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БАЯНДАМАЛАРЫ

ДОКЛАДЫ

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РЕСПУБЛИКИ КАЗАХСТАН

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THE CONTENT OF HEAVY METALS IN THE SOIL OF CENTRAL KAZAKHSTAN

Abstract. Heavy metal pollution of the environment of urbanized areas has a negative impact on the environment and human health. The whole life of mankind is connected with this soil. Soil is the main component of agricultural production. There are various fertilizers that increase soil fertility. The article provides comparative data on the content of such heavy metals as chromium, zinc and lead for 2019 and 2020 in several cities of the Akmola region. Heavy metals, as a special group of elements, exceed the background in their high concentrations due to their toxic effects on living organisms. This problem is urgent, as more pollution objects are now becoming available. Heavy metals entry into the environment is related to active human activity. Intensive industrial and agricultural use of natural resources has led to significant changes in the biochemical cycles of many of them. Their main sources are industry, motor vehicles, boiler rooms, waste incinerators and agricultural production. Industrial enterprises, roads, railway tracks, landfills, residential buildings and other facilities are adversely affected. The study of soil for heavy metals is of great practical importance. Since heavy metals may be negative, their content should be included in the MPC. The findings can form the basis for monitoring studies and integrated land cover assessment. The results of the study can also serve as a basis for a plan of work to reduce the concentration of heavy metals. Technogenic pressure has an impact on all soil components and especially on such important indicators of fertility and sustainability of lands as organic matter and microorganisms. Technogenic pressure has an impact on all soil components and especially on such important indicators of fertility and sustainability of lands as organic matter and microorganisms. At the same time, the mechanisms of soil contamination with heavy metals are still insufficiently studied, since there were no reliable control methods. At the same time, the mechanisms of soil contamination with heavy metals are still insufficiently studied, since there were no reliable control methods. One of the urgent tasks in soil science is to study the mechanisms of interaction of soil with heavy metals. This will help in the development of reliable methods for monitoring and assessing the level of pollution.

Key words: heavy metals, pollutants, ecology, environment.

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ОРТАЛЫҚ ҚАЗАҚСТАН ТОПЫРАҒЫНДАҒЫ АУЫР МЕТАЛДАРДЫҢ МӨЛШЕРІ

Аннотация. Урбанизацияланған аймақтардың қоршаған ортаның ауыр металдармен ластануы қоршаған ортаға және адам денсаулығына кері әсерін тигізеді. Адамзаттың бүкіл өмірі осы топырақпен байланысты. Топырақ ауылшаруашылығы өндірісінің негізгі құрамы болып табылады. Топырақтың құнарлығын арттыратын әр түрлі тыңайтыштар бар. Мақалада Ақмола облысының бірнеше қалаларында хром, мырыш және қорғасын сияқты ауыр металдардың 2019 және 2020 жылдардағы құрамы туралы салыстырмалы деректер келтірілген. Ауыр металдар элементтердің ерекше тобы ретінде тірі организмдерге уытты әсер етуінің арқасында жоғары концентрацияда фоннан асып түседі. Табиғи ресурстарды қарқынды өнеркәсіптік және ауылшаруашылық пайдалану олардың көпшілігінің биохимиялық циклдерінде айтарлықтай өзгерістерге әкелді. Олардың негізгі көздері – автокөлік, қазандық, қоқыс шығаратын зауыттар және ауылшаруашылық өндірістік көздері. Өнеркәсіптік кәсіпорындар, жолдар, теміржолдар, полигондар, тұрғын үйлер және басқа да объектілер қолайсыз әсер етеді. Техногендік басу топырақтың барлық компоненттеріне, әсіресе органикалық заттар мен микроорганизмдер сияқты құнарлылық пен жердің тұрақтылығының маңызды көрсеткіштеріне әсер етеді.

Сонымен қатар, әлі күнге дейін топырақтың ауыр металдармен ластану механизмдері жақсы зерттелмеген, өйткені бақылаудың сенімді әдістері болған жоқ. Топырақтағы ауыр металдарды және зиянды элементтерді анықтау үшін зерттеудің практикалық маңызы зор, себебі ауыр металдар теріс болуы мүмкін болғандықтан, олардың көлемі ШРК-дан аспауы керек. Алынған нәтижелерді топырақ жамылғысын мониторингтік зерттеулері мен кешенді бағалаудың негізі ретінде қолдануға болады. Сонымен қатар ауыр металдардың концентрациясын төмендету бойынша жұмыс жоспарына негіз бола алады.

Түйін сөздер: ауыр металдар, ластаушы заттар, экология, қоршаған орта.

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СОДЕРЖАНИЕ ТЯЖЕЛЫХ МЕТАЛЛОВ В ПОЧВАХ ЦЕНТРАЛЬНОГО КАЗАХСТАНА

Аннотация. Загрязнение окружающей среды урбанизированных территорий тяжелыми металлами отрицательно сказывается на окружающей среде и здоровье человека. С почвой связана вся жизнь человечества. Почва является основным составом сельскохозяйственного производства. Существуют также различные удобрения, которые повышают плодородие почвы. В статье приведены сравнительные данные по содержанию таких тяжелых металлов, как хром, цинк и свинец, за 2019 и 2020 годы в нескольких городах Акмолинской области. Тяжелые металлы, как особая группа элементов, превышают фон в своих высоких концентрациях из-за их токсического воздействия на живые организмы. Эта проблема актуальна, поскольку в настоящее время становится доступно все больше объектов загрязнения. Попадание тяжелых металлов в окружающую среду связано с активной деятельностью человека. Интенсивное промышленное и сельскохозяйственное использование природных ресурсов привело к значительным изменениям в биохимических циклах многих из них. Их основными источниками являются промышленность, автотранспорт, котельные, мусоросжигательные заводы и сельскохозяйственное производство. Неблагоприят-

ному воздействию подвергаются промышленные предприятия, дороги, железнодорожные пути, свалки, жилые здания и другие объекты. Техногенный прессинг оказывает влияние на все компоненты почв и особенно на такие важные показатели плодородия и устойчивости земель как органическое вещество и микроорганизмы. При этом до сих пор механизмы загрязнения почвы тяжелыми металлами недостаточно изучены, поскольку не было надежных методов контроля. Изучение почвы на наличие тяжелых металлов имеет большое практическое значение, поскольку тяжелые металлы могут быть отрицательными, их содержание должно быть включено в ПДК. Полученные результаты могут лечь в основу мониторинговых исследований и комплексной оценки почвенного покрова. Результаты исследования также могут послужить основой для плана работ по снижению концентрации тяжелых металлов.

Ключевые слова: тяжелые металлы, загрязнители, экология, окружающая среда.

Introduction. At present, the release of heavy metals into the environment is not only natural, but also anthropogenic. These include industrial waste, mining, transport, production of non-ferrous and ferrous metals, the indiscriminate use of fertilizers containing heavy metals, thermal power plants (TPPs) or general urbanization. Many heavy metals, including lead, cadmium, chromium, nickel, and mercury, are toxic. According to scientists, cadmium and lead are ubiquitous and belong to the first class in terms of exposure. Any amount of these elements is very dangerous for the human body and leads to various metabolic disorders in living organisms. MGF has shown diverse effects such as antioxidant, antiapoptotic, radical scavenging, and chelating properties. The extraction and recovery of these valuable metals has significant importance (Naraki et al., 2020:68).

Insignificant variation of the heavy metals was observed amidst the three reaches of the reservoir except for HM which showed a significant difference. Since many heavy metals impart toxicity in one or other way, they must be constantly monitored to prevent fatalities and ecological disasters (Dipak et al., 2020:13). The ratios between non-carcinogenic average daily dose (ADD) of whole wheat flour and wheat flour consumption ranged from 1.06 to 3.76, with Pb having the greatest values compared to other metals. The best fit kinetic model varied among the metals. Environmental factors or heavy metals, such as effectively cooperate in bryophyte distribution. Floodplains downstream of urban catchments are sinks for potentially toxic trace elements.

Studies of flue exhaust gases from fuel combustion plants show that in their composition the main air pollutants are carbon oxides (up to 50%), sulfur oxides (up to 20 percent), nitrogen oxides (up to 6-8%), hydrocarbons (up to 5-20%), soot, oxides and derivatives of mineral inclusions and impurities of hydrocarbon fuels (Babatunde O et al., 2020:24). Together with the exhaust, exhaust and exhaust gases, about 60-80 percent of all the heat received during the combustion of hydrocarbon fuel is discharged into the atmosphere in the form of hot gases and heated water, which also leads to thermal pollution of the atmosphere. In addition, emissions are divided into unorganized, entering the atmosphere as non-directional gas flows as a result of technical problems of the equipment, and organized - coming through specially constructed plants, which is economically profitable and environmentally safe. The pollutants themselves can also be divided into several classes: local, having a short life, and characteristic of a small territory, but nevertheless the most common, regional - spread within the region, and possess a little big term of life. Non-conserved pollutants are volatile, constantly subject to physical and chemical processes, and can be converted to other substances, both more and less toxic (Nigam et al., 2020:68).

Similar phenomena are known for silver. When heated in air, it also dissolves oxygen. If you then heat it in hydrogen above 500 C, bubbles appear in it or it loses its plasticity. The mechanism of this phenomenon is similar to the mechanism of copper hydrogen disease. Silver, not containing oxygen, being kept at 850 C in a hydrogen atmosphere for 1h, does not embitter and does not collapse. Part of the dissolved hydrogen evaporates before oxygen diffuses into silver, so the degree of destruction decreases. Gold and platinum are not subject to destruction when heated in hydrogen, since oxygen is practically insoluble in them (Kelly et al., 2020:483). The presence of lead in the exhaust of automobile engines makes them the most serious sources of environmental pollution by lead. An antiknock agent – tetra methyl- or tetraethyl lead – has been added to most gasoline since 1923 in an amount of 80 mg. When the car moves from 25 to 75% of this lead, depending on traffic conditions, is released into the atmosphere. Although the bulk of it is deposited on the ground, a significant amount of this pollutant can also be contained in the air. Of particular danger to humans and the environment are lead and its compounds contained in gas emissions from automobiles. Lead compounds, mainly tetraethyl lead (TPP), are added to gasoline to increase octane performance (Liping et al., 2020:76).

The burning of fossil fuels such as coal, oil and natural gas is the main cause of anthropogenic CO2 emissions as well as deforestation.

The purpose of work is identifying the content of hazardous elements and metals in Central Kazakhstan’s soil.

Research material and methods. The object of the study is the content of heavy metals in the soil of the cities of Akmola region such as Kokshetau and Shchuchinsk, as well as the ratio of the content in 2020 to 2019. Heavy metals such as chromium, lead, zinc and cadmium were sampled (Tuomikoski et al., 2020:5).

Experts note that it is these three factors that contribute to a high and very high level of atmospheric air pollution in settlements with such pollutants as nitrogen dioxide, carbon monoxide, sulfur dioxide, formaldehyde, hydrogen sulfide, suspended particles, phenol, and ammonia. Let's take a closer look at these points:

1. Dispersion of emissions from industrial enterprises - the result of production processes during the combustion of industrial products is the entire list of harmful substances that cause high levels of air pollution. Their dispersal in the air basin over the territory of settlements significantly affects the atmospheric air quality of cities, suburbs and towns (Manara et al., 2020:93).

2. Road congestion by urban transport - the multicomponent emissions of gasoline and diesel fuel from vehicles is one of the main sources of air pollution in settlements by nitrogen dioxide, carbon monoxide, and organic substances, and high congestion of roads, even in cities with good ventilation.

3. Low ventilation of the atmospheric space of settlements - airborne pollutants accumulate in the surface layer of the atmosphere and their concentration remains at a very high level.

Carbon monoxide CO, as mentioned above, is formed by incomplete combustion of carbon in the fuel. Similar formation occurs in the furnace when the furnace shutter is closed too soon (until the coal is finally burned (Bagova et al., 2021:5).

Result and discussion. The results of the study of the content of heavy metals in the soils of the city of Kokshetau and the ratio of the content of heavy metals in 2021 to 2020 are shown in Table 1.

Table 1 - Ratio of content of elements in Kokshetau city between 2019 – 2020.

Name of an element	The average content of an element in 2019 (mg/kg)	The average content of an element in 2020 (mg/kg)
chromium	1.2-1.6	0.36 - 0.91
lead	15.8-31.5	15.2 – 28.2
zinc	0.8 – 1.9	0.3 - 1.2
cadmium	0.37 – 1.9	0.2 - 1.27

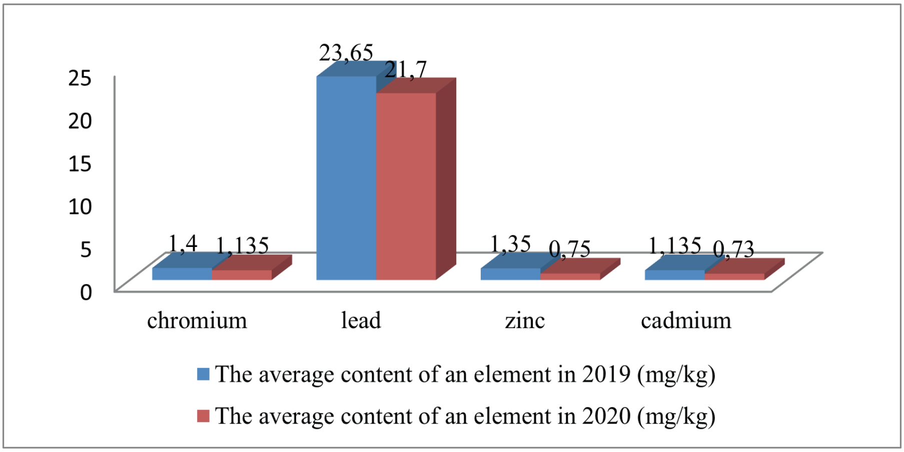

Figure 1 - Ratio of content of elements in Kokshetau city between 2019 – 2020.

Exceeding the maximum permissible concentration was noted in the glassworks for copper – 2.1 MPC.

The content of heavy metals in soil samples taken in Kokshetau is not exceeded the norm (Picture 1). In the city of Kokshetau in soil samples taken in various regions the chromium content was in the range of 0.0036 – 0.02 mg / kg, copper - 0.3 – 20.0 mg / kg, lead - 15.2 – 28.2 mg / kg, zinc – 0.3 - 1.2 mg / kg, cadmium - 0.2 - 1.3 mg / kg. The content of other heavy metals in soil samples taken in the city of Kokshetau did not exceed the norm.

Table 2 - Ratio of content of elements in Kokshetau city between 2019 – 2020.

Name of an element	The average content of an element in 2019 (mg/kg)	The average content of an element in 2020 (mg/kg)
chromium	0.86 - 1.69	0. 184 - 0. 813
lead	3.07 - 11.2	0.13 – 1.37
zinc	2.41 - 2.76	0.31 - 1. 56
cadmium	1.76 – 2.57	0.27 – 1.43

The content of other heavy metals in soil samples taken in the city of Shchuchinsk did not exceed the norm.

