құрамы зерделенген.

Электронды микроскоппен 2μm дейін ұлғайтып ренгрскопиялық талдау әдісімен бентонит пен цеолиттің ауызсу мен сарқынды ақаба суды тазарту және сапасын арттыру мақсатында қолдану барысында құрамындағы ауыр металдарды сіңіру көлемін арттыратын іргелі құрылымындағы бос қуыстар анықталды.

Эксперименттік зерттеу нәтижелері ауызсу мен ластанған сарқынды ақаба суды ауыр металдар иондарын сіңірудің ең жоғары тиімділігі 900°С температурада күйдіріліп, белсенділігі арттырылған құрамдастырылған табиғи сорбенттен байқалатынын көрсетті.

Алынған зерттеу нәтижелері статистикалық жағынан өңделді. Жүргізілген эксперименттер барысында санитарлық-гигиеналық нормалардың талаптарға сәйкес, адамның қауіпсіздік өлшемдеріне жауап беретін судың сапасы артты.

Түйін сөздер: су тазарту, сорбция, табиғи адсорбенттер, алюмосиликаттар, ауыр металдар.

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СОРБЦИОННЫЕ ХАРАКТЕРИСТИКИ МОДИФИЦИРОВАННОГО КОМПЛЕКСА ИЗ ПРИРОДНЫХ АДСОРБЕНТОВ ЦЕОЛИТА И БЕНТОНИТА

Аннотация. В статье авторы попытались создать эффективную технологию получения комплекса из природных адсорбентов на основе бентонита и цеолита, позволяющую добиться высокой степени очистки питьевых и сточных вод от загрязнений, так как наибольший пресс эко- токсичности испытывает водная среда, являясь конечным резервуаром большинства загрязняющих веществ. В связи с этим существует проблема качества питьевой воды, определяемая загрязнением природной воды, неудовлетворительной очисткой ее на водопроводных станциях, вторичным загрязнением в разводящих сетях.

Цель данного исследования заключалась в экспериментальной оценке эффективности использования природных минеральных сорбентов для очистки и кондиционирования воды.

Основной задачей исследования является получение комплексного соединения из природных адсорбентов для очищения сточной воды с одновременной сорбцией, содержащихся в ней химических и микробиологических загрязнений, способствующих обеззараживанию и умягчению воды, повышающих степень насыщения обработанной воды солями кальция, магния и микроэлементами, при этом не требующего использования сложного оборудования.

В работе представлены результаты исследования эффективности применения природных минеральных сорбентов, полученных на основе цеолита, бентонитовых глин и диатомита низкогорных частей Жетысуского (Джунгарского) Алатау для очистки и кондиционирования питьевой воды и доочистки сточных вод от сульфатов, гидрокарбонатов, нитратов, ионов тяжелых металлов и других вредных примесей.

Изучены физико-химический, минералогический состав природных сорбентов и эффективность адсорбции полученных комбинированных сорбентов, обнаружено увеличение сорбционной активности в зависимости от состава сорбента и влияния предварительной температурной модификации.

Для определения физико-химического состава использован метод количественного химического и рентгенофазного анализа цеолита Майтобинского и бентонита Мукринского месторождений, расположенных на территории Алматинской области с помощью сканирующего электронного микроскопа “EVO 50 XVP” (Carl Zeiss) с системой зондового микроанализа “INCA Energy – 350” (Oxford Instruments). Рентгеноскопический анализ с помощью электронного микроскопа с увеличением до 2μm показал пустоты в каркасной структуре цеолита и бентонита, повышающие адсорбции ионов тяжелых металлов при применении для очиски и конденесированияе сточных и питевых вод.

Установлено, что наибольшая эффективность адсорбции ионов тяжелых металлов наблюдается для сорбента, прошедшего температурную модификацию при 900°С.

Полученные результаты исследований статистически обработаны. В ходе проводимых экспериментов повысилось качество воды, отвечающее критериям безопасности человека в соответствии с санитарно-гигиеническим нормируемым требованиям.

Ключевые слова: очистка воды, сорбция, природные адсорбенты, алюмосиликаты, тяжелые металлы.

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SELECTION OF THE PARAMETERS OF A REGIONAL CLIMATE MODEL BASED ON A COMPARISON WITH OBSERVATIONAL DATA FOR THE "CENTRAL ASIA" DOMAIN

Abstract. The article presents the results of selecting the optimal parameters for the regional climatic WRF-model for the Central Asia domain. Three variants for setting the parameters of the WRF model are considered: 1) WSM6 microphysics in combination with the YSUPBL boundary layer scheme; 2) MYJPBL planetary boundary layer scheme combined with Thompson microphysics; 3) Thompson microphysics with setting of the boundary layer parameters according to the YSUPBL scheme. As data of ground-based observations, global archives of data from the Meteorological Office, United Kingdom (Climatic Research Units) and data from the laboratory of surface hydrology at Princeton University of the United States were used. The results of numerical calculations of the mean annual seasonal variability of surface temperature and precipitation are compared for all selected parameterization schemes for 4 climatic seasons in the Central Asian region. It was shown that the most preferred combination was the YSUPBL scheme with Thompson microphysics.

Key words: climate change, modeling, selection, parameterization, sensitivity, WRF.

Introduction. It is known, that the main methodological basis for solving the problem of forecasting estimates of future climate parameters is numerical modeling of the climate system using global climate models, which are based on global models of the general circulation of the atmosphere and ocean [1-2]. That the improvement of climate models requires the formulation of more accurate models of specific physical processes that determine the dynamics of the climate system for any region

In most cases, the model should be adjusted for a specific region by varying empirical coefficients in the parameterization schemes, as well as using different precipitation parameterization schemes, a planetary boundary layer, etc. Usually, regional model is evaluated by its ability to reproduce fields of precipitation and temperature of the near-surface air.

Regional climate modeling under the CORDEX (COordinated Regional Climate Downscaling EXperiment) program (https://www.cordex.org/) plays an important role, providing projections of the future climate with much greater detail and a more accurate representation of local extremes [3-6]. The higher spatial resolution of the regional model allows us to more adequately reproduce the influence of mountains and the properties of the underlying surface on atmospheric processes [7]. The allocation of their contribution can be considered the main expected result of regional modeling.

The Weather Research and Forecasting (WRF) model is a system for weather forecasting and modeling atmospheric processes, suitable for both operational and research purposes. The system is an

effective tool for the development of data assimilation techniques, parameterization of sub-grid scale weather forecast and regional climate modeling [8].

At the present stage, attempts are being made to build regional climate models (RCM) for the territories included in the Central Asia domain and taking into account the specifics of the region. So, in [9] the results of calculating air temperature, atmospheric pressure, and precipitation for the territory of the Tomsk region using the WRF predictive modeling system with various parameterization schemes are presented. For example, in [10] studies were conducted on the selection and adaptation of the optimal convection parametrization scheme in the hydrodynamic mesoscale model WRF for forecasting meteorological values in the territory of Kyrgyzstan. The calculation of the amount of precipitation during the cold period in the Western Urals using the WRF model was carried out [11].

The results of WRF simulation and downscaling of local climate in Central Asia are described in [12]. This work had two goals: (1) achieve better performance of the WRF model in simulating the observed precipitation, daily extreme temperatures in Central Asia, so to create a tool that can be used to improve understanding of weather and climate in Central Asia, and (2) create a high-resolution (20 × 20 km) meteorological dataset for the region for the period 1980–2015. The model initial and boundary conditions are derived from the ERA-Interim reanalysis data.

The model was tested with various parameterization schemes. The calculation results were compared with ground-based observations. The choice of model configuration was determined by the smallest difference in the comparisons. As a result of those tests, microphysics scheme of Thompson [13] and Betts-Miller-Janjic scheme [14] for cumulus parameterization in the model were selected. The PBL parameterization used in the model is the Mellor–Yamada–Janjic scheme [15].

It should be noted that a number of studies are also known on the sensitivity of the WRF model using different parameterization schemes for different parts of the Central Asia domain [16-20].

For Kazakhstan territory by the WRF model calculated a range of meteorological parameters (temperature field of the air near the ground and at altitude of the atmospheric pressure 850 hPa, the total accumulated precipitation and precipitation for scheme convective cloudiness, field of near surface pressure and surface wind) [21].

Methods and Data. The purpose of the numerical experiments in our study is to select a parameterization scheme describing microphysics, a planetary boundary layer, short-wave and long-wave radiation fluxes for the formation of a model that adequately reflects the processes occurring in the atmosphere, on the surface of the earth and water, with their mutual influence and model constraints for the 'Central Asia' domain. In the present study, the selection of parameters was carried out for regional climate WRF model [22].

It is possible to use various options for parameterization with varying degrees of accounting for hydrometeors in the liquid and solid phases and the processes corresponding to them [23-24].

In our study, the focus is on near-surface wind speed, precipitation, and near-surface temperature at a height of 2 meters. To calculate the temporal variability of meteorological elements in the surface and boundary layers, it is possible to use the following schemes for parameterizing:

– The Mellor-Yamada-Janjic (MYJ) parametrization is based on the turbulent kinetic energy equation, the right side of which includes terms depending on vertical gradients of wind and potential temperature that produce turbulent kinetic energy.

– Parametrization of Yonsei University (YSU). The scheme calculates the vertical exchange coefficient for the amount of motion using information on vertical gradients of temperature and wind, calculates a turbulent analogue of the Prandtl number, and determines the coefficient of turbulence for use in the equations of temperature and humidity transfer. The contribution from large vortices is determined depending on the magnitude of convective flows at the upper boundary of the surface layer, which are expressed in terms of the stability functions.

Finally, we consider three different options for specifying the parameters of the WRF model using the WSM6 microphysics is used in combination with the YSU scheme (Exp.1); combination of a planetary boundary scheme layer MYJ PBL combined with Thompson microphysics (Exp.2); in the second variant, the same microphysics is used, but the parameters of the boundary layer are set according to the YSU PBL scheme (Exp.3).

The boundary and initial conditions for the regional climate model were established on the basis of the ERA-Interim reanalysis data set (https://rda.ucar.edu/datasets/) with a 6-hour interval [25], a spatial resolution of 1,5° over the entire Earth's surface, which is about 150 km Central Asian region [26]. The fields of the meteorological parameters listed above are presented at 37 isobaric levels [27]. In each cycle of ERA-Interim reanalysis , the available observational data is combined with the previous forecast model information to calculate the evolution of atmospheric parameters (temperature, wind speed, air humidity, ozone concentration, surface pressure) and the underlying surface (temperature and humidity at a height of 2 meters, humidity and soil temperature, snow). Additionally, two global archives were used as observation data: data from the Meteorological Office, UK (CRU-Climatic Research Units), with a spatial resolution of $0,5^0$ (https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_4.00); data from the laboratory of near-surface hydrology at Princeton University, USA, with a spatial resolution of $0,25^0$ (http://hydrology. princeton.edu/data).

The study area. The entire earth's surface is divided into 14 domains have been defined with a spatial resolution of 0,44x0,44 degrees, which approximately corresponds to 50 km. There are areas of current and future climate research based on regional statistical and dynamic models. The domain must include specific physical processes that are important for the climatology of the selected region, have mesoscale or smaller space-time dimensions, which are not reflected by coarser global models. Another criterion is the additional information obtained by regional models compared to global ones. The domain of Central Asia is defined by the scientific group Science Advisory Team and looks as follows (figure 1).

