DETERMINATION OF DRINKING WATER RESOURCES IN THE KARABAKH PLAIN (AGHDAM REGION): THE ROLE OF EXPLORATION AND RESEARCH

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Abstract

Aghdam is one of the regions of Azerbaijan, located in the south-west of the country and administratively belong to the center of Aghdam city.
Until 1992, the Aghdam region, with an area of 1250 km², was considered one of the most developed districts of the republic. However, 77.4% of territory (846.7 km²) was subjected to occupation. The relief of most part of the Aghdam region is flat, although there is also a small upland area.
After the liberation of the territory of the region, in order to restore agricultural and animal husbandry activities, as well as, in accordance with the observed global climate changes, it becomes clear that it is necessary to carefully study and evaluate the water potential of fresh water in this region. Similar studies are key to successful restoration of agricultural activity and maintenance of sustainable development in new climatic conditions.
The article uses data obtained during exploratory drilling. By conducting comprehensive studies and analyzing available literary sources, the characteristics of the hydrogeological situation associated with the occurrence of groundwater and water strikes were clarified. Also, the hydrological conditions in the area where the research was conducted were studied and analyzed.
The conditions of groundwater formation, chemical composition, mineralization and other indicators of groundwater are studied, the areas of their distribution are determined, and recommendations are given for their rational use for irrigation and other purposes in agriculture and to provide the need for fresh water in the liberated Aghdam region.

Keywords: ground water, water strikes, water-bearing horizons, chemical composition, level of mineralization, filtration factor, specific capacity

I. Introduction

When conducting exploration works for a drinking water source, a complex of research surveys is performed at wells. These studies are based on various methods and involve conducting a series of tests to make sure that the water is safe for human consumption. The main stages and methods of exploration for a drinking water source are listed below:

Determining the location of a drinking water source will ensure its correct identification and monitoring.

Hydrogeological studies mainly include analysis of the conditions of occurrence and properties of soil and rock layers along the source area, reconstruction of water migration processes and identification of possible sources of pollution.

Assessing the level of water discharge entering a water source allows for determining its operational stability over different time periods.

Water quality measurement, namely analysis of the physicochemical and microbiological characteristics of water, is performed to determine the presence of contaminants such as heavy metals, bacteria, viruses, nitrates, and other substances that can make the water undrinkable.

Study potential sources of pollution near the source, such as industrial plants, agricultural waste, chemical agent depots, and other sources of contamination.

Identification of the influence of climatic conditions, such as precipitation and temperature that impact on the quality and quantity of water in the source.

Monitoring and serving. After exploration work which carried out, measurement works are conducted and serving should be carried out at the source to ensure its long-term stable and safe operation.

Carrying out these works is an important stage in the possibility of using a source of drinking water, as well as development of appropriate water supply systems for the population.

The Aghdam region is located in the transition zone of the Lesser Caucasus Mountains and the Kura-Araks lowland, in the submountain region of the Karabakh Plain, and it covers an area of 1094 square kilometers. It is geographically being favorable for agricultural activities. The Aghdam city is located in Azerbaijan and is situated in a subtropical climatic region. A subtropical climate is characterized by warm summer and moderately cool winter. General features of the subtropical climate region are:

Summer in subtropical climate is usually long, warm and dry. Average air temperatures in summer-time might have been sufficiently high, often exceeding +25°C. More than 2/3 part of the year is sunny, not enough precipitations. The average temperature ranges in July from +23°C to +26°C.

Winter in the subtropics is cooler, but generally quite mild compared to the continental climate. Temperatures in winter are kept above zero degrees Celsius, but it can sometimes drop below this mark. The average temperature is from -0.2°C to +1.8°C in January.

Rainfall is less in subtropical climates than in temperate zones. Rainfalls are unstable. The amount of annual precipitations is ranges from 300 to 550 mm, most of which falls along the submountain regions.

Humidity of the air can vary depending on the season, but overall, a subtropical climate is less humid compared to a tropical one. As elevation increases, the climate tends to become milder.

Winds in subtropical climates can play an important role in regulating temperatures and precipitations. They can be both cool and warm, depending on the direction and origin [1, 4, 9].

II. Methods

In the article the materials of the history of hydrogeological study of the Aghdam region has been analyzed and used. Geological and geophysical data from exploration drilling, chemical analysis of water samples, and a study of the current hydrological state of the studied area were processed and analyzed.

To determine the water quality of exploration wells, samples were taken, the chemical analysis data of which are given in the following Table 1.