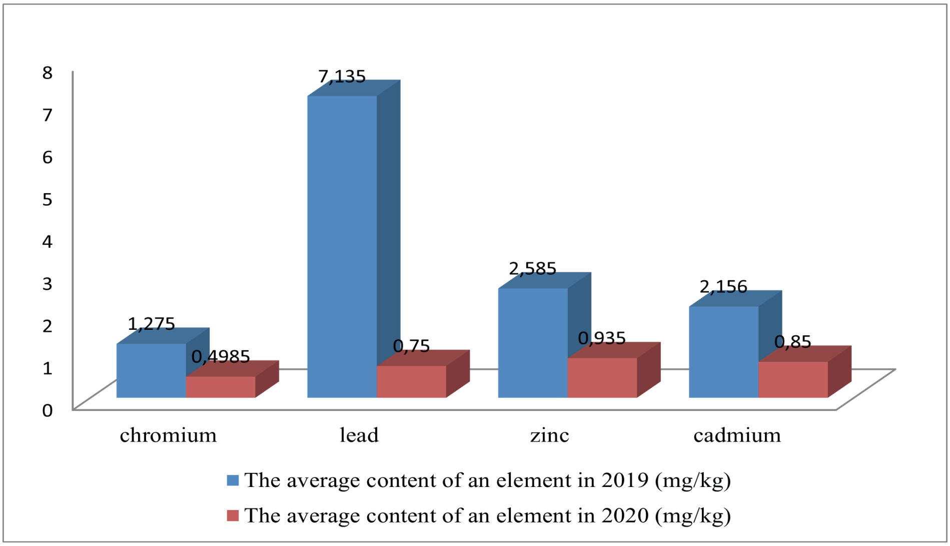

Figure 2 - Ratio of content of elements in Kokshetau city between 2019 – 2020.

Exceeding the maximum permissible concentration was noted in the st. Mirzoyan for copper - 6.3 MPC.

In the city of Shchuchinsk (Table 2) in soil samples taken in 2019 in various regions the chromium content was in the range of 0.84-1.48 mg / kg, copper - 8.13-23.2 mg / kg, lead - 2.05-10.17 mg / kg, zinc - 1.36-1.64 mg / kg, cadmium - 0.10-1.32 mg / kg. (Picture 2). In this city in soil samples taken in 2020 in various regions the chromium content was in the range of 0. 184 - 0. 813mg / kg, lead - 0.13 – 1.37 mg / kg, zinc - 0.31 - 1. 56 mg / kg, cadmium - 0.0042-0.1379 mg / kg.

Conclusion. The main technical measures and means of maintaining the air of the working area within the required limits include the following.

1. Selection of rational architectural and planning solutions allowing to reduce air pollution as much as possible;

2. Rational organization of technological processes, excluding operations related to the release of moisture, harmful vapors, gases, aerosols into working rooms, as well as the supply of overheated and cold air;

3. Extensive use of mechanization and automation of production, which allows excluding contact of workers with harmful substances;

4. Application of efficient heating, ventilation and air conditioning systems ensuring creation of comfortable conditions in the working area;

5. Application of modern mechanical cleaning equipment rooms (vacuum dust cleaning with the help of stationary and mobile installations, hydraulic cleaning, etc.);

6. Use of degassing of premises by special means at production facilities related to the release of harmful and toxic gas and vapor substances;

7. Cleaning of contaminated air in dust and gas collecting devices when it is released into the atmosphere and supplied in the room;

8. Use of personal protective equipment and taking urgent measures to normalize the air composition of the working zone during short-term operations in emergency conditions (emergency situations, etc.) in case of impossibility to reduce harmful emissions to permissible levels.

During the work of this thesis, I made the following conclusions.

Currently, there are four ways to combat harmful gaseous emissions:

- optimization of fuel combustion processes;
- purification of fuel from elements that are sources of pollutants;
- purification of flue gases from pollutants;

Compared to 2020, in 2021 there is a decrease in the volume of heavy metal emissions into the soil in these cities. These ways to reduce the volume of harmful gases will help maintain the ecosystem of the region in optimal condition.

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ҚАЗАҚСТАННЫҢ ОҢТҮСТІК ӨҢІРІНДЕГІ СОРГО ҚАНТЫНЫҢ ӨНІМДІЛІГІНЕ БИОЛОГИЯЛЫҚ БЕЛСЕНДІ ЗАТТАР МЕН ТЫҢАЙТҚЫШТАРДЫҢ ӘСЕРІ

Аннотация. Осы мақаланы зерттеудің мақсаты келесідей биологи-ялық белсенді заттарды қолданудың тиімділігін анықтауға бағытталған: Celeste Top, «Gumi 20» және Калий гуматының сорго қанты өсімдік-терінің өсуі мен дамуына және оның Қазақстанның оңтүстік өңіріндегі өнімділігіне арналған. Зерттеу объектісі болып Сорго қантының «Ка-зақстан 20» сорттары табылды. Сорго-биологиялық ерекшеліктері мен экономикалық сипаттамалары бойынша ерекше дәнді өсімдік. Оның негізгі артықшылықтары - құрғақшылыққа ерекше төзімділік, тұзға төзімділік, жоғары өнімділік, жылдар бойы егіннің тұрақтылығы, жемшөптің жақсы қасиеттері және әмбебап пайдалануға болатындығы. Эксперименттік зерттеулер көп факторлы далалық тәжірибе түрінде жалпы қабылданған классикалық әдістермен, эксперимент тәжірибе және бақылаумен жүргізілді.

Биотехнология негізінде мал азықтық дақылдармен егістік тәжіри-белер жүргізуге арналған және бөлінген учаскелер әдісімен екі фак-торлы тәжірибе орнатылды. Зерттеу нәтижелері биотехнологиялық әді-стерді қолдану арқылы алынды.

Биологиялық белсенді заттардың және азот-фосфор тыңайтқышта-рының дозаларын қолдану арқылы зерттелген әдістер нәтижесінде жұптық корреляциялық коэффициенттер алынды, олардың басым-дығы жоғары болып шықты және 0,89 ... 0,92 деңгейінде белгіленді. Алынған зерттеу нәтижелері негізінде биологиялық белсенді заттар мен азот-фосфор тыңайтқыштарының дозасын қолдану - тұқымды кең қатарға себу кезінде орынды екендігі дәлелденді. Биологиялық белсенді заттармен өңделген тұқымдардың бақылаудағы тұқымдарға қарағанда әлдеқайда жылдам дамығаны анықталды. ББЗ-мен сорго қантының өңделген тұқымдарында бақылауға қатысты ұрықтандырылған нұсқаларға қарағанда жапырақ көлемінің айтарлықтай ұлғаюы байқалды. «Казақстандық 20» үшін ФП максималды мәні калий гуматымен өңделген нұсқаларда атап өтілді - 0,982 ... 1952 млн м ^{2} /тәу/га Гуми 20-мен өңдеу кезінде көрсетілді.

Түйін сөздер: биотехнология, биологиялық белсенді заттар, сорго қанты, өнімділік, мал азықтық дақылдар.

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ВЛИЯНИЕ УДОБРЕНИЙ И БИОЛОГИЧЕСКИ АКТИВНЫХ ВЕЩЕСТВ НА УРОЖАЙНОСТЬ САХАРНОГО СОРГО В ЮЖНОМ РЕГИОНЕ КАЗАХСТАНА

Аннотация. Цель исследовании данной статьи направлено на выявление эффективности применения биологически активных веществ: Селест Топ, «Гуми 20» и Гумат Калия на рост и развитие растений сахарного сорго, и ее продуктивность в условиях южного региона Казахстана. Объектом исследований являлись Сахарное сорго – сорта «Казахстанское 20». Сорго – уникальное злаковое растение, как по своим биологическим особенностями, так и хозяйственным признакам. Его основными достоинствами являются исключительная засухоустойчивость, солевыносливость, высокая продуктивность, стабильность урожаев по годам, хорошие кормовые достоинства и универсальное использование. Экспериментальные исследования проведены общепринятыми классическими приемами, эксперимент-опыт и наблюдение, в виде многофакторного полевого опыта. Заложен был двухфакторный опыт методом расщепленных делянок и на

основании биотехнологии проведения полевых опытов с кормовыми культурами.

Результаты исследования получены при применении биотехнологических методов.

Изучаемые методы с применением доз биологически активных веществ и азотно-фосфорных удобрений, в результате чего были получены коэффициенты парной корреляции, которые оказались преимущественно высокими и были отмечены на уровне 0,89…0,92.

На основании полученных результатов исследовании доказано целосабразность применения доз биологически активных веществ и азотно-фосфорных удобрений, широкорядного посева семян.

Установлено, что обработанные семена биологически активными веществами развивались значительно быстрее по отношению к контролю. В вариантах с обработанными семенами сахарного сорго БАВ происходило значительное увеличение площади листьев на удобренных вариантах по отношению к контролю. Максимальное значение ФП у «Казахстанское 20» были отмечены в вариантах с обработкой Гумат Калия- 0,982… 1952 млн.м^2/суток/га с обработкой Гуми 20.

Ключевые слова. Биотехнология, биологически активные вещества, сахарное сорго, продуктивность, кормовые культуры.

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INFLUENCE OF FERTILIZERS AND BIOLOGICALLY ACTIVE SUBSTANCES ON YIELD OF SUGAR SORGO IN THE SOUTHERN REGION OF KAZAKHSTAN

Abstract. The purpose of the study of this article is aimed at identifying the effectiveness of the use of biologically active substances: Celeste Top, “Gumi 20” and Potassium Humate on the growth and development of sweet sorghum plants, and its productivity in the conditions of the southern region of Kazakhstan. The object of research was Sugar sorghum - varieties “Kazakhstanskoe 20”. Sorghum is a cereal plant that is unique in its biological features and economic characteristics. Its main advantages are exceptional drought resistance, salt resistance, high yield, crop stability over the years, good feed properties and universal use. Experimental studies were carried out by generally accepted classical methods, experiment-experiment and observation, in the form of a multifactorial field experiment. A two-factor experiment was established using the method of split plots and on the basis of biotechnology for conducting field experiments with fodder crops.

The results of the study were obtained using biotechnological methods.

The studied methods with the use of doses of biologically active substances and nitrogen-phosphorus fertilizers, as a result of which pair correlation coefficients were obtained, which turned out to be predominantly high and were noted at the level of 0.89 ... 0.92.

On the basis of the obtained results of the study, the wholesomeness of the use of doses of biologically active substances and nitrogen-phosphorus fertilizers, wide-row sowing of seeds was proved.

It was established that the treated seeds with biologically active substances developed much faster in relation to the control. In the variants with treated seeds of sweet sorghum with BAS, there was a significant increase in leaf area on the fertilized variants in relation to the control. The maximum value of FF at “Kazakhstanskoe 20” was noted in the treatment options with Potassium Humate - 0.982 ... 1952 million m2 / day / ha with the treatment of Gumi 20

Key words. Biotechnology, biologically active substances, sugar sorghum, productivity, fodder crops.

Кіріспе. Соңғы онжылдықта біздің елімізде, әсіресе оңтүстік аймақта дәстүрлі мал азықтық дақылдарды өсіруге қолайсыз құрғақшылық кезеңдері жиілеп кетті. Осыған байланысты топырақтың ылғал тапшылығына төзімділігі жоғары дақылдарды жерсіндіру әрекеттері жүргізілуде, мысалы: сорго-судан будандары, сорго қанты, тары, судан шөбі, амарант, чумиза және т.б.

Қазақстанда егіншілік және өсімдік шаруашылығы ғылыми-өндірістік орталығының (бұрынғы Уильямс атындағы ҚазҰҒЗИ) сорго селекциясы және тұқым шаруашылығы зертханасында алғаш рет азықтық соргоның перспективалы үлгілі сорттары мен ерте пісетін жеуге жарамды соргоның асыл тұқымдық материалы ауыл шаруашылығы ғылымдарының докторы В.М. Макаровтың басшылығымен алынды.

Дүниежүзілік ауыл шаруашылығының экологиялық жағдайы бізді ауыл шаруашылығы дақылдарын өсіру технологиясында әртүрлі мақсаттарға арналған жаңа әрі экологиялық таза биотехнологиялық әдістерді іздеуге мәжбүр етеді: өсімдіктерді зиянкестер мен аурулардан қорғау, өсімдіктердің өсуі мен дамуын ынталандыру және тиімділігі жоғары тыңайтқыштарды алу. Соңғы кезде биологиялық егіншілік мәселелеріне көбірек көңіл бөлінуде. Симбиотикалық және ассоциативті азотты түзетін микроорганизмдер, сондай-ақ фитогормондар, витаминдер, органикалық қышқылдар, антибиотиктер және басқа да биологиялық белсенді заттарды өндіретін микроорганизмдер негізінде биологиялық өнімдерді өндіру және пайдалану үшін биотехнологиялар әзірленді. Көптеген ғалымдар (Мартынова, 1996; Паников, 1994; Омарова А.Ш. 2012; Сарсенбаев Б.А. 2013; Нөкербекова Н.К. 2017.) өсімдіктердің минералды қоректенуін жақсартатынын, олардың әртүрлі күйзелістер мен фитопатогендерге төзімділігін арттырып, топырақ құнарлығын сақтай отырып, өсімдік шаруашылығы өнімі сапасының өнімділігін молайтып жоғарылататындығын дәлелдеген

I.F. Kostikovтың айтуынша, Солтүстік Қазақстан жағдайында, егіс мерзімінде себу қарқыны мен егін жинау күндері зерттелді. Зерттеушілер 108-143 ц/га деңгейінде жасыл массаны қамтамасыз ететін сорго қантының зерттелген сорттарының арасында ерте пісетін будандары неғұрлым өнімді екенін анықтады. Сорго қанты үшін оңтайлы себу мерзімі – топырақ терендігіндегі тұқымның кызуы +18...20°С. Оңтайлы себу нормасы 250 мың дана тұқымдар/га .Бұл 146 - 183 ц/га (Костиков И.Ф., және т. б 2014; 5) жинау кезінде жасыл масса мен құрғақ зат алынды.

Нөкербекова Н.К., (2017) зерттеулері бойынша Қазақстанның Оңтүстік-Шығыс каштан топырағы жағдайында сорго қанты өсімдіктерінің өсуі мен дамуының ерте кезеңдерінде азот тыңайтқыштарын қолдану қанттың сорго өсімдіктерінің бүкіл вегетациялық кезеңінде жинақталуына ықпал еткен. Сонымен қатар сорго қанты сорттарының биологиялық ерекшеліктеріне байланысты топырақтың жылжымалы фосформен болуының екі фонында да азот тыңайтқышымен тыңайтуға байланысты қанттың да, шырынның да сапалық көрсеткіштерін арттыру тенденциясы сақталды(Sanjana Reddy P., 2017;6).

Сорго өсімдігінің қолданылуы көп. Оның астығы мал шаруашылығы үшін бағалы жем және жемдеу үшін шикізат болып табылады, ал оның крахмалы – алкоголь өнеркәсібінде қолданылады. Одан жарма жасалады, Орта Азия республикаларында сорго дәнді дақыл ретінде пайдаланылады. Әлемде тағамдық өсімдік ретінде сорго бидай мен күріштен кейінгі үшінші орынды иеленеді (Bavei V., 2011;3).