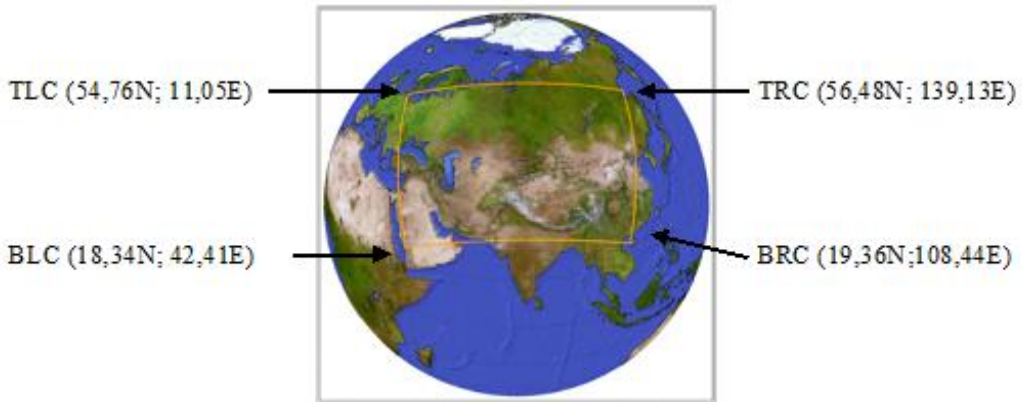

Figure 1 – Domain Central Asia (borrowed from https://www.cordex.org/domains/region-8-central-asia/)

The selected region occupies a vast expanse territory on the earth's surface. It stretches across the territory of Eurasia in the latitudinal direction for almost 5 thousand km, in the meridional direction - more than 1 thousand km. The surface relief varies from high mountains to lowlands lying below sea level. It includes several climatic zones, for example, a territory with a humid and cold continental climate in western Europe and a dry, very cold subboreal climate in the middle and eastern regions of the Siberian plateau; dry mid-latitude desert and steppe with an arid and semi-arid climate in the middle of Central Asia; Himalayas and Tibetan plateau with highland climate. There are areas of the earth's surface, within which there is approximately a homogeneous climate throughout their length.

Results and discussion. The duration of each numerical experiment is 17 years of simulation, which leads to the emergence of numerical instability caused by rounding errors. A simulation interval of 1 month was chosen. The results of numerical experiments for the selection of parameterization schemes of microphysical processes and processes in the boundary layer of the atmosphere are presented in the form of maps of the average annual seasonal variability of surface temperature and precipitation.

The difference between the average annual seasonal variability of surface temperature and precipitation, calculated by the WRF model and observations data from the CRU and Princeton University archives, was analyzed to assess the accuracy of reproducing the climate system parameters by the WRF model for the above parameterization schemes for 4 seasons of the year (period 2000-2016).

Figure 2 shows the field of average monthly surface temperature for July 2015, obtained by the output data model (Exp.1 WSM6+YSU) and interpolated in the spatial grid nodes observation data CRU - Climate Research Units. WRF results are averaged from 3-hour data, CRU data is averaged from average daily data.

As an example, long-term dynamics of average monthly temperatures for CRU and the WRF from January 2006 to December 2015. The data is obtained for the coordinates of the city of Almaty (43° N, 77° E). The correlation between WRF and CRU data for Almaty coordinates is shown in figure 3.

Figure 4 show the comparison results for the surface temperature values, for the autumn season. In the autumn period, there is a positive difference between the calculated and observed temperatures for parameterization schemes 1 and 2, and the use of the parameterization scheme 3 allowed us to obtain the most satisfactory result. The excess of the calculated values of the temperature of the surface layer in comparison with the observed in winter at 2-3°C in the Northern regions of the considered domain, for all numerical experiments with different parameterizations determined by what ERA-Interim reanalysis data already overestimate the temperature of the surface layer for winter. Similar calculations were made for all seasons of the year.

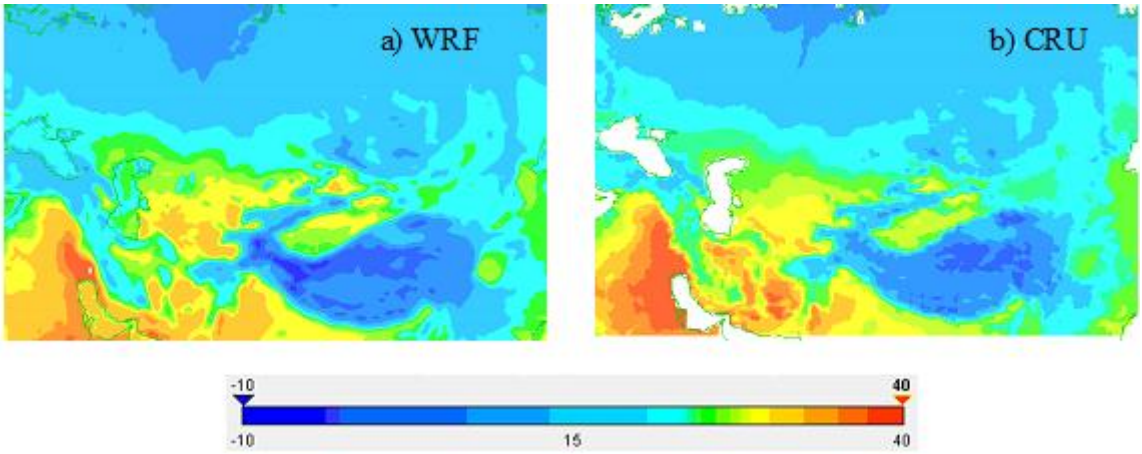

Figure 2 – Average monthly surface temperature for July 2015 according to the calculations (a) and observations (b) (Exp.1 WSM6 + YSU)

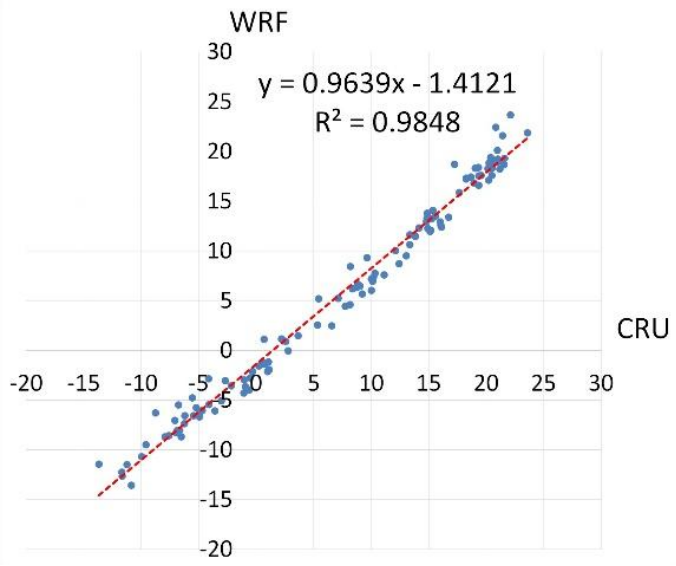

Figure 3 – The correlation between WRF and CRU data calculated from the experimental data for Almaty coordinates

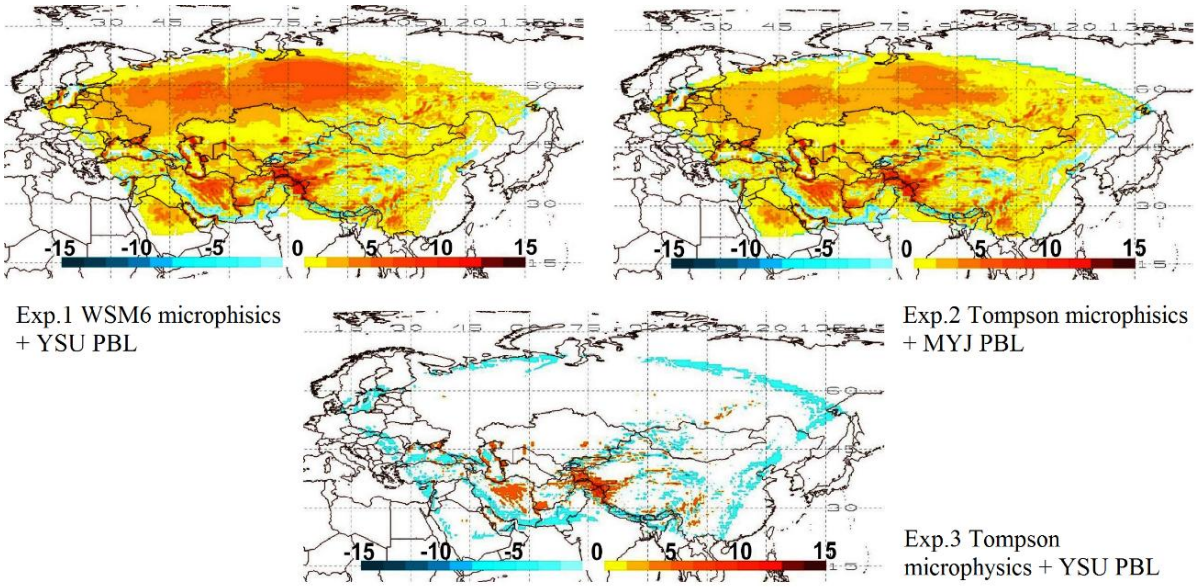

Figure 4 – The difference between the average temperature of CRU and WRF in 2000–2016, the autumn (September, October, November)

In the cold season, the best correspondence between the calculated and observed values is obtained in a numerical experiment using the parameterization scheme 3 (Exp. 3). During the summer period, the best correspondence between model calculations and observational data was obtained using the parameterization scheme 2. Similar comparisons are made between annual precipitation and ground data.

For all seasons, excluding summer, the calculated precipitation values exceeds the observed precipitation for the Western and Northern parts of the study area. Calculations by scheme 3 show better results compared to schemes 1 and 2. In some cases, anomalies occur at the Northern and Eastern borders of the domain, which is probably due to the insufficient width of the relaxation zone. The error of the average annual precipitation values calculated using the regional model does not exceed 1,5 mm/day.

The model produces a significant excess of precipitation in mountainous areas and the Asian monsoon region for autumn, spring, and winter. The opposite situation is observed in the summer. In the summer, precipitation is overestimated by the model for most of the studied domain. Their significant overestimation can be traced in arid and semi-arid regions, as well as in the humid southern parts of the domain. This is due to the fact that mid-latitude cyclones are weaker and less frequent in summer, northern fronts prevail, temperature and pressure gradients decrease over the Euro-Asian continent, and the impact on the South Asian monsoon depression. For the Northern and southern parts, there is also a slight excess of the model calculation data relative to the observed ones.

A comparison of the average long-term seasonal values of the surface air temperature and average annual precipitation according to models and observations for the period 2000-2016 for the entire territory of the studied domain was made using data from the CRU and Princeton University observation archives, ERA-Interim reanalysis and the results of calculations for the WRF RCM (Exp.3), (table).

Average long-term air temperature values and annual precipitation according to models and observations

Models and observations	Average long-term seasonal values surface temperature (^{0}C), (2000-2016)				Mean annual and mean seasonal precipitation (mm/day)			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
WRF (exp 3)	-8,13	5,36	19,51	5,65	1,29	1,57	2,30	1,69
ERA-Interim	-3,44	7,98	20,27	8,61	0,31	0,45	0,82	0,45
CRU	-7,38	6,76	19,52	6,92	0,74	1,09	2,30	1,26
Prinston Un.	-7,68	6,09	19,12	6,70	0,92	1,51	2,02	1,30

As can be seen from Table the regional climate model gives closer air temperature values at the height of 2 m, compared with the observed data, than the results of the ERA-Interim reanalysis for all seasons of the year. The total discrepancy for the domain-averaged long-term air temperature calculated from the model and observations does not exceed 2,0 ^{0}C.

It should be noted that model calculations with the parameterization scheme 3 (exp. 3) correspond better than other parameterization schemes to observational data. It can be seen the regional model data are more consistent with observational data compared to the ERA-Interim set.

The average annual precipitation according to the WSM6 scheme overestimates the data when using the YSU-Thompson scheme, and for the MYJ-Thompson scheme, this value has slight deviations from the YSU-Thompson scheme, which indicates a slight difference when using different parameterization schemes of boundary layer.