Unique natural features, the diversity of the lithological structure of Quaternary deposits, as well as ameliorative and irrigation works led to complex hydrogeological conditions of the studied territory, riches in underground water lying in alluvial-deluvial and proluvial strata of the Upper Pliocene age. Ground water along the section is found everywhere and is fed by irrigation water from rivers, channels, atmospheric precipitations and vertically seeping water strikes [6, 8, 11, 13].

In areas where precipitation prevails and irrigation is carried out, there is a rise of the ground water level in March-April, which continues until August, and a decrease in the level occurs due to evaporation and is observed from mid-September to the end of October-November. The absolute value of the ground water level varies from 200 m in the Aghdam region to -3 m toward the Kura River. Thickness of the ground waters decrease from 50-60 m in the submountain regions up to 4-5 m toward the Kura River. The total salinity of ground water more than 90% of the territory is 0.3-0.9 g/l, and only in the zones bordering Kura, it increases up to 2-5 g/l. Their chemical composition changes in the direction of water movement from hydrocarbonate to sulfate-hydrocarbonate and then to sodium-chloride.

Table 1: *Chemical water analysis data of exploration wells*

No.	indicator	measurement units	SAUS	well 1	well 2	well 3
1	Smell at 20°C	the score of degree	≤2	0	0	0
2	Color		≤20	1	17	1
3	pH	Unit pH	6-9	7,11	7,55	7.57
4	Total hardness	mmol/l	≤7	7,60	6,90	6.80
5	Salinity	mg/l	≤1000	615,8	884,7	759,3
6	dry residue	mg/l	≤1000	448	747	613
7	Calcium (Ca^{2+})	mg/l	≤100	98,2	152.3	98,2
8	Magnesium (Ma^{2+})	mg/l	≤50	32,8	29.2	23.1
9	Sodium (Na^{+})	mg/l	≤200	17,2	53,4	180,2
10	Potassium (K^{+})	mg/l	≤12	0,5	1,6	4,3
11	Hydrocarbonate (HCO_3^{-})	mg/l	-	335,5	274,5	292,8
12	Sulfates (SO_4^{2-})	mg/l	≤500	104,4	345.0	124,0
13	Chlorides (Cl^{-})	mg/l	≤350	23,0	21,6	18,1
14	Nitrates (NO_3^{-})	mg/l	≤45	3,2	5,6	8,2
15	Nitrites (NO_2^{-})	mg/l	≤3	0,018	0,017	0,056
16	Fluorides (F^{-})	mg/l	≤0.7	0,38	0,33	0,38
17	Iron (Fe)	mg/l	≤0.3	0,26	0,23	-
18	Boron (b)	mg/l	≤0.5	-	-	0,1
19	Manganese (Mn)	mg/l	≤0.1	0,087	0,064	0,052
20	Copper (Cu)	mg/l	≤0.1	0,03	0,35	0,02
21	Chrome (Cr, Vl)	mg/l	≤0.5	0,017	0,013	0
22	Phosphates (PO_4^{3-})	mg/l	≤3.5	0,20	0,60	0,09
23	Aluminium (Al^{3+})	mg/l	≤0.5	0,053	0,008	0,014
24	Nickel (Ni)	mg/l	≤0.1	0,054	0,050	0,048
25	Cobalt (Co)	mg/l	≤0.1	0,034	0,013	0,027
26	Barium (Ba^{2+})	mg/l	≤0.1	0,02	0,02	0,05

The occurrence depth of ground water depends on the features of the terrain, flow slope, rock permeability, changes in the feeding regime and rate of discharge, and decreases regularly in a wide range from west to east. Deep-seated groundwaters are observed in the upper part of the river run-off cone, however, the lowest levels are observed in inter-cone depressions. On the periphery of the region, ground water rises to the surface and forms a system of swamps. In the south-eastern part of the region, ground water is fed by water strikes. The acidity (pH) level of the main part of these waters is 6,5-7 [10, 12, 15, 19].

Since the Aghdam region is part of the Karabakh Plain, the hydrogeological conditions are similar to neighboring regions, and therefore it is considered appropriate to study both together. The site has five water strikes, which are lithologically represented by sand, gravel, large boulders and pebbles with sand and gravel aggregate. Water horizons are separated by impenetrable clays of 17-20 m to 100-130 m thick. The ameliorative state is most affected by the waters of the I pressure horizon. The depth of its roof ranges from 20-60 m to 100-120 m.