Сорғоның жасыл массасы малға тамаша жем болып табылады, оны сүрлемге де пайдаланады. Сабағы кедір-бұдыр болмай тұрып кесілген сорго жақсы пішен береді. Соңы жасыл жемге пайдаланылады немесе жайылымға пайдалануға болады. 100 кг сорго дәнінде 119 бірлік жем бар, 100 кг жасыл массада – 23,5, сүрлемде – 22,0, шөпте – 49,2 бірлік жем болады. Сорго қарды өз бойында ұстау үшін және егінді құрғақ желден қорғау үшін шымылдық ретінде пайдаланылады. Қатарлы егілген дақыл ретінде сорго – жаздық дақылдар үшін жақсы қорғаушы (Мамбетов К.К. және т.б, 2019; Дронов А.В. және т.б., 2012; Ашабоков Б.А. және т.б.,2012; Горлов, И.Ф. және т.б., 2012).

Құрғақшылыққа төзімділігі жоғары сорго еліміздің құрғақ аймақтары үшін өте құнды ФАО, 2020). Оның дақылдары Орталық Азияда, Солтүстік Кавказда және Закавказьеде, Украинаның оңтүстігінде, Молдовада, Төменгі Еділ бойында, Донда және Қазақстанда шоғырланған. Қазақстанда сорго шаруашылығы одан әрі дамуда.

Зерттеулерге сәйкес (Sorghum 2017), бірнеше жылдар ішінде сорғоның маңызды биологиялық қасиеті анықталды - ол ұзақ жылдар бойы өнімділігін төмендетпей, тұрақты дақылдарға айналды. Сорғоның тұрақты дақылдарын ендіру ауыспалы егісте өсірумен салыстырғанда белгілі бір артықшылықтарға ие. Бұл, ең алдымен, біздің еліміздің оңтүстігінде жиі кездесетін, басқа дақылдар өнімділікті күрт төмендететін беткейлерде, эрозияға ұшыраған және сортаңданған жерлерде сорго дақылдарын орналастыруға, яғни егуге қатысты болады. Ұзақ тәжірибе көрсеткендей, сорго мұндай жоғары өнім бермейді, бұл оның әлеуетіне тән. Бұл кездейсоқ, бітеліп қалған, одан да нашар жерлерге себілгенімен байланысты.

Сорго дәнінде 12-15% белок, 3,4-4,4% май, 2,4-4,8% клетчатка бар. Мал азықтық қасиеті бойынша сорго дәнінің құнарлылығы баламалы түрде тіпті арпадан да асып түседі. Дегенмен, облыс жағдайында бұл өсімдіктің өнімділік әлеуеті толық іске асырылмайды. Сорғоның өнімділігін арттыру мәселесін шешу үшін жалпы өсіру әдістері мен технологиясын әзірлеу, оның себу әдістері мен себу нормаларын анықтау, тұқымдарды таңдау, пайдалану, дақылдарды арамшөптерден қорғау үшін тыңайтқыштар мен гербицидтерді қолдануды қажет етеді (Алабушев А. В және т. б., 2017 ; Ковтунова Н.А. және т.б., 2017; Наумова, Т.В. және т.б., 2012; Teetor V.H. et al., 2011; Горпиниченко С.И., және т.б. 2005).

Соңғы жылдары Қазақстанда қанттың жетіспеушілігіне байланысты сорго қантына деген қызығушылық айтарлықтай артты. Сабақтардағы қанттың жоғары болуы әртүрлі өнімдерді өндіруде қызылша қантын алмастыра алатын меласса, сироп алуға мүмкіндік береді (Романюкин А.Е., 2016; Yerbulekova M.T., 2015).

Бүгінгі таңда зерттелетін аймақтағы сорго қанты жаңа түрінің аталған мәселелерін шешу өте өзекті мәселе болып табылады. Сондықтан, осы мақаланы зерттеудің мақсаты сорgoның өнімділігін арттыруды анықтауға бағытталған, егу әдістерін анықтауға негізделген, жалпы өсіру әдістері мен технологиясын әзірлеу бойынша жұмыс істеу керек екендігін және тұқым себу нормалары, сорттарды таңдау, тыңайтқыштар мен өсімдіктерді арамшөптерден қорғау үшін гербицидтерді қолдануға арналған.

Бұл жұмыстың ғылыми жаңалығы, бірінші рет Қазақстанның сұр топырағы жағдайында биологиялық белсенді заттар мен азот-фосфор тыңайтқыштарын қолдануды дамыту бойынша зерттеулер жүргізілді, минералды тыңайтқыштардың дозалары анықталды, сонымен қатар жасыл массаның айтарлықтай өнімін қамтамасыз ететін сорттар мен сызбалар әзірленді.

Жүргізілген ғылыми дала тәжірибелерінің нәтижесінде Оңтүстік Қазақстан аймағының жағдайына сорго қантын өсірудің бейімдеу технологиясы жасалды.

Зерттеудің материалдары мен әдістері. Тәжірибелік зерттеулер 2018-2021 жылдары М. Әуезов атындағы ОҚМУ-да «Экология және биотехнология» ҒЗИ оқу-тәжірибе алаңының аумағындағы «Құрылымдық және биохимиялық материалдар» аймақтық инженерлік бейіндегі сынақ зертханасында жүргізілді. Сынақтар жүргізілген учаске тау бөктеріндегі далалық аймақта орналасқан және топырақ-климаттық параметрі бойынша Қазақстанның оңтүстігіндегі типтік зерттеу аймағында орналасқан осы жағдайларға тән болды.

Зерттеу объектісі болып «Казақстан-20» сорттары алынды. Эксперименттік зерттеулер жалпы қабылданған классикалық әдістермен жүргізілді: эксперимент-тәжірибе және бақылау, көп факторлы далалық эксперименттер түрінде (Кирюшин және т.б., 2009; Иванов, 2008 ж. және В.Р. Вильямс атындағы Бүкілресейлік жемшөп ғылыми-зерттеу институты, 2011). Тәжірибелік жұмыс әдісіне сәйкес сондай-ақ «Агротехникалық далалық тәжірибені жүргізу әдістемесі» (Новиков, және т.б., 2010; Голубев В.В., 2017).

Сорт ЖШС «Қазақ егіншілік және өсімдік шаруашылығы ғылыми-зерттеу институтында өсірілді. Құстар зақымдамайтын сорго қантын тозаңдандыру нәтижесінде жасалды. Биіктігі 130-175 см, үлкен бұталы өсімдік өсудің бастапқы кезеңінде қарқынды дамиды, тұруға төзімді, жасыл масса мен тұқымдарды механикаландырылған агрегаттармен жинауға жарамды болды.

Сорт сабағына туралanған. Негізгі сабақта 7 жерүсті түйіні, 9 жапырақ бар. Жапырақ жасыл, ланцет тәріздес. Жапырақ тақтасы мен тамыры төмен түспеген. Жапырақ қынабы аздап өсіндісі бар ашық жасыл. Сыпыртқы ұзындығы қысқарған білікті 25-30 см. Аяқшасының ұзындығы 30-35 см. Үстіңгі жапырақтың кернейінен төбешіктің бірінші тармағына дейінгі қашықтық 5-8 см.Шыбықшасы ромб тәрізді, тікенекті, масақша қабыршақтары 6-7 см, ақ-қара, тегіс. Дәні жұмыртқа тәрізді, қоңыр түсті, толығымен дерлік қабықпен жабылған. Қабығы қоңыр-сары, эндоспермі ақ.

Жасыл массаның абсолютті құрғақ затында шикі ақуыздың мөлшері 5,8-6,2%, клетчатка 24,4-24,6%, сабақ шырынында қант мөлшері бар. Сорттың тұқым өнімділігі жақсы, жасыл массаның өнімділігі 800-870 ц/га. Өскеннен 1-ші кесуге дейінгі вегетациялық кезең 78 – 95 күн, себілгеннен бастап дәннің толық піскеніне дейін 115 – 120 күн. Сорт құрғақшылыққа төзімді, ылғалға төзімді және жоғары егіншілік фонына ие. Жамбыл, Павлодар, Оңтүстік Қазақстан облыстарында өсіруге ұсынылады.

Зерттеудің мақсаты. Қазақстанның жаңбырлы құрғақ дала зонасы жағдайында азот-фосфор тыңайтқыштары мен әртүрлі биологиялық белсенді заттардың ұтымды дозаларын бірлесіп қолдану арқылы сорго қантын өсірудің биотехнологиялық әдістерін қолдануды жетілдіру болды.

А факторы бойынша – сорго өсімдіктерінің минералды қоректенуінің төрт фоны келесі нұсқаларда зерттелді:

1. Бақылау – тыңайтқышсыз; 2.$N_{30}P_{30}$; 3.$N_{60}P_{60}$; 4.$N_{90}R_{90}$.

В факторы бойынша – үш түрлі биологиялық белсенді заттардың тиімділігі зерттелді: Селест Топ, «Гуми 20» және тұқымдарды себу алдындағы дайындықта қолданылатын Калий гуматы .

Celeste Top – табиғи биополимер, белсенді ингредиент негізі – топырақ бактерияларынан Pseudomonas aureofaciens және Bacillus megaterium оқшаулау арқылы алынған поли-бета-гидроксибутир қышқылы. Humate Kaliya принципі өсімдіктің табиғи қорғаныс реакцияларының импульсіне негізделген. Сондықтан да экстремалды температураға, пестицидтік стресске, топырақтың химиялық заттармен ластануына, құрғақшылыққа, тұздылыққа, аязға және басқа да стресстерге төзімділік артады.

Gumi 20 - белсенді биологиялық түрдегі фитогормондар мен микроэлементтер, сондай-ақ 2000 мг / л дейін фульвикалық және гуминдік қосылыстар бар. Препарат сонымен қатар ризосфералық микроорганизмдер мен фитопатогенді қамтиды.

Калий гуматы - тиімді өсу стимуляторы стресске қарсы адаптогеннің қасиеттерін біріктіреді, өнімділікті арттырады және дақылдың экологиялық тазалығын арттырады. Құрамында натрий мен калий гуматтары жоғары гумин қышқылдары мен фитогормондарға негізделген - 80%, осылайша тұқымның өнуіне қуат береді, сонымен қатар дамудың бастапқы кезеңінде күшті тамыр жүйесінің дамуын ынталандырады.

Celeste Top және «Gumi 20» химиялық құрамы зерттелетін препараттарда өсімдіктердің толық дамуына қажетті барлық қажетті микроэлементтер (B, Mo, Fe, Li және т.б.) бар екенін көрсетеді.

Сорго қанты тұқымының егістік нормасы егістік тәжірибеде 1 га жерге 300 мың дана, егу әдісі кең қатарлы, қатар аралығы 0,45 м. Егіс алдындағы топырақты дайындау үшін азот пен фосфор тыңайтқыштарының толық дозасы енгізілді . Бірінші ретті учаскелердің көлемі 42$м^2$ болды .

Далалық тәжірибеде алға қойылған мақсат пен міндеттерге сәйкес жалпы қабылданған әдістер бойынша барлық қажетті жазбалар, бақылаулар мен талдаулар жүргізілді .

Зерттеу нәтижелері. Сыртқы жағдайлар өсуге тікелей және жанама әсер етеді. Соңғысы өсу қарқыны барлық басқа физиологиялық процестердің қарқындылығына, ауа мен тамырдың қоректенуі, сумен қамтамасыз етілуі, зат алмасу және энергетикалық процестердің қарқындылығына байланысты болады. Осыған байланысты сыртқы жағдайлардың әсері осы процестердің кез келгенінің өзгеруі арқылы өсу қарқындылығына әсер етуі мүмкін. Сонымен қатар, осы немесе басқа да әсердің себептерін жеткілікті дәлдікпен анықтау әрқашан мүмкін емес, өйткені табиғи жағдайда жеке факторлардың әсері өзара тығыз байланысты. Зерттелетін ауылшаруашылық дақылдарының вегетациялық кезеңіндегі олардың өзгеру сипаты өсімдіктердің өсуі мен дамуында ғана емес, дақылдың қалыптасуы мен оның сапасында да көрініс тапты.

Сорго қанты жазғы құрғақшылыққа өте шыдамды, жауын-шашынсыз ұзақ уақыт өткеннен кейін ол биомассасын жоғалтпастан өсіп, дами алады. Сонымен қатар, сорго қанты вегетативті және генеративті мүшелердің қалыптасуы үшін вегетациялық кезеңде топырақтың ылғалдылығын үнемді түрде жұмсайды. Жүгеріден айырмашылығы, сорго әсіресе қуаңшылықта қолайлы сүрлемдік дақыл болып табылады. Бұл ауыл шаруашылығы жануарларын азықтандырудың күзгі-қысқы сыни кезеңінде азық бірліктері мен қорытылатын протеиннің мөлшері жоғары жемді үздіксіз өндіруді қамтамасыз етеді (Тыныкұлов М.Қ. 2015 ж.).

Сорго қанты экожүйесінің температуралық режимі 2018-2020 зерттеу жылдарындағы сорго қантының вегетациялық кезеңінде ауаның орташа айлық температурасының (t^0C) мәндерімен анықталды (1-кесте).

Кесте 1 – Сорго қанты аймағындағы температуралық режимге байланысты вегетациялық кезеңнің ұзақтығы (2017-2020 ғылыми-зерттеу жылдары)

Зерттеу жылдары	Ауаның орташа айлық t^0C рапс өсімдіктеріне арналған			∑ рапстың вегетация-лық кезеңінде белсенді $t^{0,}$ t^0C	Өсімдік жамылғысының ұзақтығы сорго кезеңі, күнмен
	зерттеу жылдарында	көп жылдар бойы деректер	ауа температурасының t^0C жоғарылауы		
2018	23.7	18.8	4.9	∑ 3205	114
2019	24.2		5.4	∑ 3315	116
2020	24.0		5.6	∑ 3270	110
Зерттеу жылдарындағы орташа	23.8		5.0	∑ 3263	115

Айта кету керек, ауаның орташа айлық температурасы вегетациялық кезеңдегі зерттеу жылдарында 23,3^{0}С және 24,2^{0}С болды, ал көп жылдық орташа айлық температура 18,8^0 С болды.

Далалық зерттеулер жылдарындағы ауа райы жағдайлары келесідей сипатталды: 2018 жылдың вегетациялық кезеңі (осы кезеңдегі жауын-шашын 28-ден 25 мм-ге дейін төмендеді, бұл орташа жылдық көрсеткіштен 5,5-6,6 мм-ге төмен) құрғақшылықпен сипатталды.

2019 жылы сәуір айында жауын-шашынның көп мөлшері 139 мм жауды, бұл орташа жылдық көрсеткіштерден 13,5-30,3 мм жоғары, тамызда жауын-шашын түспеді -0,0 мм (жауын-шашын мөлшері 187,7 мм, бұл 30,0 мм. көпжылдық орташа деңгейден жоғары), шілденің орташа температурасы + 30,66°C-қа жетті, ал 2019 жылдың шілдесі (+ 30,63°C) 2014 - 2020 жылдардағы ең жылылардың бірі болды.

2020 жыл ең ылғалды жыл болды (вегетация кезеңінде жауын-шашынның жалпы мөлшері 211,4 мм болды, бұл орташа жылдық көрсеткіштерден 53,4 мм жоғары).