Conclusion. We tested the ability of the WRF model to reproduce the observed parameters of the climate system within the Central Asia domain (region 8 of the CORDEX program). A number of numerical experiments were conducted to test various microphysics parametrization schemes and processes occurring in the boundary layer in order to select such a scheme that best reproduces the main characteristics of the climate.

Three combinations of the WRF model schemes were considered, based on the experience of previous regional climate studies: (Exp.1) Thompson microphysics + Mellor-Yamada-Janjic Planetary Boundary Layer (MYJ PBL) parametrization; (Exp.2) Thompson microphysics + Yenssen University Planetary Boundary Layer (YSU PBL) parametrization; (Exp.3) Single Moment 6-class parametrization (WSM6) microphysics + Yenssen University Planetary Boundary Layer (YSU PBL) parametrization.

The assessment of the region's seasonal climatology was performed for the traditional seasons of the year using three parameterization schemes.

The analysis of the difference in surface temperature fields between observations from the CRU archive and calculations using the WRF model with boundary and initial ERA-Interim conditions for different seasons of the year was carried out. Application of the parameterization scheme 3 (Exp.3) it allowed us to get the most satisfactory result.

The difference between average long-term precipitation was compared using simulation data with three parameterization schemes and observation too. Calculations by scheme 3 show better results compared to schemes 1 and 2.

Based on the obtained results, it can be concluded that the simulation data using parameterization scheme for the YSU PBL boundary layer and Thompson microphysics are better than other schemes considered in this study are consistent with observations of precipitation and surface layer temperature.

In conclusion, it should be noted that the WRF numerical regional model with selected parameterization schemes, can be used to simulate future climate projections within the Central Asia domain for various scenarios of greenhouse gases in the atmosphere (RCP (Representative Concentration Pathway) 4.5, RCP 8.5.) [28].

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«ОРТАЛЫҚ АЗИЯ» ДОМЕНІНЕ АРНАЛҒАН БАҚЫЛАУ ДЕРЕКТЕРІМЕН САЛЫСТЫРУ НЕГІЗІНДЕ АЙМАҚТЫҚ КЛИМАТ МОДЕЛІНІҢ ПАРАМЕТРЛЕРІН ТАҢДАУ

Аннотация. CORDEX бағдарламасы бойынша аймақтық климатты модельдеу болашақтағы климат жағдайына болжам жасауда жаһандық климаттық модельдерге қарағанда анағұрлым дәлдірек және жергілікті экстремалды оқиғаларды нақтырақ көрсетуде маңызды рөл атқарады. Аймақтық модель атмосфералық үдерістерге таулардың және жер бетінің әсерін көрсетеді. Олардың үлесін бөлуді аймақтық

модельдеудің күтілетін негізгі нәтижесі деп санауға болады. WRF моделі – зерттеу мақсатында және күнделікті ауа райын болжау мен атмосфералық үрдістерді модельдеу жүйесі.

Мақалада Орталық Азия аймағына арналған WRF аймақтық климат моделінің оңтайлы параметрлерін таңдау нәтижелері келтірілген. Климаттың негізгі сипаттамаларын жеткілікті баяндайтын схеманы таңдау мақсатында шекаралық қабатта жүретін әртүрлі микрофизика мен үдерістердің параметрлендіру схемаларын сынау арқылы жоғары өнімділікті есептеуіш кластерін пайдаланып, бірқатар сандық тәжірибе жүргізілді. Микрофизика және шекаралық қабат схемаларының үш тіркесімі қарастырылды: гидрометеорлардың 5 класын (бұлттағы су, жауын-шашын, бұлттағы мұз, қар және қар түйіршіктері) қолданатын Томпсонның бірреттік микрофизика схемасы атмосфералық шекара қабатының PBL MYJ схемасымен бірге, екінші нұсқада сол микрофизика қолданылады, бірақ шекаралық қабаттың параметрлері PBL YSU схемасын пайдаланады; үшінші нұсқада гидрометеорлардың 6 класы бар WRF Single Moment микрофизика схемасы мен PBL YSU схемасының үйлесуі. Таңдалған аймақтың маусымдық климатологиясы жылдың дәстүрлі жыл мезгілдеріне 2000-2016 жылдар аралығында бағаланды. Аймақтық климат моделі үшін бастапқы және шекаралық шарттар ретінде ERA-Interim реанализ мәліметтері пайдаланылды. Бақылау деректері ретінде екі ғаламдық мұрағат пайдаланылды: Ұлыбритания метеорологиялық бюросының деректері және АҚШ-тың Принстон университетінің жерүсті гидрология зертханасының деректері. Сандық есептеу нәтижелері карта-схема түрінде ұсынылған. Жерүсті қабатының температурасы мен жылдық жауын-шашын өрістерінің бақылау деректерінен айырмашылығы есептелген. Модельдеу нәтижелерін талдау барысында модель климаттық масштабтағы атмосфералық үдерістерді жеткілікті түрде сипаттайды және климаттық жүйенің негізгі параметрлерінің кеңістік-уақыт өзгерісін жақсы көрсетеді. Ерекшелікгі ретінде орографиялық әртектілігі бар аудандар – таулы және биік таулы аудандарды бақылау желісінің сирек кездесуі арқылы түсіндіруге болады. MYJ PBL шекара қабатының және Thompson микрофизикасының параметрлендіру схемалары арқылы алынған модельдеу нәтижелері жауын-шашын мен жер қабаты температурасының бақылау деректерімен сәйкестігі зерттеуімізде қарастырылған басқа схемаларға қарағанда үздік екендігі анықталды.

Таңдалған параметрлендіру схемаларын пайдаланып, WRF сандық климаттық моделін атмосферадағы көшет газ шоғырлануының түрлі сценарийлері үшін Орта Азия аймағында болашақтағы климат болжамын модельдеу үшін қолдануға болатындығын атап өткен жөн.

Түйін сөздер: климат өзгерісі, модельдеу, таңдау, параметрлендіру, сезімталдық, WRF.

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ВЫБОР ПАРАМЕТРОВ РЕГИОНАЛЬНОЙ МОДЕЛИ КЛИМАТА НА ОСНОВЕ СРАВНЕНИЯ С ДАННЫМИ НАБЛЮДЕНИЙ ДЛЯ ДОМЕНА «ЦЕНТРАЛЬНАЯ АЗИЯ»

Аннотация. Моделирование регионального климата в рамках программы CORDEX играет важную роль, обеспечивая прогнозы будущего климата с большей детализацией и более точным представлением локальных экстремальных явлений, чем глобальные климатические модели. В региональной модели воспроизводится влияние гор и свойств подстилающей поверхности на атмосферные процессы. Распределение их вклада можно считать основным ожидаемым результатом регионального моделирования. Модель WRF – система прогнозирования погоды и моделирования атмосферных процессов, подходящая как для оперативных, так и для исследовательских целей.

В статье представлены результаты выбора оптимальных параметров региональной климатической WRF-модели для региона Центральной Азии. Проведен ряд численных экспериментов на высокопроизводительном вычислительном кластере для тестирования различных схем параметризации микрофизики и процессов, происходящих в пограничном слое с целью выбора такой схемы, которая наилучшим образом воспроизводит основные характеристики климата. Рассмотрены три комбинации схем микрофизики и пограничного слоя: одномоментная схема микрофизики Томпсона, использующая 5 классов гидрометеоров (вода в облаках, осадки, лед в облаках, снег и снежная крупа) в сочетании со схемой пограничного слоя атмосферы PBL MYJ; во втором варианте используется та же микрофизика, но параметры пограничного слоя устанавливаются в соответствии со схемой PBL YSU; в третьем варианте микрофизика схема WRF Single Moment с 6 классами гидрометеоров в сочетании со схемой YSU. Оценка сезонной климатологии выбранного региона выполнена для традиционных сезонов года за период 2000–2016 гг. В качестве начальных и граничных условий для региональной модели климата были использованы данные ERA-Interim реанализа. В

качестве данных наблюдений использовались два глобальных архива: данные из Метеорологического бюро Великобритании и данные лаборатории приповерхностной гидрологии Принстонского университета США. Результаты численного расчета представлены в виде карта-схем. Рассчитаны разности полей температур приземного слоя и годовых сумм осадков с данными наблюдений. Из анализа результатов моделирования следует, что модель адекватно описывает атмосферные процессы климатического масштаба и хорошо воспроизводит пространственно-временные вариации основных параметров климатической системы. Исключение составляют районы с орографическими неоднородностями – горные и высокогорные районы, что можно объяснить редкостью наблюдательной сети. Определено, что данные моделирования с использованием схем параметризации для пограничного слоя MYJ PBL и микрофизики Thompson лучше, чем другие, рассмотренные в настоящем исследовании, согласуются с данными наблюдений за осадками и температурой приземного слоя.

Следует отметить, что численная климатическая модель WRF с подобранными схемами параметризации может быть использована для моделирования проекций будущего климата на территории домена Центральная Азия для различных сценариев содержания парниковых газов в атмосфере.

Ключевые слова: изменение климата, моделирование, выбор, параметризация, чувствительность, WRF.

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SCANDIUM EXTRACTION BY PHOSPHORUS-CONTAINING SORBENTS

Abstract. The research and development of a highly effective, economically acceptable technology for scandium extracting from in-situ leaching solutions of uranium is an urgent scientific and technical task. An effective way of separation and purification of scandium is considered to be extraction from various solutions, among which organic acid phosphorus extractants are the most promising. This article is aimed at studying the equilibrium scandium sorption characteristics from model solutions of organophosphorus ion exchangers. Scandium sorption was carried out under static and dynamic conditions. In the furtherance of desired goal, scandium sorption by phosphorus-containing ion exchangers Lewatit TP272, Lewatit TP260, D2EHPA and DRPO from model solutions was studied. Sorption isotherms and integrated kinetic curves of scandium sorption were obtained. For the studied ion exchangers, the values of static exchange capacity and total dynamic exchange capacity for scandium were determined. Saturation on the TP260 ion exchanger at 700 sp.vol. equal to 0.027 kg/m^3 and on D2EHPA ion exchanger at 2382 sp.vol. equal to 0.236 kg/m^3 were obtained during passed volumes. It was found that desorption degree with scandium-saturated Lewatit TP260 ion exchanger using a solution of 200 g/dm^3 Na_2CO_3 at room temperature was 87.26%; whereas with TVEX D2EHPA ion exchanger using solutions of sodium carbonate Na_2CO_3 (200 g/dm^3) and hydrofluoric acid HF (3.5M) was about 100%. When using a solution of ammonium fluoride NH_4HF_2, scandium extraction degree was 76%. A carbonate-alkaline solution of 0.5M NaOH + 1M Na_2CO_3 and sodium salt solution of hydrofluoric acid 3.5M NaF showed low desorption characteristics. Obtained results made it possible to select Lewatit TP260 and D2EHPA ion exchangers for further study of scandium sorption extraction.

Key words: scandium, sorption, desorption, extraction, degree of extraction, exchange capacity, filtrate.

Introduction. Scandium (Sc) is one of the most expensive rare metals with a small volume of industrial production. Despite the significant content in the earth's crust, scandium rarely forms its own deposits. The reason is that Sc does not combine with ore-forming anions. In this regard, scandium is usually stands out as a byproduct in the processing of tailings and residues of various sources, such as uranium production solutions, titanium pigment production waste, ilmenite chlorination waste, wolframium and red mud sludge processing residues [1-3]. The main line of scandium application is the production of aluminum-based alloys used in the aerospace industry, in the manufacture of sports equipment and firearms. This is facilitated by the unique properties of scandium alloys, such as a combination of high strength and low weight, heat resistance and mechanical strength. In illumination engineering scandium iodide is used as an additive in halide lamps, which are one of the most effective light sources [4-7]. Scandium is a typical dissipated lithophylic element, found exceptionally in the form of oxide compounds. Scandium's own minerals - thortveitite $Sc_2[Si_2O_7]$ and sterrettite $ScPO_4*2H_2O$ - rare and do not have industrial significance. The problem of industrial production of scandium is solved by using dissipated scandium, extracted simultaneously from ores of non-ferrous and rare metals. The scandium content in these products does not exceed tenths of a percent. Scandium oxide of various qualifications is the final product of the described schemes [8-11]. One of the main scandium sources is uranium ores containing 10^{-3} - 10^{-4}%. Global uranium manufacturing in 2016 amounted to 62,366 tons, of

which 39.4% was produced in Kazakhstan, followed by Canada (22%), Australia (10%), Niger (5.8%) and Russia (4.8%) [12]. Accordingly, scandium extraction as a by-product in uranium processing is great consequence. Currently, the processing of uranium-containing leaching solutions for scandium recovery typically uses hydrometallurgical processes, which are mainly associated with leaching, precipitation, liquid extraction and related technologies such as ion exchange and liquid membrane extraction [13-15].