The level of salinity of the I pressure aquifer varies from 0.5 g/l to 3.0 g/l. The chemical composition of water varies from hydrocarbonate to hydrocarbonate-sulfate and sulfate. This aquifer is uncovered at a depth of 20-100 m by wells in the eastern and central parts of the region, the thickness of water-bearing rocks here is 5-110 m. The waters of the I pressure horizon are mostly fresh over the entire area, but between of Khachinchay and Tartarchay the level of their mineralization increases, and on the left bank of the Kura River becomes salty.

The spreading area of pressure aquifer II is smaller than the aquifer I. The occurrence depth of its varies from 40-100 m to 180-220 m, but the thickness of water-resistant clays is 10-45 m. The lithological composition of the aquifer is represented by pebbles, sands, and gravels with a sand-clay aggregate. The thickness of pressure reservoir ranges from 60-65 m to 230-240 m. This aquifer contains mainly fresh water, in rare cases there is also water with a total salinity of 1.8 g/l. The level of mineralization of the II pressure aquifer varies from 1.0-1.5 g/l. According to their chemical composition, water belongs to the hydrocarbonate, hydrocarbonate-sulfate, and sulfate-hydrocarbonate types [13, 14, 16, 20].

In comparison with the II aquifer, the area of distribution of the III aquifer pressure complex is much smaller. The depth of the roof of this water-bearing layer is 150-300 m. The lithological composition of the aquifer consists of gravel and sand, which are underlain by water-resistant clays, the thickness of which is 20-60 m. The chemical composition of water varies from hydrocarbonate-sodium to hydrocarbonate-sulfate-sodium and sulfate-hydrocarbonate-sodium with a total degree of mineralization not exceeding 0.5 g/l.

The distribution area of the IV water-pressure (Absheron) complex almost coincides with the distribution area of the III water-pressure horizon. Boreholes have been uncovered this horizon at depths of 135-400 m or more. This horizon was not found on the left bank of the Kura River. The thickness of the water bearing rocks of this complex reaches 20-40 m, the filtration coefficient is 0.9-18.7 m/day, the water flow rate in wells is 0.6-23.2 l/sec, and the specific flow rate varies between 0.1-0.8 l/sec. m. The waters of wells drilled on this horizon gush mainly to a height of 10-15 m above the earth's surface. On the western border of the Inchachay and Tartarchay interfluve, the water level in wells decreases and there is no self-discharge.

The V pressure aquifer in the central part of this plain is uncovered by wells at a depth of 200-280 m. The filtration coefficient in wells is 4.5-5.0 m/day. While the waters of the ground and four pressure aquifers are fresh, the waters of the V aquifer are saline (Tab. 2) [17, 21, 24].

Thus, currently more than 1000 sub-artesian wells with a total flow rate of more than 21,000 m^3/sec are active in the study area[3].

Khachinchay is a left inflowing stream of the Kura River, cross flow the Aghdara, Aghdam, and Barda regions. Length of the river is 119 km and the area of its bed is 657 km^2. Khachinchay is formed by the junction of streams originating from the mountains of Hajigurd (2397 m), Uyukhlu (2316 m), Chichekli (2343 m), and Alagaya (2583 m) of the Karabakh Range. A water-storage reservoir with a capacity of 23 million cubic meters has been restored on the Khachinchay River in a relatively short time.

Until 1990, up to 800 wells were drilled mainly in the eastern part of the region, the current state of which is currently being specified. During the occupation, the forests of Aghdam and valuable reservoirs of the region were destroyed, 25 thousand hectares of the forest were cut down and turned into agricultural area. Before the occupation, there were three water-storage reservoirs on Kondalanchay, with a total capacity of 14,000 m^3. After the liberation of all regions of the Karabakh region from occupation, these reservoirs were restored in a short time, and in the near future they will play an important role in irrigating the lands of the Aghdam and Fizuli regions. The water-storage reservoir built on Gargarchay has already been restored, and work is currently underway on a project to expand this water-storage reservoir [18, 22, 25].

The power of the water complexes of Khachinchay ranges from 35 to 96 meters, filtration coefficient is fluctuate between 8.1-50.6 m/day. The width of underground flow is 1,5 kilometers, and the discharge is estimated about 140,7 l/sec. The thickness of the water-bearing horizons in the Gargarchay cones reaches 37-95 meters, the filtration coefficient is consist 17,6-41,9 m/day. The width of underground flow is also 1,5 kilometers, and the discharge about 323 liters per second is estimated.