Вегетациялық кезеңде – 2018 жылғы белсенді температуралардың қосындысы 3205^0С, 2019 жылы – 3315^0С, 2020 жылы – 3270^0С болды.

Осылайша, аз бұлттылық, күн сәулесінің көптігі, жауын-шашынның маусымдар бойынша таралу сипаты және жаңбырлы егіншілік фонындағы жылу режимі сорго қантының өсуіне қолайлы жағдай жасайды.

«Gumi 20», Celest Top және Калий гуматымен тұқым өңдеудің анықталған тәсілдері далалық жағдайда сорго тұқымының өнгіштігіне әртүрлі әсер ететіндігі тәжірибеде анықталды (2-кесте).

Дәрілік препараттармен өңдеу егістіктің өнгіштігін 16-18%-ға дейін арттырады. 2-кестеде сорго қантының сорттық тазалығы жоғары, бірақ тұқымның өнгіштігі 82,5%-ға дейін ауытқиды.

Кесте 2 – Сорго қантының тұқымдық сапасы

Сорттары	Сұрып-тау тазалығы, %	Өнімділігі, %	1000 Тұқым массасы, гр	Тұқым Себілген 1 м²/ дана.	Шыққаны м²/дана	Далалық өнімділік, %	Прорас-тинмен өңделген	
Қазақстан 20							Шыққаны м²/ дана	Далалық өнімділік, %
	99.2	82.5	24.1	30	20	66	23	74

Кесте 3-Биологиялық белсенді заттармен өңдеуге байланысты сорго қанты тұқымының танаптық өнуі (2018-2020 жж. орташа)

Сорттары	Сортты тазалық %	Өнімділік, %	Салмағы 1000 тұқымдағы, гр.	Тұқым себілген, 1м²/дана	Шыққаны, дана / м²	Далалық өнімділік, %
Бақылау (өңделмеген)						
«Қазақстан 20»	99.2	82.5	24.1	30	21	57.7
Селесте Топ						
«Қазақстан 20»	99.2	82.5	24.1	30	23	63.2
«Гуми 20»						
«Қазақстан 20»	99.2	82.5	24.1	30	26	71.5
Калий гуматы						
«Қазақстан 20»	99.2	82.5	24.1	30	28	77,0

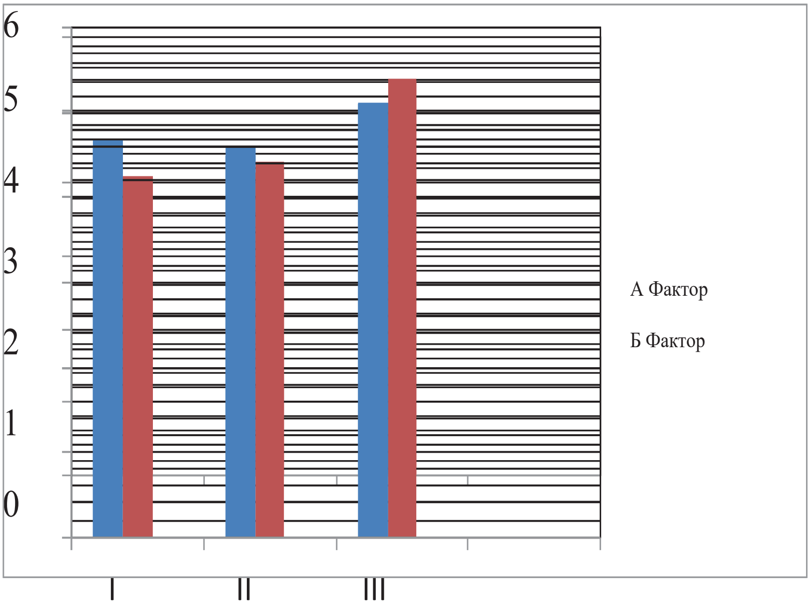
«Қазақстан 20» сортының танаптық өнгіштігі (3-кесте) биологиялық белсенді заттардың қолданылуына байланысты өзгереді, максималды танаптық өнгіштік биологиялық белсенді заттар Калий гуматы – 77,0%, одан кейін “Гуми 20” – 71,5% және Celeste Top 63,2% пайдаланғанда байқалды, бұл 10-15% бақылаудан (өңделмеген) айтарлықтай жоғары.

Кесте 4-Сорго қанты тұқымдарының тыңайтқыш дозаларына байланысты танаптық өнуі (2018-2020 жж. орташа)

Сорттары	Сорттық тазалық, %	Өсіру, %	Салмағы 1000 тұқым-дар, гр.	1м ^{2} / дана себілген тұқымдар	Көтерілген дана / м ^{2}	Далалық өну, %
Бақылау (тыңайтқышсыз)						
«Қазақстан 20»	99.2	82.5	24.1	30	21	57.7
N 30 P 30						
«Қазақстан 20»	99.2	82.5	24.1	30	22	60.5
N 60 P 60						
«Қазақстан 20»	99.2	82.5	24.1	30	24	66,0
N 90 P 90						
«Қазақстан 20»	99.2	82.5	24.1	30	27	74.2

«Қазақстан 20» сортының танаптық өнгіштігі (4кесте) азот фосфор тыңайтқыштарының әртүрлі дозаларын қолдануға байланысты өзгереді.

Азот -фосфор тыңайтқыштарын N_{90} P_{90} -74,2%, одан кейін N_{60} P_{60}-66,0%, N_{30} P_{30}-60,5% дозада қолданғанда егістіктің максималды өнуі байқалады, бұл 8-12% бақылаудан айтарлықтай жоғары (тыңайтқышсыз).



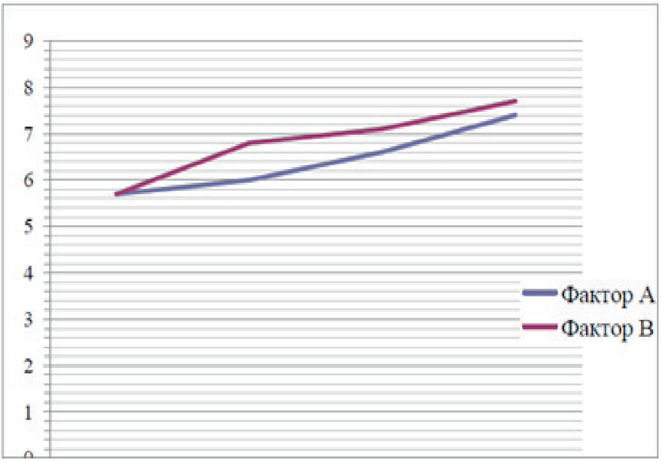


Рисунок 1- Диаграмма 1- А факторы мен В факторының ауытқуы (+/-), т/га

Кесте 5 – Сорго қанты жасыл массасының өнімділігі, т/га (орташа 2018–2020 ж.)

А факторы-тыңайтқыштардың дозалары, кг/га	В факторы – биологиялық белсенді заттар	Өнімділік, т/га орташа 2018-2020		Ауытқу (+/-), т/га	
				А факторы	В факторы
«Қазақстан 20»					
	Бақылау	11.7		-	-
	Селесте Топ	13.4		-	+1,7
	Гуми 20	13.7		-	+2,0
	Калий гуматы	14.2		-	+2,5
$N_{60} P_{60}$	Бақылау	13.2		+1,5	-
	Селесте Топ	14.8		+1,4	+1,6
	Гуми 20	15.4		+1,7	+2.2
	Калий гуматы	15.9		+1,7	+2,7
$N_{90} P_{90}$	Бақылау	13.9		+2.2	-
	Селесте Топ	18.0		+4,6	+4.1
	Гуми 20	18.2		+4,5	+4.3
	Калий гуматы	19.3		+5.1	+5.4
		2018 ж	2019 ж	2020	-
NSR $_{05\,A}$ факторы , т/га		0,58	0,49	0,36	-
NSR $_{05}$ В факторы , т/га		0,66	0,56	0,42	-
NSR $_{05}$ АВ факторларының өзара әрекеттесуі, т/га		1.15	0,97	0,72	-

Осы кестеден (5-кесте және 1-диаграмма) сорго қантының жасыл массасының өнімділігі азот-фосфор тыңайтқыштары мен биологиялық белсенді заттардың дозасын қолдануға байланысты өнімділіктің жоғарылайтынын көрсетеді. N_{30} P_{30} тыңайтқыштары мен биологиялық белсенді заттар дозасының әсерінен 2018 – 2020 жылдар аралығында орташа өнімділік Celest Top 13,4 т/га, Гуми 20–13,7 т/га және Калий гуматы – 14, 2 т /га құрады.

$N_{60}P_{60}$ тыңайтқыштары мен биологиялық белсенді заттардың дозасы әсерінен 2018–2020 жылдар аралығында орташа өнімділік Celeste Top 14,8 ц/га, гуми 20 – 15,4 ц/га және калий гуматы – 15,9 т/га құрады. $N_{90}P_{90}$ тыңайтқыштары мен өсу стимуляторлары дозасының әсерінен 2018–2020 жылдар аралығында орташа өнімділік Celeste Top – 18,0 ц/га, Гуми – 20 – 18,2 т/га және А Калий гуматы– 19,3 т/га құрады.

Сорго қантының жасыл массасының түзілуіне В факторының (биологиялық белсенді заттар) әсері тыңайтқыш дозасын $N_{60}P_{60}$ және $N_{90}P_{90}$ +1,6 - + 4,1 т/га Целесте Топпен, Гумимен қолданғанда артады. Үш жыл ішінде орта есеппен Гуми 20 - + 2,2 - +4,3 т/га және Калий гуматы - +2,7 - +5,4 т/га екендігін көрсетті. Бақылаудағы $N_{60}P_{60}$ және $N_{90}P_{90}$ дозасы бар А факторының (тыңайтқыш дозасы) әсері биологиялық белсенділігіне байланысты +1,5 - +2,2 т/га, тәжірибеде +1,4 - + 5,1 т/га болды.

2018-2020 жылдар аралығындағы тәжірибелік дала эксперимен-тіндегі нәтижелеріміз биологиялық белсенді заттар мен азот-фосфор тыңайтқыштарын кешенді қолдану сорго қантының және жалпы жасыл массаның тағамдық құндылығы мен өнімділігін арттыруға тікелей әсер ететінін көрсетті. Экономикалық тиімділікті талдауды салыстырмалы бағалау сорго қантын өндірудің экономикалық көрсет-кіштерінің көпшілігі ең алдымен ағымдағы нарықтық бағаға, сонымен қатар материалдық ресурстар мен алынған өнім деңгейіне байланысты екенін көрсетті.

Бірінші көрсеткіш негізінен әлеуметтік-экономикалық факторға байланысты болды. Екіншісі генетикалық ерекшеліктерге және сорго қантының белгілі бір топырақ-климаттық жағдайларына бейімделу деңгейіне байланысты екендігі, сонымен қатар кешеннің фонында сұр топырақта сорго дақылдарын өндіру технологиясының инновациялық элементін пайдаланып биологиялық белсенді заттар мен минералды тыңайтқыштарды қолдану болды. Осылайша, мақсатты мәселені шешуде Қазақстанның оңтүстік аймағында өсірілетін Сорго қанты тұқымдарының биологиялық белсенді заттармен өнімділігін арттыру мәселесін шешудің заманауи биотехнологиялық әдістерін зерттеп негіздедік.

Өнімнің биологиялық белсенді заттарға, оның пайдалану фонына және минералды қоректенуге тәуелділігі анықталды; Оңтүстік

Қазақстанның сұр топырағында биологиялық белсенді заттар мен азот фосфор тыңайтқыштарының ең ұтымды дозалары анықталды.

Биологиялық белсенді заттар мен тыңайтқыштардың әртүрлі комбинациялары бар сорго қанты сорттарының салыстырмалы өнімділігі анықталды , сонымен қатар жасыл массаға сапалы баға берілді. Соның негізінде мынадай қорытынды жасадық.

Қорытындылар: 1. Зерттеу нәтижелері бойынша соргоның маңыздылығы жағынан жүгеріден еш кем түспейтін Оңтүстік Қазақстанның құрғақ дала зонасында жоғары сапалы жасыл масса мен сүрлем алу үшін өте бағалы дақыл екені анықталды. Дегенмен, құрғақ аймақтарда сорго дақылдары өзінің экологиялық пластикасын жақсы көрсетеді, топырақ пен фотосинтетикалық ресурстарды тиімді пайдаланады, оларды өсіру технологиясы жақсы жұмыс істейді, олар әрқашан жоғары және тұрақты өнім береді .

2. Сорго қанты дақылдарының өнімділігін арттыру үшін сорго қантының агробиологиялық сипаттамалары бойынша биологиялық белсенді заттар мен азот-фосфор тыңайтқыштарын қолданудың биотехнологиялық әдістері зерттелді.

3. Алғаш рет түсімнің биологиялық белсенді заттарға және пайдалану фонына және минералды қоректенуге тәуелділігі белгіленді; Оңтүстік Қазақстанның сұр топырағында биологиялық белсенді заттардың және азот-фосфор тыңайтқыштарының ең ұтымды дозалары анықталды. N_{60} P_{60} және N_{90} P_{90} тыңайтқыштары мен биологиялық белсенді заттардың дозасы әсерінен 2018 – 2020 жылдар аралығында орташа өнімділік Celest Top 14,8 – 18,0 т/га, Gumi 20 – 15,4 – 18,2 т/га және калий гуматы – 15,9 – 19,3 т/га құрады.

4. N_{60} P_{60} және N_{90} P_{90} тыңайтқыштар дозалары мен биологиялық белсенді заттарды қолдану әсерлерінен 2018-2020 жылғы орташа өнімділік Celest Top- 14.8-18.0 т / га , Gumi 20 - 15, 4 -18,2 т / га және Калий гумат -15.9-19.3 т / га болды.

5. Өсу стимуляторларының әсері тыңайтқыштарды қолданбай жасыл массаның өнімділігін 5-8% -ға дейін арттыруды құрады.

6. Минералды тыңайтқыштар мен биологиялық белсенді заттарды біріктіріп қолданғанда сорго қантында жасыл масса өнімділігі орта есеппен 10 – 12% құрады.

7. Celeste Top, «Gumi 20» және Калий гуматы минералды тыңайтқыштардың дозасын азайтуға мүмкіндік беретін қоректік заттардың сіңіру коэффициентін арттыруға көмектеседі.

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RHIZOSPHERE MICROORGANISMS: INCREASING PHYTOTECHNOLOGY PRODUCTIVITY AND EFFICIENCY – A REVIEW

Abstract. The review contains information on rhizobacteria with plant growth promoting properties (PGPR), on plant mechanisms of bacterial defense against heavy metal pollution and on stimulation of plant growth by nitrogen fixation, phosphorus dissolution, siderophores, phytohormones and ACC deaminase enzyme synthesis. PGPRs are classified according to their functionality, the degree of proximity to the root and the closeness of their association with the plant, and the site of bacterial colonization, and information is provided on the taxonomic affiliation of PGPRs. Issues of phytoremediation of soils contaminated with heavy metals and methods to improve process efficiency using rhizospheric microorganism inoculants are highlighted in the review, as phytoremediation is an economically viable and environmentally friendly technology. The review considers the role of association of endophytic and rhizospheric PGPBs with a plant in enhancing the efficiency of phytoaccumulation and phytostabilisation of soils contaminated with toxic metals and plant productivity.