Liquid extraction is one of the well-established hydrometallurgical methods for concentrating scandium and purifying leaching solutions of scandium-containing raw materials. The technology for the scandium isolation is complicated by the fact that the multicomponent composition of scandium-containing solutions necessitates a combination of different methods of concentration and purification. Process flowsheets for the scandium extraction are quite difficult, so the question of developing effective methods of extraction concentrating and separation from impurities remains particularly relevant. Review of the above process engineering solutions for scandium concentrating [16-23] indicates the efficiency of sorption and the variety of ion-exchange resins used. To concentrate scandium from productive solutions of uranium in-situ leaching acid extractants are often used. Most commonly the extraction of a metal ion (Mn^{n+}) with an acid extractant at a high concentration of an element in the organic phase proceeds according to the cation exchange mechanism [18]. For scandium sorption from acidic solutions of complex salt composition, it is preferable to use highly selective phosphorus-containing ion exchangers with high scandium sorbability even when extracted from strongly acidic solutions. In turn, these acidic extractants are divided into phosphoric, phosphonic and phosphinic [22-27].

Experimental procedure. Scandium sorption was investigated using a sulfuric acid solution simulating ISL uranium solutions. Standardized test solution for scandium sorption with a volume of 60 dm^3 was prepared by dissolving scandium oxide Sc_2O_3 with a purity of 99.9% in a hot solution of 60% sulfuric acid (CP 94.6%) at a temperature of 80^0C for 0.5 hour. Investigation process of scandium extraction from sulfate solutions was carried out using phosphorus-containing ion exchangers, main specifications of which are presented in table 1. The following solutions were used in the experiments: sodium carbonate Na_2CO_3, ammonium biflouride NH_4HF_2, fluohydric acid HF, sodium fluoride NaF, sodium hydroxide NaOH, citric acid $C_6H_8O_7$.

Research methods. Before work samples of ion exchangers were preconditioned with hydrochloric acid and caustic soda solutions according to the procedure described in [28]. Cation exchangers were converted to H^+ form, polyampholytes to the H^+ and SO_4^{2-} form when working with sulfuric solutions. Further, the resins were transferred to the working form by holding for 24 hours in the appropriate medium, after which they were washed with distilled water to a pH of 3-3.5.

Investigation of sorption under static conditions, a weighed portion of the resin in the range from 0.04 to 4 g was placed in a container with a volume of 5 dm^3, a certain amount of solution with a known concentration of scandium was injected into it and the container was hermetically closed and placed on a LS110 radial shaker. Taking into account the extremely low concentrations of scandium, the study under static conditions was carried out with a large ratio of the solution volume to the weight of the ion exchanger V:W=1000:1 (5 dm^3:5 g). Stirring of the container was carried out to prevent resin's particles deposition for 48 hours.

Table 1 – The main specifications of the resins used in the work

Resin	Functional groups	Matrix type	Granules size in the air-dry state, mm
Chelating resins			
Lewatit TP272	bis(2,4,4-trimethylpentyl)phosphinic acid	macroporous, cross-linked polystyrene	0.30÷1.60
Lewatit TP260	aminomethylphosphonic acid	macroporous, cross-linked polystyrene	0.40÷1.25
Solid extractants			
D2EHPA	di-(2-ethylhexyl)phosphoric acid	macroporous, hypercrosslinked polystyrene	0.65÷2.50
DRPO	different radical phosphine oxide	macroporous, hypercrosslinked polystyrene	0.25÷0.80

Stirring of the container was carried out to prevent resin's particles deposition for 48 hours. Samples for analysis were taken at certain time intervals without interrupting the experiment. System's volumetric change as a result of sampling did not exceed 5%. Sorption isotherm from the solution was taken off varying the ratio of the solution volume to the ion exchanger mass V:m. The solution was contacted with the resin also until equilibrium was established. The equilibrium static exchange capacity (SEC), calculated by the residual scandium content in the solution, was determined by the formula 1:

$$SEC = \frac{C_0 - C_e}{C_0} \cdot \frac{V}{m}, \quad (1)$$

where: C_0 - scandium concentration in the initial solution, mg/dm^3 or mmol/dm^3; C_e - the equilibrium concentration of scandium in solution after sorption, mg/dm^3 or mmol/dm^3; V - the volume of solution taken for testing, dm^3; m - ion exchanger's sample weight, g.

Investigation of sorption under dynamic conditions, prehydrated in distilled water and converted into the desired form, the ion exchanger was placed in a 30cm^3 organic glass column (the ratio of the height of the sorbent layer to the diameter h/d = 4.8:1). The solution was passed from bottom to top through an ion exchanger until the resin was completely saturated with scandium. The specific load was 10 sp.vol./sp.vol./hour. At a controlled flow rate, the solution at the column outlet was fractionally selected for analysis. Throughput raterate was set using a peristaltic pump. Total dynamic exchange capacity (TDEC) was calculated by the formula 2. Solutions were analyzed by inductively coupled plasma atomic emission method on an Optima 8300DV spectrometer from Perkin Elmer, LLC.

$$TDEC = \frac{(C_0 - C_a) \cdot V}{m_{i.e.}} \quad (2)$$

where: C_0 - scandium concentration in the initial solution, mg/dm^3 or mmol/dm^3; C_a - an average scandium concentration in solution, mg/dm^3 or mmol/dm^3; V - passed solution volume, dm^3; $m_{i.e.}$ - ion exchanger's sample weight, g.

The distribution coefficient of scandium was calculated by the formula 3:

$$K_d = \frac{(C_0 - C) \cdot V}{C \cdot m} \quad (3)$$

where: K_d - distribution coefficient of scandium, cm^3/g; C_0 - scandium concentration in the initial solution, mg/dm^3 or mmol/dm^3; C - scandium concentration in mother solution, mg/dm^3 or mmol/dm^3; V - passed solution volume, dm^3; m - ion exchanger's sample weight, g.

Result and discussion. Sorption isotherm characterizes the state of ion-exchange equilibrium at a constant temperature. Researches of scandium sorption isotherm were carried out at a concentration range as close as possible to the technological conditions of uranium leaching. Scandium sorption isotherms on an ion exchangers were removed by varying the initial concentration in the solution from 0.03 to 0.6 mg/dm^3 ($0.67*10^{-3} \div 13.3*10^{-3}$ mmol/dm^3). The value of ion exchanger's capacity was calculated by the formula 1, the distribution coefficient by the formula 3. Research results of scandium sorption isotherms are shown in table 2.

Table 2 – Results of scandium sorption isotherms research

Ion exchanger	Scandium equilibrium concentration in the solution, mmol/dm^3*10^3	Ion exchanger capacity, mmol/g*10^3	Distribution coefficient K_d, cm^3/g
TP272	1.68	2.14	1756.0
	3.95	4.16	1112.8
	6.12	5.10	914.6
	8.28	6.42	1194.8
	12.24	10.14	862.8
TP260	1.28	1.15	1108.6
	4.12	2.86	689.6
	7.76	3.66	788.0
	10.21	4.85	646.6
	12.80	6.82	658.8

Coninuation of table 2

D2EHPA	1.16	4.08	3546.2
	3.42	8.95	4122.3
	6.00	14.56	4852.6
	9.20	20.12	3896.2
	12.48	27.82	3452.5
DRPO	1.32	1.24	666.5
	3.44	2.75	768.8
	7.22	6.54	844.0
	9.12	7.26	716.8
	12.42	9.96	708.6

As can be seen from the graphs in figure 1, scandium sorption isotherms within the studied concentration range are close to rectilinearly type. Isotherms were processed by the instrumentality of the Langmuir and Henry equations [29]. The processing results in coordinates 1/E-1/C (Langmuir equation) and E-C (Henry equation) are presented in table 3.

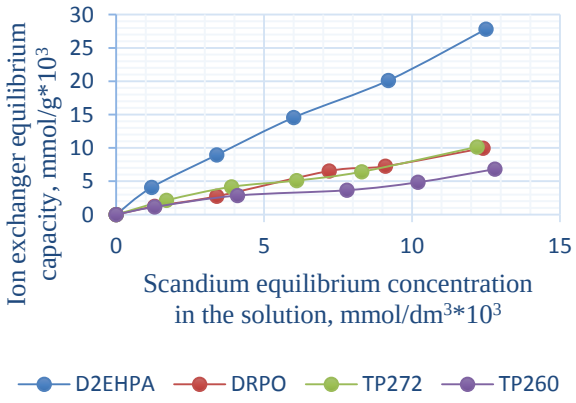

Figure 1 – Scandium sorption isotherms from standardized test solutions with TP272, TP260, D2EHPA, DRPO

Based on the presented results analysis, it can be concluded that there is no significant difference between the correlation coefficients in the two equations for the studied resins in the selected concentration range and conditions.

Table 3 – Scandium sorption isotherm processing results

Ion exchanger	Equation	Concentration range, mmol/dm^3*10^3	Constant K, dm^3/g (Henry) or g/mmol (Langmuir)	Correlating coefficient, R^2
TP272	Henry	1.68÷12.24	1.12	0.8692
	Langmuir		198.622	0.7458
TP260	Henry	1.28÷12.80	0.72	0.9742
	Langmuir		108.55	0.9413
D2EHPA	Henry	1.16÷12.48	3.56	0.9826
	Langmuir		16.68	0.9748
DRPO	Henry	1.32÷12.42	0.82	0.9832
	Langmuir		3.10	0.9812

Scandium sorption kinetic characteristics were studied by the limited-volume method in an installation with a thermostatically controlled cell at temperatures of 293 K in such a way that the exchange process occurred in a stirred solution with a volume of 5000 cm^3 with an initial composition of

0.22 mg/dm^3. In this case, sorbed ion concentration in the solution changes during the experiment, which affects the speed of the process. With sufficiently intensive mixing, an equilibrium distribution of the ion concentration in the entire solution volume is achieved, excluded layers directly adjacent to the grain layer (boundary layer). The integrated kinetic sorption curves of scandium, considered at a temperature of 293K, are shown in figure 2.

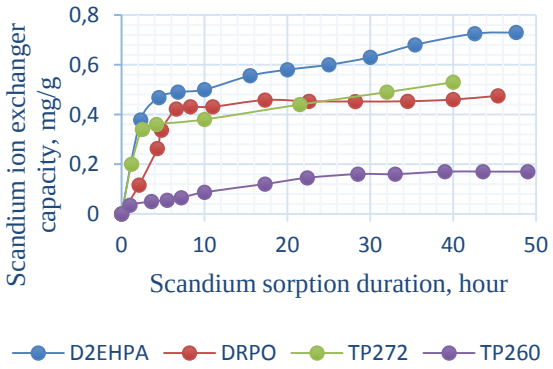

Figure 2 – Integrated kinetic curves of sorption of scandium from model solutions with TP272, TP260, D2EHPA, and DRPO ion exchangers at a temperature of 293K

Figure 2 shows that TP260 ion exchanger showed the lowest kinetic and capacitive indices, TP272 and DRPO ion exchangers are saturated with scandium in about 6 hours, while D2EHPA resin exhibits a lower saturation rate at a significantly higher equilibrium capacity. However, the strong affinity of the ion exchanger to the recoverable element expectedly complicates scandium subsequent extraction from the resin phase during desorption. Obtained results made it possible to select Lewatit TP260 and D2EHPA ion exchangers for further study of scandium sorption extraction. Before scandium sorption on selected ion exchangers under dynamic conditions, an experiment was conducted in a static mode. In this case, the ratio of L:S was 1000:1 (5 dm^3 of scandium-containing solution: 5g of resin). The container was stirred to prevent resin's particles from occurring for 48 hours, after which a sample of the solution was taken and analyzed for scandium. Table 4 contains data on the scandium sorption results in static conditions. Sorption extraction of scandium under dynamic conditions was carried out according to the procedure described above, from a sulfate solution at a specific load of 10 sp.vol./ sp.vol./hour. The results of scandium sorption on the ion exchangers TP260 and D2EHPA are shown in tables 5 and 6. With the passed volume of solutions, the calculated saturation of 0.027kg/m^3 was obtained.