Table 2: *Hydrogeological parameters of aquifers of the Karabakh (Aghdam) plain (up to 300-400 m)*

Ground-water horizon	Occurrence depth of the roof of aquifer	Statistic or piezometric level, m	Slope of the hydro-relief	Thickness of aquifers, m	Well flow rate, l/sec	Filtration coefficient of water-bearing rocks, m/day
Ground water	-	0,7-31	0,014-0,001	5-50	0,06-20	0,2-93,2
I pressure horizon	20-100	+2,4-56	0,03-0,0003	4-109,5	0,07-11,7	0,9-38,7
II pressure horizon	70-270	+15,1-22	0,01-0,001	5-104	0,16-13,8	0,1-10,2
III pressure horizon	115-290	+15-7. 5	0.008-0.004	to 51	0,1-10,3	0,5-11,6
IV pressure horizon (Absheron)	125-400 and more	+15-7,8	0,007-0,003	20-40	0,6-23,2	0,9-18,8
V pressure horizon (Aghjagil)	200-380	+3-11,1	0,01-0,005	3-43	0,16-1,2	1,6-4,5

Analysis of the hydrogeological and hydrological conditions of the territory of the Aghdam and the Karabakh regions as a whole indicates that there are water resources available for both soil irrigation and drinking water supply in the area. However, the water monitoring effective management and utilization of surface and groundwater resources is required. The measures should be taken in accordance with the requirements of the "Smart Village" and "Smart City" projects [9, 23].

In the recent past, two channels were dig out from the Tartar River to transfer water from Aghdara to the Aghdam region. In the closest time, the issue of transferring water via the Upper Karabakh Cannel to Aghdam will be solved. Additionally, a significant number of artesian wells will be restored or drilled, and they will be integrated into the water supply cycle.

In summary, active steps are being taken to restore water resources for drinking water supply, soil irrigation, and water resources management within the framework of the "Smart Village" and "Smart City" projects.

The result of this study is the identification of potential fresh water reserves, determination of sufficiency for water supply in cities, villages and hamlets, as well as the possibility of using them for irrigation of agricultural land, and development of ways for their rational exploitation.

Discussions

Due to large-scale climate changes in the territory of the Aghdam region, there is an extremely actual and urgent need to restore agricultural and livestock activities. Climate change processes have had a negative impact on the agricultural sector, reducing yields, deteriorating pasture quality and threatening the food security of the local population. At the same time, to solve these problems, it is extremely important to carry out a complex of studies of the current hydrogeological state of the territory. These studies are aimed for studying the distribution and conditions of underground water resources, as well as assessing their availability. The results of hydrogeological studies will allow to accurately determine and rethink about the prospects for restoring and optimizing agricultural and livestock activities in this area.

One of the main aspects of research is the providing of high-quality drinking water for both the city and surrounding settlements. The correct assessment of the hydrogeological situation determines the possibility of providing the population with a reliable and safe source of drinking water, which is important for the health and well-being of residents.

However, for irrigation purposes, the Yukhari Mil Channel was built, passing via the study area. The construction of the channel, along with global climate changes, caused a drop in the water level of the Kura River, which give a reason of the necessity of exploration and use of underground waters in the Aghdam region.

The geological structure of the studied area includes Mesozoic, Paleogene, Neogene and Quaternary deposits. Unique natural features, a variety of lithological structure of Quaternary deposits, active ameliorative and irrigation works the complex hydrogeological conditions in the studied area have been created. The territory is rich by underground waters and situated in alluvial-deluvial and proluvial strata of the Upper Pliocene [2, 3, 5, 7].

In order to clarify the groundwater reserves and their use for the national economic needs of the liberated territories of the Aghdam region, three exploration wells with a depth of 170-174 m were drilled in 2021-2022.

Drilling to a depth of 170 meters can be carried out using various methods and technologies, such as hand, vertical and horizontal drilling, as well as hydraulic fracturing.

Hand drilling can be used at shallow depths of the aquifer.

Vertical drilling. Currently, there are various types of drilling rigs, including rotary and rod-type, allowing to carry out the trunks of inclined and vertical wells.

Horizontal directed drilling for water can be used when it is necessary to take into account certain restrictions on the surface, for example, the need to preserve existing infrastructure [22-25].