Key words: Plant, rhizosphere, PGPB, mechanism, productivity, phytoremediation.

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РИЗОСФЕРАЛЫҚ МИКРООРГАНИЗМДЕР: ФИТОТЕХНОЛОГИЯНЫҢ ӨНІМДІЛІГІН АРТТЫРУ ЖӘНЕ ОНЫҢ ТИІМДІЛІГІ

Аннотация. Мақалада өсімдіктердің өсуін ынталандыратын қасиеттері бар (PGPR), ауыр металдармен ластанған ортадан өсімдіктерді бактериялық қорғау механизмдері және азотты бекіту, фосфорды еріту, сидерофорлар, фитогормондар және АЦК-деаминазы ферментін синтездеу арқылы өсімдіктердің өсуін ынталандырушы ризосфералық бактериялар туралы ақпарат ұсынылады. Функционалдылығы, тамырға жақындық дәрежесі және олардың өсімдікпен байланысының жақындығы, бактериялардың колонизациялану орны бойынша PGPR классификациясы қарастырылды, PGPR-дің таксономиялық тиістілігі туралы деректер келтірілді. Мақалада ауыр металдармен ластанған топырақты фиторемедиациялау мәселелеріне және оның ризосфералық микроорганизмдер-инокулянттардың көмегімен тиімділігін арттыру әдістеріне ерекше назар аударылды, өйткені бұл технология экономикалық тиімді және экологиялық таза технология болып саналады. Сонымен қатар улы металдармен ластанған топырақтарды фитотұрақтандыру және фитожинақтау тиімділігін және өсімдік өнімділігін арттырудағы эндофитті және ризосфералық PGPR-дың өсімдікпен байланысының маңызы қарастырылады.

Түйін сөздер: өсімдік, ризосфера, PGPR-бактериялар, механизм, өнімділік, фиторемедиация.

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РИЗОСФЕРНЫЕ МИКРООРГАНИЗМЫ: ПОВЫШЕНИЕ ПРОДУКТИВНОСТИ И ЭФФЕКТИВНОСТИ ФИТОТЕХНОЛОГИИ

Аннотация. В обзоре представлены сведения о ризосферных бактериях, обладающих стимулирующими рост растений свойствами (PGPR), механизмах бактериальной защиты растений от загрязненной тяжелыми металлами среды и стимуляции роста растений посредством азотфиксации, растворения фосфора, синтеза сидерофоров, фитогормонов и фермента АЦК-деаминазы. Рассмотрены классификация PGPR по функциональности, степени близости к корню и тесноте ассоциации их с растением, места колонизации бактерии, приведены данные о таксономической принадлежности PGPR. Особый акцент в статье уделили вопросам фиторемедиации почвы, загрязненной тяжелыми металлами и методам повышения ее эффективности с помощью ризосферных микроорганизмов-инокулянтов, так как данная технология является экономически выгодной и экологически безопасной технологией. В обзоре рассматривается роль ассоциации эндофитных и ризосферных PGPR с растением в повышении эффективности фитоакумуляции и фитостабилизации почв, загрязненных токсичными металлами и продуктивности растений.

Ключевые слова: растение, ризосфера, PGPR-бактерии, механизм, продуктивность, фиторемедиация.

Introduction. The organs of higher plants represent a special ecological niche inhabited by microorganisms. In the course of their development, they act as centers for the formation of microbial communities - epiphytic, which settle on the surface of various plant organs, or endophytic, which invade, colonize and multiply in plant tissues (Bulgarelli et al., 2013; Feoktistova et al., 2016). Microorganisms living on the surface of above-ground plant organs are called phyllospheric, while those living in the root zone are called rhizospheric. The roots of plants are surrounded by soil - a medium densely populated by various microorganisms. The distance from the root determines how close the relationship is between the plants and the microorganisms living in their root zone. The soil microorganisms inhabiting the rhizosphere (a narrow soil zone about 0 to 8 mm in diameter that directly surrounds the plant roots) or the rhizoplane (the surface of the plant roots) form more or less strong associations with the plant's root system and form specific rhizosphere communities. Such relationships are characterized by the terms "associative bacteria", "associative relationship", "associative symbiosis" (Döbereiner, 1983).

Rhizospheric microorganisms colonize the area around and on the surface of the root unevenly, mainly in its upper part, and attach themselves to the pores of the cell walls. The existence of microorganisms and strong associations in these ecological niches, both within the root tissue and in the rhizoplane and rhizosphere, is primarily due to the active secretion of various low molecular weight substances such as amino and organic acids, sugars and various secondary metabolites by the root cells (Fan et al., 2018; Mitter et al., 2016). The microorganisms were found to be unevenly distributed within the same root: abundance increases in the area of the young apical roots, where the maximum release of soluble organic compounds takes place (Vives-Peris et al., 2020).

Materials and methods. The rhizospheric effect, which characterizes the increased number and activity of microorganisms in the root zone, increases after seed germination and reaches a maximum during flowering and fruiting depending on the composition of root exudates during plant development (Ray et al., 2020; Weyens et al., 2009). Thus, the root zone of young plants is dominated by gram-negative bacteria of the genera Pseudomonas, Flavobacterium, Azotobacter, etc., which are replaced by gram-positive bacteria of the genus Bacillus and actinobacteria of the genera Mycobacterium and Streptomyces as the plants age (Feoktistova et al., 2016).

The specificity of the microorganisms in the rhizosphere of a given plant species can be taken into account, i.e., a symbiotic relationship can only be established between certain species, which determines the specificity of the symbiosis (Kidd et al., 2017). For example, Fan et al. (2018) investigated the species diversity of plant root-associated bacteria in 6 cultivated and 20 wild plant species. Using 16S rRNA gene sequence analysis, the authors showed that 446 bacterial isolates were distributed among four phyla (Proteobacteria, Firmicutes, Actinobacteria, and Bacteroidetes), 32 families, and 90 genera. Proteobacteria formed the largest group of isolates (240): 40% ectophytic and 60% endophytic bacteria. In the rhizosphere, representatives of the genera Bacillus and Pseudomonas dominated; the most important endophytes were Microbacterium and Pseudomonas. Some genera, such as Stenotrophomonas, Yersinia, Labrys, and Luteibacter, were associated with specific plant species.

For soil bacteria that have a positive effect on plant growth, live in the rhizosphere and rhizoplane of plants and have the ability to colonize the root surface, survive, multiply and compete with other microbiota, Kloepper et al. (1980) coined the term PGPR, i.e., rhizobacteria that stimulate plant growth. PGPRs are found not only around but also within plant roots (endophytic bacteria colonizing apoplastic spaces inside the plant). No soil bacteria have been found to colonize these spaces (Rosier et al., 2018; Santoyo et al., 2021). Taxonomically, PGPRs are extremely diverse and are divided into extracellular and intracellular depending on the degree of proximity to the root and the closeness of association with plant. Extracellular PGPRs: representatives of the genera Agrobacterium, Arthrobacter, Azotobacter, Azospirillum, Bacillus, Burkholderia, Caulobacter, Chromobacterium, Erwinia, Flavobacterium, Micrococcous, Pseudomonas, Serratia, etc., while intracellular PGPRs are representatives of the genera Allorhizobium, Azorhizobium, Bradyrhizobium, Mesorhizobium belonging to Rhizobiaceae family. The majority of rhizobacteria belonging to the intracellular group are gram-negative rods; a smaller proportion are gram-positive rods, cocci or pleomorphic rods (Bhattacharyya et al., 2012).

Mechanisms of plant growth stimulation by PGPRs. The mechanisms of the positive effect of rhizobacteria on plant vital activity vary (Hayat et al., 2010). PGPRs influence plant growth and development either directly or indirectly (Glick, 2012). Different bacteria can influence plant growth and development under different conditions by using both of these mechanisms together or separately (Ojuederie et al., 2017). Indirect stimulation of plant growth occurs by reducing or preventing the harmful effects of phytotoxic microorganisms. This may involve a reduction in the Fe available to phytopathogens in the rhizosphere, the synthesis of enzymes that lyse the cell walls of fungi, and competition with harmful microorganisms for a place on plant roots. The mechanism of plant growth stimulation is the antagonistic relationship between PGPRs and phytopathogenic microorganisms

(Chowdhury et al., 2015). Direct stimulation of plant growth consists of: 1) supplying the plant with substances synthesized by the bacteria or facilitating the entry of nutrients from the environment into the plant (e.g. microbial nitrogen fixation); 2) synthesizing siderophores that can dissolve and accumulate Fe from the soil and supply it to plant cells; 3) production of various phytohormones, including auxins (e.g. indolyl-3-acetic acid (IAA), cytokinins, and gibberellins) which can influence different stages of plant growth; 4) a mechanism to dissolve minerals such as phosphorus, which then becomes readily available to the plant; 5) enzymes that can influence plant growth and development (e.g. 1-aminocyclopropane-1-carboxylic acid (ACC) (Le et al., 2019; Shaposhnikov et al., 2011) The screening of rhizospheric and endophytic microorganisms for the presence of the above properties serves as a basis for obtaining an effective PGPR inoculant to enhance plant growth for economic purposes, both to increase the yield of food crops and to promote the development of phytoremediation agents on contaminated soils (Schmidt et al., 2018; Mamirova et al., 2019).

Nitrogen fixation. Nitrogen is a nutrient for plant growth and productivity. Although the atmosphere consists of ~78% nitrogen, it is not available to plants. The ability to biologically fix molecular nitrogen (N_2) is only possessed by prokaryotes, which convert N_2 into ammonia with the help of the enzyme nitrogenase. The highest intensity of N_2 fixation can be developed by those microorganisms that interact with plants and use the products of their photosynthesis to maintain nitrogenase activity. The N_2 fixation is carried out by a complex enzyme, nitrogenase (Kim et al., 1994). Structurally, the N_2 fixation system differs among bacterial genera. Most biological N_2 fixation occurs through the activity of Mo-nitrogenase, which is present in all diazotrophs (Spaepen et al., 2011). Dinitrogenase reductase provides electrons with high reducing power, while enzyme dinitrogenase uses these electrons to reduce N_2 to ammonia (Kim et al., 1994).

Genetic control of N_2 fixation occurs at several levels: ammonium, nif-specific, amino acid, oxygen, nitrate, molybdenum, and temperature levels (Spaynk et al., 2002).

N_2-fixing bacteria are divided into symbiotic characterized by nodules formation as a result of host-symbiont interaction, where rhizobia act as intracellular symbionts, and non-symbiotic or associative ones, which provide only a small amount of fixed N_2 necessary for the bacteria-associated host plant (Bhattacharyya et al., 2012; Glick, 2012; Spaepen et al., 2011). Bacteria from the following genera have a high potential for N_2 fixation: Azospirillum, Azotobacter, Achromobacter, Agrobacterium, Bacillus, Beijerinckia, Clostridium, Enterobacter, Herbaspirillum, Klebsiella, and Pseudomonas (Morgun et al., 2009).

Phosphate solubilization. Plants can only take up inorganic phosphorus and its concentration in soil is very low as most of the organic phosphorus present in soil is insoluble and may constitute 4-90% of the total phosphate (Yadav et al., 2015). Despite its high content in soil, phosphorus bioavailability limits the plant growth, development, and productivity. The concentration of phosphorus available to plants in soil solution is about 1 mM and rarely reaches 10 mM (Lambers et al., 2006). The ability of some microorganisms to convert insoluble phosphorus (organic and inorganic phosphates) into an available form such as orthophosphate is an important feature of PGPB for increasing crop yield (Khan et al., 2007; Rodríguez et al., 2006). Microorganisms can use two systems to increase the concentration of exogenous phosphate: 1) by hydrolyzing organic phosphates under the action enzymes (non-specific acid phosphatases, phytases, phosphonates, and C-P lyases); 2) by dissolving mineral phosphates through the production of organic and inorganic acids (Rodríguez et al., 2006). Phosphate-solubilizing bacteria include members of the genera Azospirillum, Azotobacter, Bacillus, Beijerinckia, Bradyrhizobium, Burkholderia, Enterobacter, Erwinia, Flavobacterium, Microbacterium, Pseudomonas, Rhizobium, and Serratia (Bhattacharyya et al., 2012; Morgun et al., 2009). The strains of Pseudomonas, Bacillus, and Rhizobium are among the most potent phosphate solubilizes (Rodríguez et al., 1999).

Inoculation of seeds or soil with phosphate-solubilizing bacteria improves the solubilization of bound soil phosphorus and applied phosphates, resulting in higher crop yields. The combination of phosphate application and bacteria can be a cheap source of phosphate fertilizer for crop production (Yadav et al., 2015).

Siderophores synthesis. To ensure the availability of Fe, PGPRs synthesize siderophores. Almost all facultative anaerobic and aerobic microorganisms (especially bacteria and fungi) produce extracellular siderophores that bind the iron necessary for their growth. Phytopathogens also produce their own siderophores, but unlike PGPR siderophores, they bind iron ions much more slowly. Among the fungi that synthesize siderophores, representatives of the genera Penicillium and Aspergillus dominate, while among the bacteria, representatives of the genera Achromobacter, Agrobacterium, Enterobacter, Pseudomonas, Serratia, Bacillus, and Pseudomonas dominate (Haas, 2014; Lawongsa et al., 2008). The main function of siderophores is to convert Fe bound to proteins or water-insoluble compounds into the ionic form Fe^{3+}

accessible to microorganisms (Loper et al., 1999; Rajkumar et al., 2006). However, in addition to main function, siderophores also have the ability to chelate other heavy metals such as Al^{3+}, Zn^{2+}, Cu^{2+}, Pb^{2+}, and Cd^{2+}, which can influence the homeostasis and resistance of microorganisms to heavy metals (Złoch et al., 2016).

Plant siderophores have a much lower affinity for iron. Therefore, plants in soils contaminated with metals are unable to accumulate significant amounts of Fe in the absence of bacterial siderophores. In order to alleviate the plants stress caused by high metal concentrations in the soil, microorganisms synthesize siderophores (Saha et al., 2016). PGPR siderophores have different chemical structures and usually have a high affinity for Fe, with which they form stable complexes that can be taken up by plants (Loper et al., 1999). In order to obtain the required amount of Fe from the environment, they have developed mechanisms that increase the solubility and dissolution rate of the Fe^{3+} oxyhydroxides prevalent in aerobic soils. Chemically, these mechanisms are based on the weakening of the Fe-O bond through reduction, chelation, and protonation. Physiologically, two different mutually exclusive strategies are distinguished: (1) release of siderophores capable of dissolving external Fe^{3+} and subsequent absorption of the Fe^{3+}-siderophore complex; (2) reduction of Fe^{3+} to absorb the more soluble Fe^{2+} ion. In higher plants, the increase in their ability to convert extracellular Fe^{3+} to Fe^{2+} is part of physiological and morphological events operating to achieve adequate internal Fe levels. This series of traits determines the efficiency of Fe content in a species or cultivar, which in turn influences the yield of economically important plants and the natural distribution of species.

Phytohormones synthesis. The microbial production of individual phytohormones such as auxins and cytokinins has been well studied (Selvakumar et al., 2008; Spaepen et al., 2007).