Table 4 – Results of scandium sorption in static conditions

Ion exchanger	Sc concentration, mg/dm^3		Extraction degree, %	Resin capacity, kg/m^3
	initial	final		
TP260	0.186	0.155	16.72	0.031
D2EHPA		0.139	25.27	0.047

Table 5 – Results of scandium sorption on the ion exchange TP260

Specific volume, unit	0	100	200	300	400	500	600	700	α, kg/m^3
Sc concentration, mg/dm^3	0.186	0.081	0.157	0.161	0.180	0.184	0.183	0.176	0.027

Table 6 – Results of scandium sorption on the ion exchange D2EHPA

Specific volume, unit	0	150	320	486	650	780	942	1120	α, kg/m^3
Sc concentration, mg/dm^3	0.186	0.028	0.063	0.098	0.104	0.104	0.084	0.069	
Specific volume, unit	1190	1430	1566	1678	1860	2059	2218	2382	0.148
Sc concentration, mg/dm^3	0.062	0.058	0.055	0.057	0.058	0.064	0.069	0.072	

Saturation was 0.148 kg/m^3, with the passed solution volume; the following calculated saturation was obtained: 0.236 kg/m^3. Thus, it was possible to obtain saturation on the TP260 ion exchanger at 700 sp.vol. equal to 0.027 kg/m^3 and on D2EHPA ion exchanger at 2382 sp.vol. equal to 0.236 kg/m^3. Scandium was desorbed from saturated ion exchangers in organic glass columns with a volume of 30 cm^3 (the ratio of the height of the sorbent layer to diameter h/d = 4.8:1) filled with a saturated resin from a previous sorption experiment. From the bottom up, a desorption solution was passed through a clamped ion exchanger using a peristaltic pump, and the specific load was 1 sp.vol./sp.vol./h. At a controlled flow rate, sorption filtrates were fractionally selected for analysis. Scandium desorption from saturated Lewatit TP260 ion exchanger was carried out under dynamic conditions with a sodium carbonate solution Na_2CO_3 with a concentration of 200 g/dm^3. Main results of the experiment on the scandium desorption from resin TP260 are shown in table 7 and figure 3.

Table 7 – Results of scandium desorption from resin TP 260 in dynamic conditions

Specific volume, unit	0	1	2	3	4	5	6	7	8	9	10
Sc concentration, mg/dm^3	0	1.98	6.25	4.56	2.40	1.22	0.84	0.62	0.45	0.23	0.23
Sc extraction, %	0	5.64	18.12	37.24	57.22	70.15	81.15	82.20	84.36	85.52	87.26

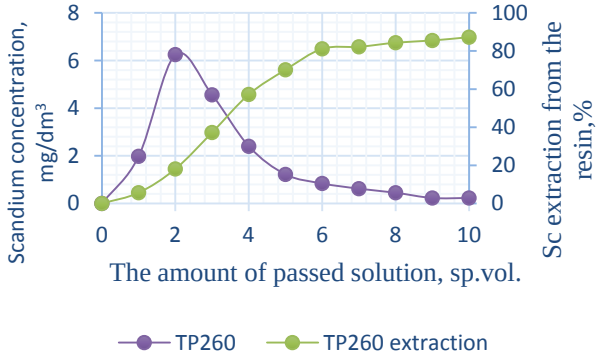

Figure 3 – Scandium desorption curve and degree of scandium extraction from TP260 resin

Desorption degree with scandium-saturated Lewatit TP260 ion exchanger using 200 g/dm^3 Na_2CO_3 and passing 10 sp.vol. at room temperature it was 87.26%, which allows making a conclusion about effectiveness of selected scandium desorbent. Scandium desorption from saturated TVEX D2EHPA ion exchanger was carried out under static conditions using various desorption solutions. The volume of saturated D2EHPA resin for each experiment was 5 cm^3. Desorption solutions volume was 200 cm^3. Desorption solutions of the following concentration were used: 200 g/dm^3 Na_2CO_3; 3.5M NH_4HF_2; 3.5M HF; 3.5M NaF; 0.5M NaOH + 1M Na_2CO_3; 5% citric acid. Results of scandium desorption from resin TVEX D2EHPA in static conditions are shown in table 8 and figure 4. It was established in [30] that scandium can be extracted from D2EHPA with carbonate - alkaline solutions or solutions of hydrofluoric acid or its salts. But then again, carbonate-alkaline solutions application for scandium desorption from TVEX is unacceptable, because D2EHPA will be emulsified and washed out from the TVEX's phase. Certain salts of hydrofluoric acid are also unallowable, as this will lead to the formation of sparingly soluble complex salts in TVEX's phase.

Table 8 – Results of scandium desorption from resin TVEX D2EHPA in static conditions

Desorbing solution	Scandium concentration in strippant, mg/dm^3; during desorption, hour						Extraction degree, %
	1	2	4	6	12	24	
Na_2CO_3	0.60	1.13	2.33	3.10	4.33	7.05	~100
NH_4HF_2	1.8	2.62	3.35	3.65	3.75	4.32	76
HF	4.74	5.53	5.86	6.27	6.56	7.22	~100
NaF	0.0025	0.068	0.068	0.065	0.070	0.096	2
NaOH + Na_2CO_3	0.48	0.85	1.15	1.20	1.15	1.09	13
Citric acid	0	0	0	0	0	0	0

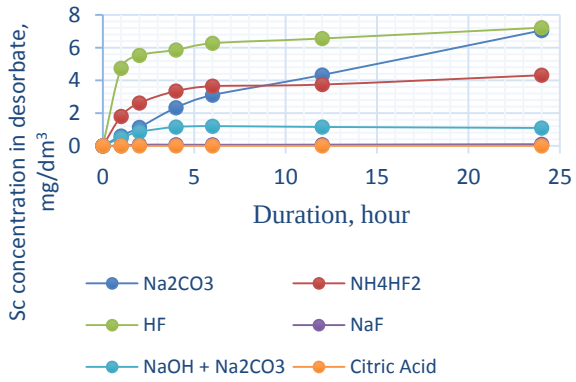

Figure 4 – Kinetic curve of scandium desorption from TVEX D2EHPA resin using various desorption solutions and extraction degree from the resin

From the data presented in table 8 and figure 4, it can be seen that when using solutions of sodium carbonate Na_2CO_3 (200 g/dm^3) and hydrofluoric acid HF (3.5M) as desorption solutions, almost complete scandium desorption from the TVEX D2EHPA resin was observed in static conditions. Nevertheless, a carbonate-alkaline solution of 0.5M NaOH + 1M Na_2CO_3 and a 3.5M solution of sodium salt of hydrofluoric acid NaF showed very low desorption characteristics. An ammonium fluoride NH_4HF_2 solution, devoid of the disadvantages of carbonate-alkaline desorbates, is applied to desorb scandium from phosphorus-containing ion exchangers. In our experiments desorption degree with scandium-saturated TVEX D2EHPA ion exchanger using a 3.5M solution of NH_4HF_2 at room temperature was 76%. As can be seen, the desorption results obtained are in good agreement with the literature.

Conclusion. Scandium equilibrium sorption characteristics from model solutions by organophosphorus ion exchangers were studied. Scandium sorption by selected ion exchangers was carried out under static and dynamic conditions. Saturation on the TP260 ion exchanger at 700 sp.vol. equal to 0.027 kg/m^3 and on D2EHPA ion exchanger at 2382 sp.vol. equal to 0.236 kg/m^3 were obtained during passed volumes. It was found that desorption degree with scandium-saturated Lewatit TP260 ion exchanger using a solution of 200 g/dm^3 Na_2CO_3 was 87.26%; whereas with TVEX D2EHPA ion exchanger using solutions of sodium carbonate Na_2CO_3 (200 g/dm^3) and hydrofluoric acid HF (3.5M) was about 100%. A carbonate-alkaline solution of 0.5M NaOH + 1M Na_2CO_3 and sodium salt solution of hydrofluoric acid 3.5M NaF showed low desorption characteristics. Consequently, phosphorus-containing ion exchangers Lewatit TP260 and TVEX D2EHPA can be proposed as promising sorbents for scandium extraction from uranium in-situ leaching solutions.

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ФОСФОРЛЫ СОРБЕНТТЕРМЕН СКАНДИЙДІ БӨЛІП АЛУ

Аннотация. Ғылымды қажет ететін инновациялық технологиялардың дамуы сирек кездесетін жер элементтерін өндіру әрі пайдалануға байланысты, олардың арасында скандий перспективті. Скандийдің ықтимал қайнаркөзінің бірі – уранды жерасты шаймалау ерітінділері. Қазақстанда скандий өндірісінің мығым әлеуеті бар. Уранды жерасты сілтісіздендіру арқылы скандий алудың жоғары тиімді, экономикалық тұрғыдан тиімді технологиясын зерттеу және әзірлеу өзекті ғылыми-техникалық міндет болып саналады. Скандийді бөлудің және тазартудың ең тиімді әдісі – әртүрлі ерітінділер экстракциясы. Органофосфор

қышқылының экстрагенттері скандийді экстракция және скандийді басқа элементтерден бөлу үшін перспективті болып келеді.

Зерттеу аясында фосфорлы Lewatit TP272, Lewatit TP260, ҚЭ Д2ЭГФҚ (қатты экстрагент ди-(2-этилгексил) фосфор қышқылы) және ФОР (түрлі радикалды фосфин оксиді) иониттерімен модельді ерітінділерден скандий сорбциясы зерттелді. Сорбциялық изотермалар және скандий сорбциясының интегралды кинетикалық қисықтары алынды. Зерттелетін иониттер үшін скандийдің статикалық алмасу сыйымдылығы және толық динамикалық алмасу мүмкіндігі анықталды. Алынған нәтижелер скандийдің сорбциялық экстракциясын одан әрі зерттеу үшін Lewatit TP260 және ҚЭ Д2ЭГФҚ иониттерін таңдауға мүмкіндік берді.

Сорбцияны статикалық жағдайда зерттеуде 0,04 ден 4 г дейінгі шайырдың өлшенген бөлігі 5 дм^3 көлеміндегі контейнерге орналастырылды, оған нақты скандий концентрациясы бар ерітіндінің белгілі бір мөлшері енгізілді, контейнерді мықтап жауып, LS110 радиалды шайқаушыға салынды. Зерттеу ерітінді көлемінің ионит массасына шексіз қатынасы арқылы жүргізілді С:Қ 1000:1 (5дм^3:5 г). Динамикалық жағдайда сорбцияны зерттеуде ионит 30 см3 органикалық әйнек бағанына орналастырылды (сорбент қабаты биіктігінің диаметрге қатынасы h/d = 4,8:1). Ерітінді түбінен жоғарыға шайыр скандиймен қаныққанға дейін ионит қабаты арқылы өткізілді. Меншікті жүктеме 10 меншікті көлем/менш.көл./сағат болды. Ерітінділердің өткізіп алынған көлемі бойынша TP260 ионитте 700 менш.көл. қанықтырылды (ол 0,027 кг/м^3 тең) және Д2ЭГФҚ ионитте 2382 менш.көл. (ол 0,266 кг/м^3 тең).