To increase drilling efficiency, hydraulic fracturing can be applied. This method involves injection of fluid into the rock formation under high pressure for the destruction of rocks, with the aim of subsequent increase in water yield. In some cases, explosive drilling is used for drilling rocks at greater depths. This method requires specialized knowledge and equipment, as well as ensuring safety and accuracy in conducting the technological operations. During explosive drilling, special casing and cementing materials can be required, as well as equipment to ensure the stable operation of the well and prevent the collapse of its borehole.

In the Aghdam area, plans also to use installation of the explosive drilling with a downhole pneumatic hammer [20-22].

Conclusion

1. A groundwater horizon and five water strikes have been identified in the studied area. The first three pressure aquifers are associated with Quaternary deposits, while the IV and V horizons are found in the Aghjagil and Absheron stage formations. The chemical composition characterized

by calcium-magnesium, hydrocarbonate, and hydrocarbonate-sulfate waters. The pH value increases from 6,9 to 8,6 in the direction of the Kura River.

2. Infiltration and filtrate waters are play a significant role in the formation of the regime characteristics of groundwater. To increase the productivity of irrigated lands and protect them from salinization, it is necessary to prevent the salt accumulation in the soil. It is extremely important to observe a certain water regime to maintain the moisture concentration in the soil at the level necessary for plant growth. To prevent the rise of the groundwater level, it is necessary to control the distribution of irrigation water according to established and calculated norms.

3. To fundamentally improve irrigated lands, it is necessary implementation of agrotechnical, complex-operational, organizational-economic, and hydromeliorative measures. Improving the ameliorative situation can only be achieved by regulating and improving irrigation methods and increasing the efficiency of drainage systems.

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References

[1] Alekseev, V.I. (2020). Study of changes in the global climate as a complex system using wavelet phase-frequency functions, phase-frequency and phase-time characteristics of heliocosmic and climatic variables. Part 1–2. Bulletin of the Tomsk Polytechnic University. Engineering of georesources, 331, 7, 238-250. [in Russian]. DOI: 10.18799/24131830/2020/7/2733

[2] Amalfitano, S., Bon, A.D., Zoppini, A., Ghergo, S., Fazi, S., Parrone, D., Casella, P., Stano, F., Preziosi E. (2014). Groundwater geochemistry and microbial community structure in the aquifer transition from volcanic to alluvial areas. Water Resources. 65, 384–394. DOI: 10.1016/j.watres.2014.08.004

[3] Babayev, N.I., Tagiyev, I.I. (2015). New information on chemical content of mineral and thermal waters of Azerbaijan’s Quba-Khachmaz.Euros. Union of Sci. 11. 46-52.

[4] Barthel, R.A. Call for more fundamental science in regional hydrogeology. Hydrogeology Journal. 2014, 22, 3, 507-510. DOI: 10.1007/s10040-014-1101-9

[5] Bondarenko, L.V., Maslova, O.V., Belkina, A.V., Sukhareva, K.V. (2018). Global climate change and its aftermath. Herald of the Russian Economic University named after B. Plekhanova. 2, 84-93. https://doi.org/10.21686/2413-2829-2018-2-84-93

[6] Bravo, S., García-Ordiales, E., García-Navarro, F.J., Amorós, J.Á., Pérezdelos-Reyes, C., Jiménez-Ballesta, R., Esbrí, J.M., García Noguero, E.M., Higueras P. (2019). Geochemical distribution of major and trace elements in agricultural soils of Castilla La Mancha (central Spain): finding criteria for baselines and delimiting regional anomalies. Environmental Science and Pollution Research. 26, 4, 3100–3114.

[7] Selvaggi, R., Damianić, B., Goretti, E., Pallottini, M., Petroselli, C., Moroni, B., La Porta, G., Cappelletti, D. (2020). Evaluation of geochemical baselines and metal enrichment factor values through high ecological quality reference points: a novel methodological approach. Environmental Science and Pollution Research. 27, 1, 930-940.

[8] Gyulmamedov, Ch.D. (2021). Influence of the Upper Shirvan Canal on the change in hydrogeological and reclamation conditions of the Shirvan steppe of Azerbaijan. Bulletin of the Tomsk Polytechnic University. Georesource engineering. 332, 10, 116–126. DOI https://doi.org/10.18799/24131830/2021/10/3399

[9] Imanov, F.A., Alekbarov, A.B. (2017). Modern changes and integrated water resources management in Azerbaijan. Baku. [in Russian]

[10] Israfilov, Yu. H, Israfilov, R. H., Guliyev, H. H., Efendiyev, G. M. (2016). Risk assessment of the water resources losses of the Azerbaijan republic due to climate changes. News of ANAS, Earth Sciences, 3-4.