Auxins. Bacterial auxins initiate and elongate roots, develop lateral roots and root hairs, which is important for the active uptake of nutrients by the plant, its growth and resistance to stress (Frankenberger et al., 2020; Spaepen et al., 2007). The most important natural representative of auxins is indolyl-3-acetic acid (IAA). IAA can act as a mutual signaling molecule in interactions between microbes and plants. Microorganisms use the phytohormone in interactions with plants as a strategy to colonize them for a mutualistic or parasitic relationship (Spaepen et al., 2007). Interest in the microbial synthesis of IAA is also growing due to another recently discovered property of auxin in Arabidopsis, the plant protection from phytopathogenic bacteria (Spaepen et al., 2011). IAA can be synthesized not only by plants but also by 80% rhizobacteria (Duca et al., 2020). This ability is possessed by bacteria belonging to different genera such as Aeromonas, Acetobacter, Alcaligenes, Agrobacterium Azospirillum, Bradyrhizobium, Enterobacter, Commamonas, Rhizobium, Pseudomonas, and Xanthomonas (Weyens et al., 2009). The biochemical pathways and genetic regulation of IAA synthesis are under active investigation. Currently, 5 tryptophan-dependent pathways are distinguished (with the formation of the following key metabolites: indole-3-acetonitrile, indole-3-acetaldehyde, indole-3-acetamide, indole-3-pyruvate, and tryptamine) and a single tryptophan-independent pathway is suspected (Spaepen et al., 2007). Rhizobacteria that synthesize IAA from tryptophan are very diverse, but the most important genera are Azotobacter, Azospirillum, Enterobacter, and Klebsiella.

Cytokinins and gibberellins. Much less information is available on the microbial synthesis of cytokinins and gibberellins. Cytokinins stimulate cell division and increase the growth of plant tissues, stimulate shoot growth and inhibit root development. The effective stimulation of plant growth by bacterial cytokinins has been demonstrated by many researchers (Arkhipova et al., 2007; Gutiérrez-Mañero et al., 2001). Gibberellins are involved in changing the plant morphology and tissue growth, especially shoots. Microorganisms in the rhizosphere can also produce or modulate phytohormones under in vitro conditions, so that they can alter the content of phytohormones influencing the plant hormone balance and response to stress (Morgun et al., 2009). The gibberellins formation is characteristic of rhizospheric bacteria, mainly of the genera Azotobacter, Azospirillum, Pseudomonas, Bacillus, Flavobacterium, Clostridium, and Agrobacterium (Tsavkelova et al., 2006). Cytokinins are synthesized by rhizobacteria belonging to the genera Azotobacter, Azospirillum, Pseudomonas, and Bacillus (Morgun et al., 2009).

ACC-deaminase synthesis and its role in the phytohormone ethylene reduction. The phytohormone ethylene is very important for the normal development of a plant, especially in its early stages. The hormone is produced endogenously by almost all plants and is also produced by various biotic and abiotic processes in the soil and plays an important role in triggering various physiological changes in plants. Among the numerous effects of ethylene on plants (seed germination, morphogenesis, flower induction, fruit ripening), the most commonly observed are inhibition of elongation and growth of lateral roots, development of root hairs, usually in response to abiotic and biotic stresses. Ethylene is not only a plant growth regulator, but is also considered a stress hormone (Arshad et al., 2007; Lawongsa et al., 2008). Under stress conditions such as high salt concentrations, drought, extreme temperatures, high light intensity, flooding, radiation, insect injury and feeding, polyaromatic hydrocarbons, heavy metals and pathogenicity, endogenous ethylene levels are greatly increased, which negatively affects overall plant growth and response to stress (Deikman, 1997).

Higher plants produce the hormone ethylene from L-methionine via intermediate compounds (S-adenosyl-L-methionine and 1-aminocyclopropane-1-carboxylic acid, ACC) (Yang et al., 1984). Glick et al. (1998) suggested that microorganisms containing ACC deaminase, which degrades the ethylene precursor to ammonium and α-ketobutyrate, may act as PGPRs by eliminating ACC, thereby lowering ethylene levels in developing and/or stressed plants. The yield of ethylene produced by the plant decreases as a consequence of the ACC decline in the plant and its excretion by bacteria (Glick, 2003). Belimov et al. (2005) showed that bacteria of different origin having ACC deaminase activity stimulated plant growth in soils containing phytotoxic Cd concentrations. In addition, Wang et al. (2000) showed that bacterial strains exerting biocontrol and carrying ACC deaminase genes were able to protect plants more effectively against viral phytopathogens. To date, bacterial strains with ACC deaminase activity have been identified in a variety of genera, including Acinetobacter, Achromobacter, Agrobacterium, Alcaligenes, Azospirillum, Bacillus, Burkholderia, Enterobacter, Pseudomonas, Ralstonia, Serratia, and Rhizobium (Kang et al., 2010; Zahir et al., 2009).

PGPR bacteria are thought to attach to the seeds or roots surface of developing plants in response to tryptophan or other molecules present in plant secretions, whereupon the bacteria synthesize and secrete IAA, some of which can be taken up by the plant (Patten et al., 2002). This IAA, together with the plant's endogenous IAA, can stimulate growth and induce the synthesis of ACC synthase, which converts S-adenosyl-L-methionine to ACC. Some of the ACC formed in this way is isolated from the plant seeds or roots along with other low molecular weight compounds normally present in root exudates (Patten et al., 2002). ACC, which is present in plant secretions, is taken up by bacteria and subsequently converted to ammonium and α-ketobutyrate by ACC deaminase. This reduces the amount of ACC outside the plant, so that the plant has to release larger amounts of ACC to maintain the balance between external and internal amounts. Firstly, the bacteria cause the plant to synthesize more ACC than would be necessary, and secondly, they stimulate the release of ACC from the plant.

The literature data shows that rhizobacteria stimulating plant growth not only have the potential to survive under stressful conditions, but also stimulate plant growth.

PGPR application to increase plant productivity. A strong incentive for the study of PGPR in the 70-80s was its obvious prospects for solving the problems of agrobiotechnologies related to achieving consistently high and qualified yields. Soil microbiological studies focused primarily on achieving practical goals: soil fertility, biological plant protection against diseases, sources of biologically active substances - plant growth stimulants (Simpson et al., 2011; Singh et al., 2011). The PGPR beneficial effects on plant growth and nutrition through a number of mechanisms including N_2 fixation, synthesis of siderophores, phytohormones and ACC deaminase have spurred the PGPR strains commercialization (Glick et al., 1998). PGPRs were classified according to functionality into the following categories: biofertilisers (increasing the nutrients availability for plants); phytostimulants (stimulating plant growth by phytohormones); rhizoremediators (degradation of organic pollutants); biopesticides (disease control mainly through the production of antibiotics and antifungal metabolites) (Somers et al., 2004). Numerous actinomycetes (Micromonospora sp., Streptomyces spp., Streptosporangium sp., Thermobifida sp., etc.) as major components of the microbial communities in the rhizosphere, which have inhibitory effects on various pathogens, are used as biocontrol agents to reduce plant infections and diseases and contribute to normal growth and development (Bhattacharyya et al., 2012; Glick, 2012). Currently, many bacteria (Agrobacterium, Alkaligenes, Arthrobacter, Azotobacter, Azospirillum, Bacillus, Burkholderia, Brevibacterium, Caulobacter, Chromobacterium, Enterobacter, Flavobacterium, Gluconacetobacte, Klebsiella, Micrococcus, and Pseudomonas) are commonly used as vaccines and actively included in commercial organic products and biofertilisers as an alternative to chemical ones polluting environment (Ortíz-Castro et al., 2009; Simpson et al., 2011; Singh et al., 2011). The process of Fe binding by PGPR siderophores leads to phytopathogens growth inhibition and plant growth enhancement, therefore, they are used as bacterial fertilizer (Bhattacharyya et al., 2012; Jing et al., 2007).

In recent decades, the scope of PGPR has expanded and they are now being considered not only for agriculture but also for soil bioremediation, as many PGPRs are resistant to pollutants (Belimov et al., 2009).

Based on the knowledge of plant-bacteria association interaction and examples of improvement of plant growth and nutrition by inoculation with beneficial microorganisms, the role of some biotic and abiotic factors in these interactions is studied and the possibility of using associative bacteria to increase plant resistance to various stresses is evaluated (Belimov et al., 2005, 2009). Microorganisms have different mechanisms of biological plant defense that manifest themselves both at the cellular level and at the population level. The interaction of plants and PGPRs aims at joint survival in a plant-microbial association under adverse environmental conditions. They can minimize the harmful effects of pollutants through reduction, oxidation, methylation or demethylation, compartmentalization and transformation to a less toxic state in the composition of engineered plant-microbial complexes (Hassan et al., 2017). Identifying the effect of enhanced biodegradation of pollutants in the root zone was the reason for combining the efforts of plant physiologists and microbiologists in developing phytoremediation biotechnology - the use of plants and their associated microorganisms to cleanse the environment matrices - and is considered the most promising approach due to its low cost and environmental friendliness. Isolation, screening and bacterization of plants with heavy metal-resistant PGPRs is considered an important tool to improve growth and increase the efficiency of phytoremediation of soils (Cho, 2020; Ojuederie et al., 2017).

Applying PGPRs to improve phytoremediation efficiency of heavy metals-contaminated soils. Phytoremediation strategies using rhizobacteria adapted to heavy metals are attracting more and more attention, as soil contamination with toxic elements is a serious environmental problem that negatively affects human health and agriculture. Phytoremediation is a promising method for the remediation of environments contaminated with heavy metals. However, there is a limitation: long remediation time, low biomass, inhibition of growth and development, and slow and limited bioavailability of some elements (Karimi et al., 2017; Kong et al., 2017).

Various agricultural practices, growth regulators and microbial organisms are used to improve biomass production and increase phytoremediation efficiency (Hu et al., 2018; Nebeská et al., 2019). Of particular interest is the study of rhizospheric bacteria, which belong to the PGPRs, as they are resistant to metals in the composition of engineered plant-microbial complexes while having a growth-promoting effect on phytosanitizing plants (Oh et al., 2015; Ullah et al., 2015). Endophytic or rhizobacterial microorganisms are used in the establishment of plant-microbial associations (Kidd et al., 2017; Ren et al., 2019). The main advantage of using endophytic microorganisms in conjunction with plants in phytoremediation is that any toxic xenobiotic ingested by the plant can be degraded within the plant, reducing phytotoxic effects and eliminating toxic effects on herbivorous animals living in or near contaminated areas (Ryan et al., 2008). Siciliano et al. (2001) studied the endo- and rhizosphere microbiomes of different grass species growing in oil-contaminated and nitroaromatic soils and found that contaminant concentration was the most important factor determining the structure and function of the rhizosphere and root endosphere microbiome. In addition, the plant-specific and selective effect influenced the prevalence of specific catabolic genes. Thus, the cane fescue rhizosphere community was characterized by the enrichment of catabolic genes such as alkane monooxygenases, naphthalene dioxygenases and nitrotoluene monooxygenases, while the predominance of catabolic genes in the clover rhizosphere decreased (Siciliano et al., 2003). This suggests that plants can control microbial signs of degradation in the rhizosphere and thus phytoremediation activity.

There is a great deal of information in the literature that under the effect of PGPR both the removal of heavy metals by plants and their entry into the plants increases. Given the differences in the attitude of plants and microorganisms towards elements, two mechanisms are therefore being considered in phytotechnology: phytoextraction and phytostabilisation (Ma et al., 2011). Bacteria from the PGPR group can improve the regenerative capacity of plants or reduce the phytotoxicity of polluted soils. In addition, plants and bacteria can form specific associations in which the plant provides the bacteria with a specific carbon source that induces the bacteria to reduce the phytotoxicity of the contaminated soil. On the other hand, plants and bacteria can form non-specific associations in which normal plant processes stimulate a microbial community that degrades contaminants in the soil through normal metabolic activities (Jing et al., 2007).

Phytoaccumulation or phytoextraction is the ability of a plant organism to extract pollutants from contaminated soils and accumulate them in aboveground organs. Phytoextraction involves the use of plants capable of accumulating metals in aboveground organs (Cunningham et al., 1996). Contaminated plant biomass must be disposed of and transported to special landfills to reduce the transfer of contaminants through the food chain. Disposal of contaminated biomass is believed to be more cost effective than disposal of contaminated soils (Arthur et al., 2005). PGPR-associated strains contribute to the uptake of metals by the plant from the soil through an increase in root surface area, the formation of root hairs, an increase in the solubility of elements, and their transfer in the soil-root-aboveground biomass system. These properties of microorganisms are used in phytoextraction technology (Glick, 2014; Visioli et al., 2015).

Heavy metals can be toxic to metal-accumulating and metal-tolerant plants if the metal concentration in the environment is high enough. This is partly attributed to iron deficiency in a number of different plant species in soils contaminated with heavy metals. Furthermore, low Fe content in plants grown in the presence of high heavy metal concentrations usually causes these plants to become chlorotic, as iron deficiency inhibits both chloroplast development and chlorophyll biosynthesis (Imsande, 1998). Therefore, microbial siderophores are used as iron chelators that can regulate iron availability in the rhizosphere of plants (Loper et al., 1999). In addition, low iron content in plants grown in the presence of high heavy metal concentrations usually causes these plants to become chlorotic, as iron deficiency inhibits both chloroplast development and chlorophyll biosynthesis (Imsande, 1998). However, microbial iron siderophore complexes can be taken up by plants and thus serve as a source of iron for plants. Therefore, it has been suggested that the best way to prevent plants from becoming chlorotic in the presence of high heavy metal concentrations is to provide them with a siderophore-producing bacterium. This suggests that some plant growth-promoting bacteria can significantly increase plant growth in the presence of heavy metals, including nickel, lead and zinc (Burd et al., 2000), allowing plants to develop longer roots and better rooting in the early stages of growth (Glick et al., 1998). The results of the study suggest that inoculation of plants PGPB with siderophore-producing bacteria can improve the bioavailability of elements, thereby accelerating the process of remediation of metal-contaminated soils by phytoextraction. Siderophore-producing PGPB strains help reduce plant stress by forming stable complexes with environmentally hazardous toxic metals such as Cd, Cu, Cr, Pb and Zn (Rajkumar et al., 2006). For example, in the article by Złoch et al. (2016), the selection of the most effective strains of siderophore-producing bacteria isolated from the roots (endophytes) and rhizosphere of Betula pendula L. and Alnus glutinosa L. growing at two sites contaminated with heavy metals in southern Poland, the siderophore-producing bacterial strains were found to be more numerous in the rhizosphere (47%) than in the root (18%). The strains from the genus Streptomyces synthesized of siderophores most efficiently. Under the stress of Cd^{2+} in the soil, Streptomyces sp. secreted three types of siderophores - hydroxamates, catecholates, and phenolates. Addition of an element to the soil increased the synthesis of siderophores, especially the synthesis of ferrioxamine. Siderophore-producing Pseudomonas aeruginosa increased the uptake of Cr and Pb by shoots when Zea mays was inoculated. The translocation coefficient was 4.3 and 3.4, respectively (Braud et al., 2009).