Динамикалық жағдайда қаныққан иониттен Lewatit TP260 натрий карбонаты Na_2CO_3 ерітіндісімен (концентрациясы 200 г/дм^3) скандийді десорбциялау үдерісі жүзеге асырылды. Бөлме температурасындағы десорбция дәрежесі 87,26% көрсетті. Қаныққан ҚЭ Д2ЭГФҚ иониттен скандийді десорбциясы түрлі десобциялық ерітінділерді қолдана отырып, статикалық жағдайда жүргізілді. Төмендегі концентрациядағы десорбциялық ерітінділер пайдаланылды: 200 г/дм^3 Na_2CO_3; 3,5M NH_4HF_2; 3,5M HF; 3,5M NaF; 0,5M NaOH + 1M Na_2CO_3; 5% – лимон қышқылының ерітіндісі (citric acid). Натрий карбонаты Na_2CO_3 ерітіндісін және гидрофторлы қышқылды HF десорбциялық ерітінді ретінде пайдалану кезінде статикалық жағдайда ҚЭ Д2ЭГФҚ шайырынан скандийдің толық десорбциясы байқалды. Аммоний фторидінің NH_4HF_2 ерітіндісін қолданғанда скандийдің бөліп алу дәрежесі 76% көрсетті. Карбонатты-сілтілі ерітіндісі және натрий тұзының гидрофторлы қышқылының ерітіндісі NaF аса төмен десорбция сипаттамаларын көрсетті.

Түйін сөздер: скандий, сорбция, десорбция, экстракция, бөліп алу дәрежесі, алмасу сыйымдылығы, сүзінді.

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ИЗВЛЕЧЕНИЕ СКАНДИЯ ФОСФОРСОДЕРЖАЩИМИ СОРБЕНТАМИ

Аннотация. Развитие наукоемких инновационных технологий связано с получением и применением редкоземельных элементов, среди которых перспективным является скандий. Один из потенциальных источников скандия – растворы подземного выщелачивания урана. Казахстан обладает необходимым потенциалом для производства скандия. Исследование и разработка высокоэффективной, экономически приемлемой технологии извлечения скандия из растворов подземного выщелачивания урана является актуальной научно-технической задачей. Наиболее эффективным способом разделения и очистки скандия является экстракция из различных растворов. Кислотные фосфорорганические экстрагенты являются перспективными для экстракции и отделения скандия от других элементов.

В рамках работы проведены исследования сорбции скандия фосфорсодержащими ионитами Lewatit TP272, Lewatit TP260, ТВЭКС Д2ЭГФК и ФОР из модельных растворов. Получены изотермы сорбции и интегральные кинетические кривые сорбции скандия. Для исследуемых ионитов определены значения СОЕ и ПДОЕ по скандию. Полученные результаты позволили выбрать иониты Lewatit TP260 и Д2ЭГФК для дальнейшего изучения сорбционного извлечения скандия.

При исследовании сорбции в статических условиях навеску смолы в диапазоне от 0,04 до 4 г помещали в емкость объемом 5 дм^3, вводили в нее определенное количество раствора с известной концентрацией скандия, герметично закрывали емкость и ставили ее на радиальный шейкер LS110. Исследование в статических условиях проводили при большом соотношении объема раствора к массе ионита Ж:Т 1000 : 1 (5дм^3 : 5 г). При изучении сорбции в динамических условиях ионит помещали в колонку из оргстекла объемом 30 см^3 (отношение высоты слоя сорбента к диаметру h/d = 4,8:1). Через слой ионита пропускали раствор снизу-вверх до полного насыщения смолы скандием. Удельная нагрузка составляла 10 уд.об./уд.об./час. При пропущенных объемах растворов удалось получить насыщение на ионите TP260 при 700 уд.об. равным 0,027 кг/м^3 и на ионите Д2ЭГФК при 2382 уд.об. равным 0,236 кг/м^3.

Десорбцию скандия с насыщенного ионита Lewatit TP260 проводили в динамических условиях раствором карбоната натрия с концентрацией 200 г/дм^3 Na_2CO_3. Степень десорбции при комнатной температуре составила 87,26 %. Десорбцию скандия с насыщенного ионита ТВЭКС Д2ЭГФК проводили в статических условиях с использованием различных десорбирующих растворов. Были использованы десорбирующие растворы следующей концентрации: 200 г/дм^3 Na_2CO_3; 3,5М NH_4HF_2; 3,5М HF; 3,5М NaF; 0,5М NaOH + 1М Na_2CO_3; 5% – раствор лимонной кислоты (citric acid). При использовании растворов карбоната натрия Na_2CO_3 и фтористоводородной кислоты HF в качестве десорбирующих растворов наблюдалась практически полная десорбция скандия со смолы ТВЭКС Д2ЭГФК в статических условиях. При использовании раствора фторида аммония NH_4HF_2 степень извлечения скандия составила 76%. Карбонатно-щелочной раствор и раствор натриевой соли фтористоводородной кислоты NaF показали весьма низкие десорбирующие характеристики.

Ключевые слова: скандий, сорбция, десорбция, экстракция, степень извлечения, обменная емкость, фильтрат.

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DEVELOPMENT OF CONTROL SUSPENSION OF ATTACHMENT OF A BULLDOZER

Abstract. Analysis of research in the field of improving the working equipment of the bulldozer showed that the applied kinematic schemes of the bulldozer attachments do not allow changing the cutting angles in accordance with ground conditions, in connection with which the possible reduction of soil resistance to cutting and energy consumption of earth-transport vehicles is not ensured. There is a methodology of settling the definitions of rational parameters of hanging equipment of bulldozer, which provides depth of the tool with the angle of cut α=55÷60° and is next automatical decreace till α=20÷25° at definite thickness of shavings, dependent on the category of cultivated soil. Change of angle of cut and its characteristics will be settled according to definite analytical dependence. It lowers the energy capacity to 8.1÷67.8% because of the increase of shaving thickness or rising the working speed and creates conditions for lowering the working expenditures 17.5%, the basic cost of works - 18.8%, specific investment of the machine - 15.6% and given expenditures - 18.5%.

Key words: bulldozer, suspension, knife, cutting angle, brace, ground.

Introduction. The bulldozer is a widespread earth-moving transport vehicle (EMM) due to its simplicity of construction, versatility and relatively low cost. To ensure the penetration of the blade into the ground, it is installed with a cutting angle of 55-60°, which reduces the resistance when buried, but creates additional resistance when cutting the soil. Improvement of the construction of the suspension of the working equipment (WE) of the bulldozer, which ensures the adaptation of its cutting angle in the process of digging, depending on the indices of the physical and mechanical properties of the soil and the operating mode, is a promising direction that increases the efficiency of EMM.

The creation of a suspension, which will ensure a synchronous change in the angle and depth of cutting, improves the technical and economic indicators and simplifies the construction of the WE bulldozer. Therefore, the rationale for the rational kinematic parameters of the WE suspension of a bulldozer with a variable cutting angle is an urgent task.

The purpose of the work is to increase the efficiency of EMM by reducing the energy consumption of the cutting process of soils by adapting the cutting angle when the blade is buried, taking into account the soil category provided by the parameters of the bulldozer's WE suspension [17,18].

Scientific novelty of work consists in justifying the parameters of the bulldozer RO suspension with synchronous change of the angle and depth of cutting, depending on the category of the ground being developed, which significantly reduces the energy consumption of the EMM [1,4,11].

Methods. The considered resistance to penetration of the bulldozer knife with a stationary machine. Deepening of the working body of the bulldozer into the ground is represented as pressing into an array of

a stamp having a complex shape, on which the force developed by the drive mechanism acts. Under the action of the gravity of the working element and the force developed by the drive, a stress occurs in the soil massif on both sides of the knife edge (front and rear), the size and distribution of which depend on the load, the geometric parameters of the knife and the parameters of the soil. The forces acting on the edge of the knife with indentation are determined by the method of S.S. Golushkevich.

An increase in the cutting angle reduces the size of the projection of the implanted part of the blade to the horizontal plane, and, accordingly, reduces the area of contact with the ground and the volume of the prism of the bulging. As a result, the specific vertical pressure of the knife on the ground increases and its resistance to the introduction of the blade decreases. Consequently, the burial of the working body of the bulldozer into the ground with a stationary machine must be carried out with a large cutting angle.

Deepening the working body of the bulldozer into the ground while the machine is moving ahead of the cutting blade creates a strained ground condition on only one side, located in front of the knife in the course of travel. Therefore, the resistance to burial of the blade when driving the machine is less than when the machine is stationary. Thus, this allows the blade to be embedded in the ground with smaller cutting angles. From this it follows that the most rational trajectory of the working motion of the blade of the suspension to be investigated is the one that, at the moment of its introduction into the ground, the cutting angle has a maximum value and then decreases it, which is optimal by minimizing the energy consumption of the cutting process.

This can be realized by the WE suspension of the bulldozer with a hinged brace. When the blade is buried, the cutting angle in this case will automatically change, which will simplify the construction of the WE bulldozer and significantly reduce the fatigue of the driver. Reduction of the cutting angle when the blade of the bulldozer WE suspension is buried is determined by the coordinates of the points of attachment of the hinged brace to the tractor base and on the dump, the length of the splitting a and the depth of the dump, and does not depend on the parameters of the physical and mechanical properties of the soils [1,2,3,4].

The scheme [5,6,7,15] of the suspension of the WE bulldozer is represented in the form of a flat mechanism consisting of links connected by hinges. In this case, the suspension is a four-link shunting arm of the *ABCD* (figure 1, a) in the form of a closed four-link chain with one degree of freedom, in which the driving link *AB* (brace), the connecting rod *BC*, the distance between the points of fastening of the bracing and the pushing bar on the dump) and the fixed link *AD* distance between the points of attachment of the brace and the pushing bar on the base machine). In mechanisms with one degree of freedom, one generalized coordinate completely determines the position of all links of the mechanism. By changing the slope angle φ of the *DC* link, it is possible to determine the slope angle ψ of the department link *AB*, and also vice versa, knowing the position of the master *DS* and the follower AB links, determine the angle λ of the turn of the connecting rod link *BC*. For this purpose, in the scheme of the four-link mechanism we select conditionally the parallelogram *ABB'D*. From the *BCB'* and *DCB'* , by the cosine theorem we determine the length of the *CB*:

$$/CB'/ = L^2 + l^2 - 2Ll\cos\lambda\,;\ /CB/ = R^2 + r^2 - 2Rr\cos(\varphi - \psi)$$

where *L* - is the length of the fixed link *AD*; *l* - length of the connecting rod of the aircraft; λ - is the angle of rotation of the connecting rod link *BC* to the fixed link *AD*; *R* - is the length of the *DC* link; *r* - length of the driven link *AB*; φ - is the angle of inclination of the *DC* link to the vertical axis; ψ - is the slope angle of the follower link *AB* to the vertical axis.