[11] Kerimov, V.M., Sharifov, J.J., Mammadli, M.Z. (2021). Hydrogeological conditions of the Ganykh-Ayrichay valley. In the book: the development of science and practice in a globally changing world in terms of risks. Collection of materials of the IV International scientific-practical conference. Makhachkala. 71-76. DOİ: 10.34755/irok.2021.46.94.048

[12] Montcoudiol N., Molson J., Lemieux J.M. (2014). Groundwater geochemistry of the Outaouais Region (Quebec, Canada): a regional-scale study. Hydrogeology Journal. 23, 2, 377–396.

[13] Tagiev, I.I., Kerimov, V.M., Sharifov, D.D. (2021). Characteristics of the hydrogeological massifs of the Greater, Lesser Caucasus and Talysh (Azerbaijan) taking into account global climate change. Visnyk of Taras Shevchenko National University of Kyiv: Geology, 3(94), 95-102. http://doi.org/10.17721/1728-2713.94.12

[14] Tagiev, I.I., Kerimov, V.M. (2021). Prospects for the development of alternative energy and the use of thermal waters in Azerbaijan. Ural Geolog. Journal. 3(141), 51-57.

[15] Tagiev, I.I., Babaev, N.I. (2017). Some geochemical and hydrogeologial, regularites of formtion and distribution of mineralwaters of Azerbaijan. XXXIX International Scientific and Practical Conference Actual problems in modern science and ways to solve them, Moscow, 15-19.

[16] Tagiyev I.I., Ismailova M.M., Karimov V.M., Sharifov J.J. (2022). Groundwater of Ganikh-Ayrichay foothills on the prospects of use. Reliability: Theory and Applications. 3(66), 17, 76-81. DOI: https://doi.org/10.24412/1932-2321-2022-366-76-81

[17] Wang J., Zuo R., Caers J. (2017). Dickovering geochemical patterns by faktor-based cluster analysis. Journal of Geochemical Exploration. 181, 106–115.

[18] Wang, S. Lee, W., Son, Y. (2017). Low carbon development pathways in Indian agriculture. Change Adaptation Socio-Ecological Systems, 3, 18-26. https://doi.org/10.1515/cass-2017-0002

[19] Substantiation of dth air drill hammer parameters for penetration rate adjustment using air flow Gorny zhurnal, Yungmeister D. A., Isaev A. I., Gasimov E. E., Gorny zhurnal, 2022, 2022(7), pp. 72-77. DOI: 10.17580/gzh.2022.07.12

[20] Jungmeister D. A., Gasymov E. E., Isaev A. I. Substantiation of the design and parameters of the device for regulating the air flow in down-the-hole hammers of roller-cone drilling rigs. Mining Informational and Analytical Bulletin. - 2022. - No. 6-2. - pp. 251-267.
DOI: 10.25018/0236_1493_2022_62_0_251.

[21] Yungmeister D. A., Timofeev M. I., Isaev A. I., Gasymov E. E. Improvement of tunnel boring machine S-782 cutter head. Mining Informational and Analytical Bulletin. - 2023. - No. 1. - pp. 107-118. DOI: 10.25018 / 0236_1493_2023_1_0_107.

[22] Panteleenko F.I. Increasing the productivity of magnetic abrasive processing using diffusion-alloyed powders / F.I. Panteleenko, G.V. Petrishin, V.V. Maksarov, D.D. Maksimov // Russian Engineering Research. 2023. Vol. 43. No. 4 pp. 470-473.
DOI: 10.3103/S1068798X23050179

[23] Maksarov V.V. Quality control of complex contour surfaces in aluminum alloy items during magnetic abrasive finishing / V.V. Maksarov, D.D. Maksimov, M.S. Sinyukov // Tsvetnye Metally, No. 4. 2023. pp. 96-102. DOI: 10.17580/tsm.2023.04.13

[24] Zhukov, I.A., Martyushev, N.V., Zyukin, D.A. et al. Modification of Hydraulic Hammers Used in Repair of Metallurgical Units. Metallurgist 66, 1644–1652 (2023). https://doi.org/10.1007/s11015-023-01480-w

[25] Yungmeister D., Gasimov E. Drill rig with a down-the-hole hammer for regulating the drilling rate by changing the air flow //E3S Web of Conferences. – EDP Sciences, 2021. – T. 326. – C. 00018.