Phytohormones such as IAA released by PGPR also induce plant growth, are responsible for metal uptake and activate the plant defense response against heavy metal stress (Spaepen et al., 2011). It is believed that in addition to the production of siderophores, auxin, glutathione, low and high molecular weight proteins, intracellular polyphosphate granules and polyhydroxy butyric acid (Kulaeva et al., 2004). For example, when Populus euphraticaa was inoculated with a PGPB strain of Phyllobacterium sp. C65 that produced auxin, production decreased when the zinc concentration in the medium increased. The C65 strain helped Populus euphraticaa extract zinc more efficiently from the polluted environment, facilitating growth inhibition caused by heavy metals (Zhu et al., 2015). Bacteria are known to alter the ability of plants to bioaccumulate metals by releasing metal-immobilizing extracellular polymeric substances as well as metal-mobilizing organic acids and biosurfactants (Ma et al., 2016). PGPRs produce ACC deaminase, which reduces the production of the stress hormone ethylene. Extracellular polymeric substances secreted by bacteria, mainly consisting of polysaccharides, proteins, nucleic acids and lipids, play an important role in complexing with metals, reducing their bioavailability (Pinto et al., 2018).

The use of PGPRs does not always lead to increased uptake of metals by plants and soil remediation. PGPRs can reduce the mobility of metals through the mechanisms of biosorption and bioaccumulation (Pratush et al., 2018). In biosorption, metals are immobilized through various microbial processes such as precipitation, accumulation, sequestration and transformation (Ma et al., 2016). In addition, the ionic state of heavy metals (Cr, Fe, Mn, Hg, and Se) is influenced by reduction and/or oxidation, which transform the toxic mobile form into a less toxic immobile form (Ma et al., 2011).

Results and discussion. Phytostabilisation is based on the ability of plants or plant compounds to stabilize soil pollutant levels at low levels by depositing heavy metals or reducing the valence of metals in the rhizosphere, absorption and sequestration in root tissues, or adsorption on root cell walls (Gerhardt et al., 2017; Kumpiene et al., 2012). An advantage of phytostabilisation is that it does not require the removal of hazardous biomass compared to phytoextraction. In phytostabilisation, plants that are highly resistant to metals can be used to immobilize heavy metals in the subsurface and reduce their bioavailability. This prevents their migration into the ecosystem and reduces the likelihood of metals entering the food chain. The use of plant-associated bacteria capable of synthesizing IAA and other indole derivatives in the medium is thought to increase the flow of exudates into the rhizosphere. This leads to intensive proliferation of the bacteria and binding of elements in chelate complexes. As a result, plants can accumulate more pollutants due to the increased solubility and bioavailability of toxic heavy metals. The ability to synthesize auxins, found in many bacterial strains, e.g., from the genera Azospirillium, Pseudomonas and Bacillus, activates the growth of plant roots and provides a strategy for their colonization (Dodd et al., 2010). It is believed that the increased synthesis of bacterial IAA under the influence of Pb^{2+} and Cd^{2+} ions lead to increased exudation of carbon compounds and lectins by plant roots, which in turn leads to increased colonization of plant roots by microorganisms (Pishchik et al., 2016). Over time, the number of populations on the roots reaches a state of equilibrium as some of the populations migrate from the rhizoplane to the rhizosphere. As the number of bacteria in the rhizosphere increases, so does the number of free Pb^{2+} and Cd^{2+} ions bound in chelate complexes that are inaccessible to the plants. As a result, the uptake of metals by plants decreases significantly (up to 6-fold). The use of plant-associated bacteria capable of synthesizing IAA and other indole derivatives in the medium increases the flow of exudates into the rhizosphere. This leads to an intensive proliferation of the bacteria and the binding of elements in chelate complexes. As a result, the plants can accumulate more pollutants due to the increased solubility and bioavailability of toxic heavy metals. Yongpisanphop et al. (2021), an S3 strain was isolated from the rhizosphere of Pityrogramma calomelanos, which grows on heavily Pb-contaminated soils, produces siderophores and is unable to dissolve phosphate. Partial analysis of the 16S rRNA gene identified this isolate as a strain phylogenetically closely related to Arthrobacter humicola. When inoculated with the isolated Pityrogramma calomelanos strain, the authors showed Pb immobilization, leading to the conclusion that this strain can be recommended for lead phytostabilisation. Enhancement of phytoremediation of lead in soil using the wild species Onopordum acanthium by inoculation with some arbuscular mycorrhizal fungi and PGPR was found to increase Pb bioavailability, dry matter yield of shoots and roots, and absorption of the element by the plant (Karimi et al., 2017), mainly through the root system. When inoculated with arbuscular mycorrhizal fungi and PGPR, the Pb concentration in the O. acanthium root was 1.75-2.71 and 1.25-1.53 times higher than in the control (non-inoculated plants). Furthermore, the article by Shabaan et al. (2021) confirmed that PGPRs are an effective means of reducing Pb mobility and can be used effectively for phytostabilisation. The authors showed that the length of shoots and roots of Pisum sativum L. inoculated with PGPR when grown on soils contaminated with Pb at concentrations of 0, 250, 500 and 750 mg kg^{-1} increased by 21, 15, 18% and 72, 80, 84%, respectively, compared to non-inoculated control. Fresh biomass of shoots and roots also increased at Pb concentrations of 250, 500 and 750 mg kg^{-1} by 51, 45, 35% and 57, 101, 139%, respectively. Moreover, PGPR inoculation reduced Pb concentration in roots and shoots by 57, 55, 49%, and 70, 56, 58%, respectively, compared to the control (non-inoculated plants). The authors suggest using PGPR to improve the efficiency of phytostabilisation of soils contaminated with the toxic element lead. Lead is a very harmful and second most toxic element in nature, characterized by high persistence. It is ranked number one on the list of priority hazardous substances and causes adverse effects when released into a living system (Shabaan et al., 2021). Furthermore, Hassan et al. (2017) showed the effect of PGPR Bacillus cereus and Pseudomonas moraviensis on wheat yield on saline soil contaminated with trace elements. The authors found the maximum decrease in the coefficient of biological concentration for Cd, Co, Cr and Mn. Inoculation of wheat with the P. moraviensis strain reduced the biological accumulation factor, the translocation factor for Cd, Cr, Cu, Mn and Ni.

Thus, regulating the accumulation of heavy metals through PGPR is at the heart of a strategy to address the consequences of environmental pollution. Phytostabilization technology (conversion of chemical compounds into a less mobile and active form) is promising for obtaining environmentally friendly products, as the problem of disposing of the polluted biomass is eliminated, unlike phytoextraction technology. The site for phytoremediation is specific, i.e., the use of plants in certain soils and under certain climatic conditions does not guarantee their successful use in others. The specificity of the interaction of PGPR with heavy metal resistance depends on the soil environment, plant type, bioavailability of metal contaminants, composition of root exudates and nutrient content. The daily increasing contamination of soils and water bodies with plant metals can best be managed by interaction with metal-resistant PGPR. This has been the impetus for new research and the identification of potential PGPRs that play an effective role in phytoremediation (Shinwari et al., 2015).

Conclusion. Analysis of scientific literature data indicates that PGPRs in the composition of engineered plant-microbial complexes help the plant tolerate high metal toxicity due to their resistance to metals and their simultaneous ability to positively affect phytoremediation productivity. By altering the solubility and thus the bioavailability of metals, PGPRs have the potential to improve phytoremediation processes and contribute to an increase in the accumulation of heavy metals in plants, their migration in the “soil - root - soil part of the plants” system (this property is used in phytoextraction technology) or their localization mainly in the root system, i.e., transfer to a less mobile and active form through phytostabilisation.

Undoubtedly, the question of the relationship between bacteria and plants in plant-microbial associations requires fundamental investigation. How do plants form a microbial community in their root zone that is closely associated with plants in the presence of environmental pollutants, and how does inoculation of plants with microorganisms that stimulate their growth promote soil purification? One of the complex issues in the relationship between bacteria and plants in plant-microbial associations is the problem of the genetic mechanism of plants that determines the ability of a plant to interact with beneficial microorganisms. In this context, ohmic technologies such as metagenomics, metaproteomics, metatranscriptomics, etc. have been actively developed in recent years to better understand the function and interaction of plants and associated microorganisms. It is believed that the combination of phytotechnology and ohmic technologies can open up new opportunities for phytoremediation in persistent pollution. known or emerging pollutants (Vocciante et al., 2022).

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ECOLOGICAL AND BIOLOGICAL CHARACTERISTICS AND ECONOMIC VALUE OF THE SPECIES RIBES AUREUM PURSH. IN ARID CONDITIONS

Abstract. Identification of economically valuable qualities of golden currant in the conditions of the Volgograd region in order to introduce it into nurseries, protective forest plantations and landscaping facilities is a particularly relevant area of research. The forest-growing conditions of the arid zone imply a constant expansion of the range of tree and shrub species. The purpose of the research was to study the growth and development, to determine the phytoncid properties of leaves, the amount of heavy metals, the biochemical composition and biological value of the fruits of the species Ribes aureum Pursh. In conditions of dry steppe and semi-desert. In the Volgograd region, the authors for the first time studied and proved the high ecological plasticity, economic value and adaptation of golden currant for various purposes. Information on the heavy metal content of fruit may be used for bioindication, the amino acid content of fruit may be used for medical purposes. Indicators on the structure of the leaf blade, drought resistance and racial differences will determine the type and design of protective and landscaping plantations where the species under study can be used. It has been established that golden currant goes through a full cycle of seasonal development, blooms well and bears fruit, has high fruiting rates. The species studied by the authors has decorative properties, which makes it promising for use in landscaping, tolerates pruning well, allowing you to form the desired shape of the crown, perfectly binds the soil with roots, is a honey plant, which allows it to be used in forest reclamation plantings. With the help of a properly selected irrigation system, it is possible to improve and accelerate the growth and development of currant seedlings in nurseries and grow seedlings that meet all the requirements of GOST.

Key words: currant, growth, development, biochemical composition of fruits, heavy metals, yield.

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RIBES AUREUM PURSH ТҮРЛЕРІНІҢ ЭКОЛОГИЯЛЫҚ ЖӘНЕ БИОЛОГИЯЛЫҚ СИПАТТАМАСЫ ЖӘНЕ ҚҰРҒАҚ ЖАҒДАЙДА ЭКОНОМИКАЛЫҚ ҚҰНДЫЛЫҒЫ

Аннотация. Волгоград облысы жағдайында алтын қарақаттың экономикалық және құнды қасиеттерін питомниктерге, қорғаныш орман екпелеріне және көгалдандыру объектілеріне енгізу үшін анықтау зерттеудің ерекше өзекті бағыты болып табылады. Құрғақ аймақтың орман өсіру жағдайлары ағаш-бұта түрлерінің ассортиментін үнемі кеңейтуді қажет етеді. Зерттеудің мақсаты жапырақтардың фитонцидтік қасиеттерін, ауыр металдардың мөлшерін, биохимиялық құрамын және құрғақ дала мен шөлейт жерлерде Ribes aureum Pursh түрлерінің өсуі мен дамуын, жемістерінің биологиялық құндылығын анықтау болды. Волгоград облысында авторлар алғаш рет жоғары экологиялық икемділікті, экономикалық құндылықты және түрлі мақсаттар үшін алтын қарақаттың бейімделуін зерттеді. Жемістердегі ауыр металдардың құрамы туралы мәліметтер биоиндикация үшін, ал жемістердегі аминқышқылдарының құрамы медицина үшін пайдаланылуы мүмкін. Жапырақ пышағының құрылымы, құрғақшылыққа төзімділік және өсу айырмашылықтары зерттелетін түрді қолдануға болатын қорғаныс және көгалдандыру екпелерінің түрі мен дизайнын анықтайды. Алтын Қарақат маусымдық дамудың толық циклынан өтіп, жақсы гүлдейді және жеміс береді. Авторлар зерттеген түрлер сәндік қасиеттерге ие, бұл оны көгалдандыруда қолдануға перспективалы етеді, кесуге жақсы төзеді, тәждің қажетті пішінін қалыптастыруға мүмкіндік береді, топырақты тамырымен жақсы бекітеді, Дұрыс таңдалған суару жүйесін қолдана отырып, питомниктерде Қарақат көшеттерінің өсуі мен дамуын жақсартуға және жеделдетуге және ГОСТ талаптарына сәйкес келетін көшеттерді өсіруге болады.

Түйін сөздер: Қарақат, өсу, даму, жемістердің биохимиялық құрамы, ауыр металдар, өнімділік.

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ЭКОЛОГО-БИОЛОГИЧЕСКАЯ ХАРАКТЕРИСТИКА И ХОЗЯЙСТВЕННАЯ ЦЕННОСТЬ ВИДА RIBES AUREUM PURSH. В АРИДНЫХ УСЛОВИЯХ

Аннотация. Выявление хозяйственно-ценных качеств смородины золотистой в условиях Волгоградской области с целью внедрения в питомники, защитные лесные насаждения и объекты озеленения является особо актуальным направлением исследований. Лесорастительные условия аридной зоны предполагают постоянное расширение ассортимента древесно-кустарниковых видов. Цель исследований заключалась в изучении роста и развития, определении фитонцидных свойств листьев, количества тяжелых металлов, биохимического состава и биологической ценности плодов вида Ribes aureum Pursh. в условиях сухой степи и полупустыни. В Волгоградской области авторами была впервые изучена и доказана высокая экологическая пластичность, хозяйственная ценность и адаптация смородины золотистой для различных целей. Сведения о содержании тяжелых металлов в плодах могут применяться для биоиндикации, содержание аминокислот в плодах может использоваться для медицины. Показатели по строению листовой пластинки, засухоустойчивости и ростовым различиям определят тип и конструкцию защитных и озеленительных лесонасаждений, где может применяться изучаемый вид. Установлено, что смородина золотистая проходит полный цикл сезонного развития, хорошо цветет и плодоносит, имеет высокие показатели плодоношения. Изученный авторами вид обладает декоративными свойствами, что делает его перспективным для использования в озеленении, хорошо переносит обрезку, позволяя сформировать нужную форму кроны, отлично скрепляет почву корнями, является медоносом, что позволяет использовать его в лесомелиоративных насаждениях. С помощью правильно подобранной системы орошения возможно улучшить и ускорить рост и развитие саженцев смородины на питомниках и выращивать саженцы, отвечающие всем требования ГОСТа.

Ключевые слова: смородина, рост, развитие, биохимический состав плодов, тяжелые металлы, урожайность.

Введение. Сельскохозяйственное производство в условиях Волгоградской области ведется в сложных климатических и почвенно-гидрологических условиях (Ivanov, Kulik, 2006). В результате возрастающей интенсификации сельскохозяйственного производства природные ландшафты земледельческих районов страны подвергались значительной антропогенной модификации. Наиболее существенные изменения в них внесло защитное лесоразведение, направленное на борьбу с эрозией почв и засухой, а также селекционный подбор хозяйственно ценных видов. В насаждениях различного назначения используется разнообразный ассортимент деревьев и кустарников, их биологические свойства отражают их отношение к факторам внешней среды. Смородина золотистая, как перспективный кустарник, имеет огромное значение для лесомелиорации и питомниководства (Burmenko, Sorokopudov, 2015; Wynia, 2011; Temperate Plants Database, 2020; Mehmet, 2018; Mataraci, 2012). Подбор перспективных видов смородины имеет значительный практический и теоретический интерес (Sorokopudov, Burmenko, 2017). Целенаправленный отбор исходного материала проводится из имеющегося разнообразия для подбора родительских форм, с учетом места их происхождения и произрастания. При этом, влияние неблагоприятных факторов произрастания, таких как высокие и низкие температуры, бедные почвы, и т.д., позволяет при отборе потомства в F_2 и последующих поколения выделить образцы, обладающие повышенной приспособленностью к конкретным условиям среды.