Equate the value $/CB'/$ and converting the resulting expression, we find the value of the angle λ:

$$\lambda = \arccos\left(\frac{L^2 + l^2}{2Ll} - \frac{R^2 + r^2}{2Ll} + \frac{Rr}{Ll}\cos(\varphi - \psi)\right). \quad (1)$$

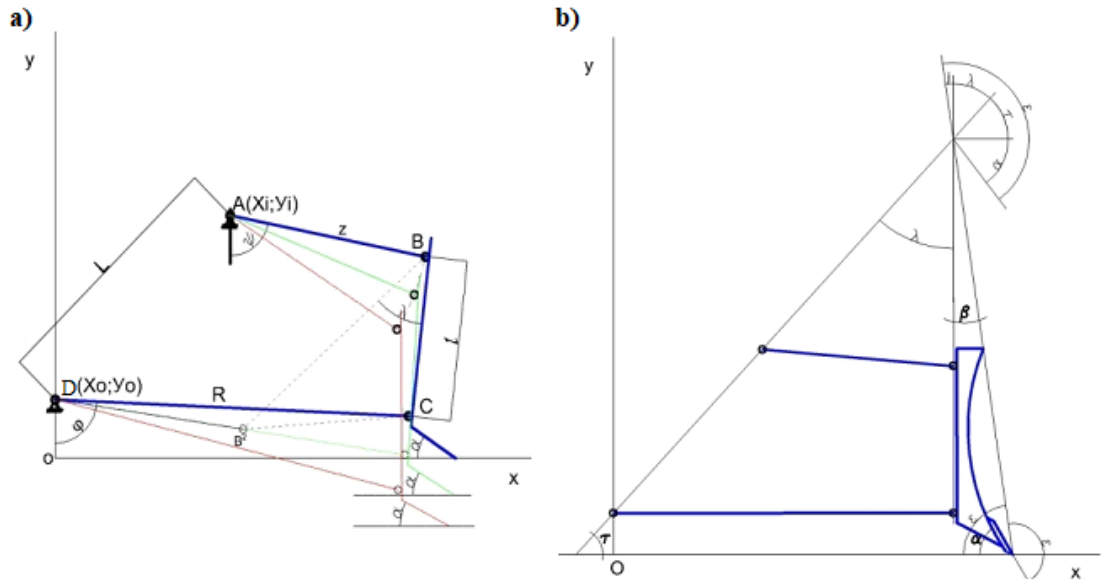


Figure 1 – Suspension scheme (a) with articulated luxury and determination of cutting angle (b)

The angle of rotation of the crank arm on the articulated four-link diagram corresponds to the angle of rotation of the blade of the bulldozer under actual conditions when its position changes.

The main angles $\lambda, \omega, \tau, \beta_0$, that characterize the suspension but also the structure of the dump will be transferred to the point O_1 of the intersection of the line connecting the points of fastening of the pushing beam and the brace on the base machine, with the line of fastening of the same elements on the dump (figure 1, b). The cutting angle will be:

$$\alpha = \omega - \beta_0 - \tau - \lambda, \tag{2}$$

where ω- is the angle between the line connecting the upper edge of the dump surface with the cutting edge of the blade knife and the dummy blade element, ω = 160°; τ - is the angle between the line connecting the points of fastening of the bracing and the pushing bar on the base of the tractor, and the horizontal axis:

$$\tau = arctg\left(\frac{Y_i - Y_0}{X_i - X_0}\right)$$

where X_i, Y_i - are the coordinates of point *A*; X_0, Y_0 - are the coordinates of point *D*; β_0 - is the angle between the line connecting the points of fastening of the bracing and the pushing beam on the dump, and the line connecting the upper edge of the dumping surface with the cutting edge of the middle knife blade, $\beta_0 = 19 \div 21°$.

We set the angles $\lambda, \omega, \tau, \beta_0$ in equation (2) and obtain:

$$\alpha = 141^\circ - arctg\left(\frac{Y_i - Y_0}{X_i - X_0}\right) - \arccos\left(\frac{L^2 + l^2}{2Ll} - \frac{R^2 + r^2}{2Ll} + \frac{Rr}{Ll}\cos(\varphi - \psi)\right). \tag{3}$$

The value of the cutting angle α in expression (3) is determined by the points of fastening of the brace on the base of the tractor and on the dump, i.e. the length of the brace, and also the depth of the blade (with the value of φ and ψ). Thus, the obtained expression makes it possible to determine the cutting angle of the WE bulldozer for all intermediate values (the thickness of the cut chips).

During the operation of the bulldozer, the soil resistance to digging is composed of the main parts: soil resistance *Wp*, resistance to movement of the chip along the blade *Wc* and resistance to movement of the prism of the inclusion *Wnp* [8,9,10,12].

$$W_k = W_p + W_c + W_{np} \quad (4)$$

Resistance of cutting the soil taking into account the cutting angle on the basis of the results of research by A.N. Zelenin and N.G. Dombrovsky looks like this:

$$W_p = K_a K_p bh \quad (5)$$

where K_α - is a coefficient that depends on the cutting angle; K_p - specific resistance to cutting; b - length of blade; h - depth of cut.

Based on the graph proposed by Yu.A. Vetrov, for describing the changes in the cutting force going to overcome the frontal resistance of the knife for different ranges of the cutting angle, expression (5) can be expressed by the following spline function:
at a cutting angle of 45° <α<60°:

$$W_p = K_p bh\left[1 - 0.033\left(60^0 - \alpha\right)\right] \quad (6)$$

at an angle of 37° <α<45°

$$W_p = 0{,}5K_p bh\left[1 - 0.029\left(45^0 - \alpha\right)\right]; \quad (7)$$

at a cutting angle of 20° <α<37.5°

$$W_p = 0{,}35K_p bh\left[1 - 0.019\left(37{,}5^0 - \alpha\right)\right]; \quad (8)$$

Forces to overcome the resistance to displacement of the prism of drawing is determined by the formula:

$$W_{np} = \frac{bH^2}{2K_{np}} p_{zp} g\mu_2, \quad (9)$$

where g - is the acceleration due to gravity; H - blade height without visor; K_{np} - coefficient depending on the characteristics of the soil and the shape of the blade; ρ_{zp} - is the density of the groove; μ_2 - is the coefficient of internal friction of the soil.

Forces to overcome the resistance to movement of chips on the dump is determined by the formula:

$$W_C = \frac{bH^2}{2K_{np}} p_{zp} \cos\alpha\left(\frac{\mu_1 + \mu_2}{2}\right) \quad (10)$$

where μ_1 - is the coefficient of external friction of the soil.

Thus, the components of the digging forces of the displacement of the prism and chips are approximately conserved on other soils. This is because the parameters of gravity and friction of loosened soils vary in relatively small limits. Only the cutting depth that the bulldozer can provide for pulling force is significantly changed.

Results. The results of experimental studies of the effect of attachment points and articulated brace on the cutting angle, depth of cutting and resistance to digging. Experimental studies were carried out for various variants of attachment of a hinged brace, one end of which is set from the top downwards along the height of the botulinum on its rear side (points 1,2,3,4,5,6,7,8 and 9). The other end is fixed on the tractor base: on the horizontal line from right to left on the side of the engine frame (points 1 ', 2', 3 ', 4', 5, 6 'and 7) or on the vertical line from the bottom up the side of the engine cooler (points 1", 2", 3", 4", 5", 6" 7"), while the points 3 and 3" are combined [7,8].

The change in the position of the suspension bracket WE when the dump is buried is accompanied by a change in the angle of the inclination of the pushing bar (figure 2).

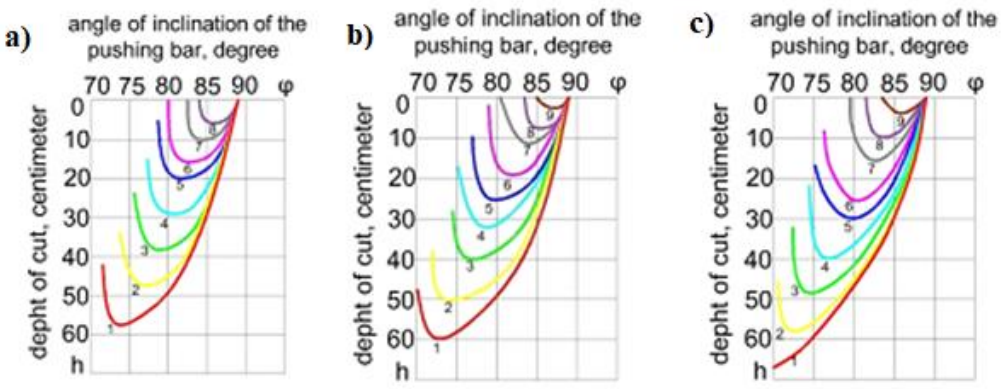
The displacement of the pushing bar downward to a certain angle is accompanied by an increase in the cutting depth to a certain value, further angular displacement of the pushing bar is accompanied by a sharp turn of the blade, which leads to a deepening of its cutting edge and a decrease in the depth of cutting. Such a change in depth of cut is retained when the hinged brace is attached to the tractor base both horizontally and vertically. In both cases, the point of change in the cutting depth is characteristic, after which the cutting edge is deepened, is determined by the length of the brace. Its increase when moving the

fixing point of the brace on the back of the blade from point 1 to point 9 leads to an increase in the thickness of the chips, at which a sharp turn of the blade occurs.

Processing of the results of experimental studies allowed to establish the maximum depth of cutting, at which the cutting edge extends depending on the parameters of the suspension, the RO bulldozer with a hinged brace:

$$h_{\max} = -1.6 \cdot 10^{3} + 2.2 \cdot 10^{-4} \cdot L^{2} + 5.009 \cdot 10^{-4} (l + r)^{2} + 5.7824 \cdot 10^{-12} (l + r)^{2} \cdot L^{2}. \qquad (11)$$

This dependence simplifies the calculation of the maximum depth of cutting of the bulldozer, since the value of the coordinated parameters is averaged. Therefore, the expression obtained can be used for any kinematic suspension parameters with a hinged brace [9,10].



a, b, c - attachment points on the side of the engine frame, respectively 5', 6' and 7'; 1,2,3,4,5,6,7,8, and 9 - points of attachment on the blade

Figure 2 – The relationship between the angle of inclination of the pushing beam and the depth of cut when the coordinates of the points of attachment of the hinged brace change

When the dump is buried, the enlarged pendant WE of the bulldozer increases the cut-off chips and reduces the cutting angle. When a certain critical depth of cut is reached, it begins to decrease with a leading tendency to reduce the cutting angle. The change in the depth and angle of cutting is determined by the coordinates of the points of attachment of the hinge brace (figure 3).

The suspension of the bulldozer WE controls the spatial movement of the blade with simultaneous changes in the depth and angle of cutting. This leads, in turn, to a change in the resistance to cutting, the movement of chips along the dump surface, the displacement of the prism of drawing, and the resulting resistance to digging. Therefore, the evaluation of the effectiveness of the coordinates of different points of attachment of the hinge brace can be carried out only from the standpoint of energy indicators. In this regard, consider the emerging resistance when using the bulldozer's WE suspension and changing the coordinates of the points of attachment of the hinged brace for I, II, III and IV soil categories.

As a result of the processing of the machine experiment, the equation of regression of resistance to cutting of soil of the first category, in kN:

$$W_{p} = 10{,}193 + 328{,}33 \alpha h \qquad (12)$$

The graph of this dependence for various attachment points of the hinged brace is shown in figure 5 from which it is evident that when the blade is lowered, an increase in chip thickness results in an increase in the cutting resistance to a certain depth, further lowering of the blade results in its intensive rotation, which is accompanied by a deepening of the cutting edge with a sharp decrease in the cutting angle. As a result, the resistance to cutting is reduced and its dependence on depth in graphical form is expressed in the form of a loop.

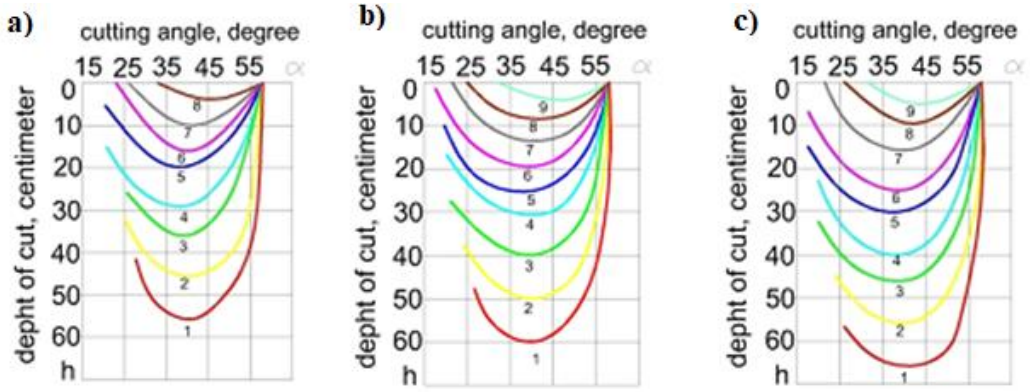
The resulting resistance to cutting is not the determining energy indicator of the process of soil development, so it is advisable to analyze the total resistance to digging. The nature of the change in resistance to digging for I, II, III and IV soils is similar to the described dependence of the change in the cutting force, and the absolute values increase. Because the power plant power of a particular basic machine.

Constant, then increasing the emerging resistances digging the ground leads to a decrease in chip thickness. From this it follows that it is necessary to find the position of the coordinates of the points of attachment of the hinges of the brace, which would satisfy the requirements of all categories of soils.

Analysis of the influence of the coordinates of the points of attachment of the hinged brace on changes in the angle and depth of cutting, resulting in the resistance to cutting and digging, showed the multiplicity of solutions to the variants of the brace. The category of soil affects the location of the brace, for practical conditions it is necessary to have a minimum number of permutations of the brace on the blade and the base tractor. The processing of experimental data by mathematical statistics allowed us to establish the relationship between the parameters of the WE suspension of a bulldozer with a variable cutting angle and digging resistance for I-IV soil categories, which has the form in kN:

$$W_к = 27{,}17 + 5{,}21K_p\alpha h \tag{13}$$

This dependence makes it possible to determine the resistance to digging with a variable cutting angle depending on the kinematic parameters of the bulldozer's WE suspension. It is valid for any suspension parameters.



a, b, c - attachment points on the side of the motor frame, respectively,
5', 6' and 7'; 1,2,3,4,5,6,7,8 and 9 - fixing points on the blade.
Figure 3 – The relationship between the angle and the depth of cut when changing the coordinates of the hinge brace

Increasing the thickness of the chip to be cut increases the resistance to digging, the rate of increase is somewhat lower than that of chip thickness, due to the reduction in the cutting angle. So, for example, when one end of the brace is set at point 7 and the other end of the brace is moved from point 6 to point 3, the maximum depth increases from 25 cm to 47 cm, i.e. 1.88 times, and resistance to digging increases in this case for the I category from 62 kN to 105 kN (1.69 times), for the IV category from 229 kN to 373 kN (1.63 times). This leads to a disproportionate distribution of the cost of resistance to digging for 1 cm of the thickness of the cut chips.

In real conditions, the thickness of the chips cannot increase indefinitely, since the power of the power plant of a particular tractor is constant, assume that the pulling force of the basic T-130 tractor is fully realized on digging the soil, on the basis of this assumption, we determine the maximum possible depth and resistivity for digging for different variants of points fixing the brace taking into account the soil category [13,14,15,16].

Analysis of the variants of the braces with the minimum values of the resistivity to digging shows that the braces with fastening along the vertical line of the base tractor have higher specific indicators. This indicates that in these cases, the suspension does not ensure proper minimization of the cutting angle, which leads to higher values of the resulting resistances. Therefore, such options for fastening the hinge brace are excluded from further analysis.

To assess the effectiveness of the adopted options for fastening the hinged brace, we determine the deviation from the best value of the energy index and the depth of digging. With a pulling force of 100 kN for the 1st category of soil, the minimum value of the specific resistance to digging and the maximum chip thickness is provided by the variant of the brace 7'-4. Recommended brace 5'-3, which increases energy consumption by 9.3% and reduces the maximum depth by 12.5%. For category II, the best option is the

6-6 variant of the brace, the recommended option for paccos 5'-5 raises energy costs by 0.4%, but increases the maximum depth by 5.3%. For category III, the best value corresponds to a brace - 4'-6, the recommended brace 5'-7 raises energy consumption by 3.1% and reduces the maximum depth by 9.1%. The greatest deviation corresponds to the IV category of the soil, because the chip thickness is small (5 cm) and its deviation even by 1 cm is expressed by a large number of percentages

Comparative analysis by the energy cost criterion and the maximum digging depth of the most effective variants of attaching the hinged brace and the unified recommended version of the brace shows that the deviations are within the accuracy of the engineering calculation.

Reducing the cutting angle with the burial of the dozer blade reduces the digging resistance, which allows increasing the thickness of the cutter chip at a constant power of the base tractor engine or increasing the cutting speed of the ground. In both cases, the productivity of the proposed equipment is increased in comparison with the basic cutting angle 55^0.

Changes in the productivity of the proposed basic equipment - DZ 27C (table 1) in the construction of the embankment of a 1.0 m high road in real conditions of the WE bulldozer suspension in comparison with the base leads to an increase in productivity for the 8.1 and 13.2%, respectively, of the I-II ground categories, up to 38.0 and 67.8 % on soils of III - IV categories and gives a significant reduction in labor costs by 17.5%, a decrease in the prime cost of soil development - 18.8%, unit investment in a complex of machines - 15.6% and a reduction of the reduced costs - 18.5%.

Conclusion. The proposed suspension of the working equipment of the bulldozer provides the adaptation of the cutting angle in the conditions of changing ground background, which increases the productivity of the machine complex by building embankments from side reserves by 8.1% for soils of the 1st category for 13.2% of category II, 38% for the III category and for reducing labor costs on 17.5%, prime cost of working out of a ground 18.8%, specific investments on a complex of cars of 15.6% and the resulted expenses of 18.5%.

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БУЛЬДОЗЕРДІҢ АСЫНДЫ ЖАБДЫҒЫНЫҢ БАСҚАРМАЛЫ АСПАСЫН ӘЗІРЛЕУ

Аннотация. Бульдозерлер топырақты қабатпен қазуға арналған және оны кейіннен қайырма күрегінің алдында жерүсті бойынша шағын қашықтыққа жылжытады. Ойық пен үйінді салу, траншея мен қазан шұңқырды қайта жабу, жер бетін қатаң жоспарлау, қиғаш терраса салу, сусымалы жүк өңдеу және орнын ауыстыру, жекелеген ағаш құлату, тас жою, бетін қоқыстан, қардан тазарту, аршу жұмыстарында, сондай-ақ итергіш скреперлер ретінде пайдаланылады. Бульдозер жұмысының тиімділігі базалық трактор өткізгіштігіне және оның тарту-тіркеу қасиеттеріне байланысты.

Бульдозердің жұмыс жабдығын жетілдіру саласындағы зерттеулерді талдау бульдозердің аспалы жабдығының қолданылатын кинематикалық схемалары топырақ жағдайларына сәйкес кесу бұрыштарын өзгертуге мүмкіндік бермейтінін көрсетті, осыған байланысты топырақ кедергісінің кесу және жер қазу-тасымалдау машиналарының энергия шығыны қамтамасыз етілмейтінін байқатты.

Бульдозердің жұмыс жабдығын асындысының кинематикалық параметрлеріне байланысты топырақ санаттарын есепке ала отырып кесу бұрышын есептеу үшін теңдеу ұсынылды. Бұл теңдеуді талдау үйінді қозғалысының ең ұтымды траекториясы енгізу кезінде кесудің ең жоғарғы бұрышын (α=55÷60°) қамтамасыз ететін, кейіннен оны азайту (α=20÷25°).

Машиналық эксперимент нәтижесінде регрессиялық теңдеу алынды, жұмыс орны аспасының кинематикалық параметрлерінен кесу тереңдігі оған жеткен кезде үйіндінің кесетін жиегін тереңдетіледі, бұл топырақты әзірлеу үдерісінің энергия сыйымдылығын азайтуды және бульдозер өнімділігін орташа 8÷17%-ға арттыруды қамтамасыз етеді.

Машиналық эксперимент деректерін статистикалық өңдеу нәтижесінде көшіруге толық кедергіні анықтау бойынша регрессия теңдеуі алынды, ол I-IV санатты топыраққа арналған жұмыс жабдығы аспасының параметрлерін оңтайландыруға мүмкіндік туғызады.

Бұл жұмыста бульдозердің аспалы жабдығының үйлесімді өлшемдерін анықтау әдістемесі берілген. Үйлесімді параметрлер α=55÷60° кесу бұрышы бар қайырманы тереңдету және жер қабатының өңдеу категориясына, белгілі бір қалыңдықта кесілген жаңқаға байланысты қайырманың кесу бұрышы α=20÷25°-қа дейін азайтылады. Кесу бұрышының өзгерісі және оның сипаттамасы белгілі бір аналитикалық тәуелділік арқылы анықталады. Жаңқаның көлемін үлкейту немесе жұмыс жылдамдығын арттыру арқылы кесу үдерісінің энергосыйымдылығын азайтуға және өнімділігін 8.1÷67.8%-ға көбейтуге болады, бұл еңбек күшінің шығынын 17.5%-ға, жұмыстың өзіндік құнын 18.8%-ға, машинаның күрделі қаржы бөлу үлесін 15.6%-ға, келтірілген шығынды 18.5%-ға азайтуға мүмкіндік береді.

Түйін сөздер: бульдозер, асынды, пышақ, кесу бұрышы, қима, топырақ.

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РАЗРАБОТКА УПРАВЛЯЮЩЕЙ ПОДВЕСКОЙ НАВЕСНОГО ОБОРУДОВАНИЯ БУЛЬДОЗЕРА

Аннотация. Бульдозеры предназначены для послойной разработки грунтов с их последующим перемещением перед рабочим органом (отвалом) по поверхности земли на небольшие расстояния. Их используют при сооружении выемок и насыпей, обратной засыпке траншей и котлованов, грубой планировке земляной поверхности, устройстве террас на косогорах, штабелировании и перемещении сыпучих грузов, подготовительных работ для валки отдельных деревьев, удаления камней, расчистки поверхности от мусора, снега, на вскрышных работах, а также в качестве толкачей скреперов. Эффективность работы бульдозеров в значительной мере зависит от проходимости базового трактора и его тягово-сцепных свойств.

Анализ исследований в области совершенствования рабочего оборудования бульдозера показал, что применяемые кинематические схемы навесного оборудования бульдозера не позволяют изменять углы резания в соответствии с грунтовыми условиями, в связи с чем не обеспечивается возможное снижение сопротивления грунтов резанию и энергозатрат землеройно-транспортных машин.

Предложено уравнение для расчета угла резания в зависимости от кинематических параметров подвески рабочего оборудования бульдозера с учетом категорий грунтов. Анализ этого уравнения показывает, что наиболее рациональной траекторией движения отвала является та, которая обеспечивает максимальный угол резания в момент внедрения (α=55÷60°) с последующим его уменьшением (α=20÷25°).

В результате машинного эксперимента получены регрессионные уравнения, максимальной глубины резания от кинематических параметров подвески рабочего оборудования бульдозера, при достижении которой происходит выглубление режущей кромки отвала, что обеспечивает снижение энергоемкости процесса разработки грунтов и повышение производительности бульдозера в среднем на 8÷17%.

В результате статистической обработки данных машинного эксперимента по определению полного сопротивления копанию получено уравнение регрессии, которое позволяет оптимизировать параметры подвески рабочего оборудования для грунтов I-IV категорий.

Разработана методика определения рациональных параметров навесного оборудования бульдозера, обеспечивающая глубину резания инструмента с углом α=55÷60°, в последующем автоматически уменьшается до α=20÷25° при определенной толщине стружки, зависящей от категории обрабатываемого грунта. Изменение угла резания и его характеристика будет определяться по определенной аналитической зависимости. Это снижает энергоемкость до 8,1÷67,8% из-за увеличения толщины стружки или увеличения скорости обработки и создает условия для снижения трудовых затрат на 17,5%, себестоимости разработки грунта – 18,8%, удельных капиталовложений на машину – 15,6% и приведенных затрат – 18,5%.

Ключевые слова: бульдозер, мотыга, нож, угол резания, сечение, грунт.

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МАЗМҰНЫ

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