Материалы и методика исследований. Для определения эколого-биологического потенциала исходных форм Ribes aureum Pursh. изучались следующие хозяйственно-ценные признаки растений: фенологические фазы развития, устойчивость к абиотическим и биотическим факторам, продуктивность, качественные характеристики. Изучение фенологии и изменчивости морфологических признаков и биологических особенностей видов проводилось с апреля по ноябрь по методике Главного ботанического сада (Methods of phonological observation in the Botanical gardens, 1979; Novikov, Novikov, 2010). Фенологическая программа наблюдений включала фиксирование у растения следующих фаз: 1Пч2 – начало разверзания почек, 1Цв3 – полное цветение, 1ПБ1 – начало роста побегов, 2ПБ2 – окончание роста побегов, 2Л3 – полное облиствение, 1Пл3 – плодоношение, 1Л4 – начало расцвечивания листьев, 2Л5 – массовый листопад.

Ранжирование показателей по степени адаптации позволило выявить наиболее устойчивые виды по географическим местоположениям и установить закономерность их изменчивости по приспособляемости к климатическим условиям среды и ее сопряженность с тепловым и водным режимами.

Экологическая пластичность определялась нормой реакции. Пластичность – способность организма существовать в определенном диапазоне значений экологического фактора. По степени пластичности по отношению к отдельным факторам все растения подразделяют на группы (Kosulina, 1993). При изучении разнообразия в полевых условиях определялась принадлежность смородины к определенным экологическим группам, жизненным формам, отношение к влаге, свету, питанию.

Для расчетов пользовались агломеративным иерархическим алгоритмом классификации на основе евклидовых расстояний:

$$p(x_{ij}) = \sqrt{\sum(x_{il}-x_{ji})^2} \qquad (1)$$

где l - признаки; k - количество признаков

Водный дефицит листьев и их водоудерживающая способность определялась с помощью метода насыщения с последующим взвешиванием и высушиванием образцов при температуре 105 °С.

Программы MS Excel, Statistica позволили провести статистическую обработку данных и их анализ.

Результаты и их обсуждение. С целью интродукции и отбора перспективных хозяйственно-ценных видов растений, в 1962 году начал создаваться дендрарий ВНИАЛМИ (ныне ФНЦ агроэкологии РАН), а также производственные участки филиалов (Kleinman et al., 1961).

Возраст смородины золотистой (Ribes aureum Pursh., ареал – Северная Америка) (Agroatlas, 2020) к 1984 году составлял 18 лет, высота

– 2,2 метра, зимостойкость – 1 балл (растение не обмерзает), засухоустойчивость – 1 балл (растение не реагирует на засушливые условия), цветение – 5 баллов (полное обильное цветение, на растении 100% распустившихся цветков или соцветий), плодоношение – 4 балла (хорошее плодоношение, урожай полноценных плодов около 75%, считая от полного плодоношения растений данного вида или формы), жизненность – 1 балл (хорошая жизненность, растение хорошо развито, имеет здоровый вид, хорошо развитые побеги, почки и листья, нормальную их окраску, обильно или хорошо цветет и плодоносит).

Камышинский дендрарий ВНИАЛМИ был заложен в 1931 году на площади 7,5 га. Смородина золотистая была высажена на участок в 1938 году, семена были получены из Камышина. Фанерофит (вид, у которого почки возобновления находятся высоко над землей), кустарник высотой 2 метра, репродуктивная способность которого косвенно определялась по числу плодоносящих поколений – 1 поколение (репродуцент), семязачатки смородины золотистой сформировались в климатических условиях района интродукции впервые, она была рекомендована к выращиванию в дендрологических садах, в богарных условиях произрастания с редким поливом в течение вегетационного периода. Растение не обмерзало (7 баллов), повреждения листьев засухой не обнаруживалось (6 баллов), обильно цвело и хорошо плодоносило (5 и 4 балла соответственно), давало дружные всходы в открытом грунте (4 балла).

При освоении Терско-Кумских песков учитывались суровые условия региона – сухой континентальный климат, годовая амплитуда температур до 80°С. Среднегодовое количество осадков уменьшается с юго-запада на северо-восток с 400 до 250 мм. Число дней с ветром превышает 300. Выращивание лесонасаждений в данных условиях затруднено из-за недостатка осадков, поэтому главным источником водного питания растений служат грунтовые воды. Смородина золотистая была рекомендована для выращивания на пастбищезащитных насаждениях, которые повышают урожай кормовых трав на 15-20%, создают условия для отдыха животных в жаркое время года, защищают их от сильного ветра, пыльных бурь и метелей, позволяют проводить регулярный выпас скота, широко применять пастбищеобороты, что с большим эффектом отражается на сохранности пастбищ и повышении их кормовой емкости. Смородину вводят в опушечные ряды с расстоянием между основными продольными полосами не более 20-30 Н, направление их – перпендикулярное к вредоносным ветрам (ССВ-ЮЮЗ). Они создаются из 3-5 рядов при ширине междурядий 4-5 м.

При посадке зеленых зонтов у птицеводческих ферм смородина рекомендовалась, как плодовая порода, что способствовало дополнительному обеспечению птиц витаминным кормом. Алтайская агролесомелиоративная и лесная опытная станция до 1954 года находилась в системе ВНИАЛМИ, затем была передана ВНИИЛМ. Смородина золотистая впервые прошла испытание на бедных светло-серых бугристых песках, а также успешно зарекомендовала себя на полях с повышенным засолением почв.

В 1946 году Ачикулакская опытная станция заложила дендроучасток, в котором смородина золотистая была испытана, как хозяйственно-ценный, быстрорастущий вид, в посадках вдоль трасс Сухопадинского и Левобережного каналов смородина в составе насаждений отличалась интенсивным ростом и развитием.

В Поволжской опытной агролесомелиоративной станции с 1931 года был разработан крупный агролесомелиоративный питомник, где была заложена плантация из сеянцев смородины золотистой с целью изучения сбора и хранения семян.

На опытном участке ВНИАЛМИ в 1959 году на площади 7 га урожай смородины составил 45 ц/га, валовой сбор – 31,5 тонн., саженцы – 0,5 тыс. шт, увеличив объем валовой продукции в натуральных показателях в 3-4 раза и в денежном выражении в 3 раза с учетом планируемого снижения отпускных цен на 35-40%.

Ribes aureum Pursh. (Смородина золотистая) – компактный кустарник семейства Крыжовниковые (Grossulariaceae), высотой до 2-2,5 м. Ареал достаточно широкий, занимает площадь центральной и южной частей России, Кавказ, Азербайджан, Дальний Восток, степную часть Приуралья, спорадически может встречаться в посадках Санкт-Петербурга, Москвы, Кирова, Вологды, Екатеринбурга, Иркутска, Омска, Новосибирска, Апшерона, Баку, Ашхабада, в Таджикистане, Узбекистане, в защитных лесных насаждениях степной и лесостепной зон юго-востока Волгоградской обл., Нижнего Поволжья, Казахстана, Западной Сибири, Алтая (GOST, 2013).

Для оценки биологического потенциала вида Ribes aureum Pursh. проводилось сопоставление развития и репродуктивных способностей, выявление экологической пластичности вида, которая служит мерой успешности интродукции в засушливом регионе и дает возможность его практического использования для целей мобилизации биоресурсов и питомниководства.

Степень ежегодного вызревания побегов смородины золотистой определяет их более или менее успешную перезимовку, визуально вызревание побегов определялось по одревеснению, окраске и развитию наружных покровов, по заложению степени сформированности и защищенности почек, по времени окончания роста побегов и окончанию листопада (Табл.1).

Таблица 1 – Общая оценка биоморфологичеких параметров вида Ribes aureum Pursh.

Признак	Характеристика	Единицы измерения	Достигнутый уровень параметров
1	Высота куста	м	1,7-2,0
2	Крона куста	-	полураскидистая
3	Побегообразовательная способность куста	степень	хорошая
4	Способность восстановления при повреждениях	степень	высокая
5	Продолжительность периода вегетации	сутки	170
6	Адаптационная способность к засухе	-	высокая
7	Морозостойкость	градус	–35 градусов
8	Степень вызревания побегов	балл	1
9	Плодоношение	балл	5

У смородины золотистой на протяжении вегетационного периода наблюдалась незначительная внутрипопуляционная изменчивость фенофаз. Изучение влияния фотопериодов на сроки начала цветения показало, что данный вид относится к длиннодневным растениям, способным зацветать и давать наибольший прирост побегов лишь после известного периода развития на длинном дне. Чаще всего его порог длины дня близок к 15-16 часам. В природных условиях Волгоградской области длина дня с весны и до конца лета держится в пределах 14-16 часов, что обеспечивает смородине беспрепятственный переход к цветению. Сроки цветения смородины в природных условиях определяются, прежде всего, термическим режимом.

Длительность фенологических фаз и ритм жизненных процессов смородины зависит от историко-ботанико-географических, фитоценологических и экологических причин. В засушливых условиях смородина золотистая сохраняет ритм сезонного развития, а экологические причины определяют особенности ее сезонных смен фенофаз, зависящие от ритма окружающей среды и взаимосвязанные с фенофазами ритмы основных жизненных функций – транспирации и ассимиляции.Диаметр кроны кустарника играет важную роль при проектировании насаждений различного типа. У смородины золотистой он составляет минимально 48,3-56 см, в среднем 101,18-102,31 см, максимально 148,0-152,20 см. По наиболее важным морфометрическим параметрам куста можно построить пример дендрограммы ближайших сходств (Табл. 2).

Таблица 2 – Исходные данные

Название пункта	Длина побега	Кол-во побегов	Окружность кроны	Длина черешка листа	Ширина листа	Длина листа	Количество жилок
Волгоград	138	11	148	2.35	4.11	3.49	12.5
Дубовка	144	16	152	2.72	4.69	4.18	12.3

1. $p(x_{1,2}) = \sqrt{(138\text{-}11)^2 + (144\text{-}16)^2} = 180.31$

   $p(x_{1,3}) = \sqrt{(138\text{-}148)^2 + (144\text{-}152)^2} = 12.81$

   $p(x_{1,4}) = \sqrt{(138\text{-}2.35)^2 + (144\text{-}2.72)^2} = 195.86$

2. Полученные данные помещаем в Таблицу 3 (матрицу расстояний).

Таблица 3 – Матрица расстояний

№ п/п	1	2	3	4	5	6	7
1	0	181	13	196	194	195	182
2	181	0,0	194	16	14	14	4
3	13	194	0,0	209	206	207	195
4	196	16	209	0,0	3	2	14
5	194	14	206	3	0,0	0,9	12
6	195	14	207	1,9	0,9	0,0	13
7	182	4	195	14	12	12	0,0

3. По данным поиска наименьшего расстояния следует, что объекты 5 и 6 наиболее близки $P_{5;6} = 0.9$, поэтому их можно объединить в один кластер (Табл. 4).

Таблица 4 – Объединение кластеров

№ п/п	1	2	3	4	[5]	[6]	7
1	0	181	13	196	194	195	182
2	181	0,0	194	16	14	14	4
3	13	194	0,0	209	206	207	195
4	196	16	209	0,0	3	2	14

[5]	194	14	206	3	0,0	0,9	12
[6]	195	14	207	1,9	0,9	0,0	13
7	182	4	195	14	12	12	0,0

Формируя новую матрицу расстояний, выбираем наименьшее значение из значений объектов № 5 и № 6.

В результате имеем 6 кластеров: $S_{(1)}$, $S_{(2)}$, $S_{(3)}$, $S_{(4)}$, $S_{(5,6)}$, $S_{(7)}$

Из матрицы расстояний следует, что объекты 4 и 5, 6 наиболее близки $P_{4;5,6}$ = 1, 85, поэтому они так же объединяются в один кластер (Табл. 5).

Таблица 5 – Объединение кластеров по схожести признаков

№ п/п	1	2	3	[4]	[5,6]	7
1	0	180.314	12.806	195.86	193.22	181.921
2	180.314	0	193.041	15.849	13.243	3.992
3	12.806	193.041	0	208.563	205.924	194.618
[4]	195.86	15.849	208.563	0	1.852	13.957
[5,6]	193.22	13.243	205.924	1.852	0	11.327
7	181.921	3.992	194.618	13.957	11.327	0

В результате формирования новой матрицы расстояний имеем 5 кластеров: $S_{(1)}$, $S_{(2)}$, $S_{(3)}$, $S_{(4,5,6)}$, $S_{(7)}$, объекты 2 и 7 объединяются в один кластер, как наиболее близкие (Табл. 6).

Таблица 6 – Объединение кластеров по признакам 2 и 7

№ п/п	1	[2]	3	4,5,6	[7]
1	0	180.314	12.806	193.22	181.921
[2]	180.314	0	193.041	13.243	3.992
3	12.806	193.041	0	205.924	194.618
4,5,6	193.22	13.243	205.924	0	11.327
[7]	181.921	3.992	194.618	11.327	0

Далее результаты формирования новой матрицы показывают наиболее близкие значения признаков 2, 4, 5, 6 и 7 (Табл. 7).

Таблица 7 – Объединение кластеров по признакам 2,7, 4, 5 и 6

№ п/п	1	[2,7]	3	[4,5,6]
1	0	180.314	12.806	193.22
[2,7]	180.314	0	193.041	11.327
3	12.806	193.041	0	205.924
[4,5,6]	193.22	11.327	205.924	0

Объекты 1 и 3 объединяются в один кластер, как наиболее близкие (Табл. 8).

Таблица 8 – Объединение кластеров по признакам 1 и 3

№ п/п	[1]	2,7,4,5,6	[3]
[1]	0	180.314	12.806
2,7,4,5,6	180.314	0	193.041
[3]	12.806	193.041	0

В конечном итоге, имеем два кластера: $S_{(1,3)}$, $S_{(2,7,4,5,6)}$ (Табл. 9).

Таблица 9 – Итоговый результат по объединению кластеров

№ п/п	1,3	2,7,4,5,6
1,3	0	180.314
2,7,4,5,6	180.314	0

Таким образом, при проведении кластерного анализа по принципу «ближайших сходств» получили два кластера, расстояние между которыми равно Р=180,31. Темпы роста и развития смородины являются фенотипически пластичным признаком, модифицируемым внешними воздействиями. Различные темпы прироста и высоту куста можно рассматривать как адаптивную модификацию, обеспечивающую приспособление вида к условиям окружающей среды. У смородины золотистой в условиях сухостепной и полупустынной зоны складывается особенный фенологический тип, выражающийся в интенсивности возрастных изменений и процессов роста. Ювенильный период составляет 1,5-2 года, но в этих условиях данный вид проявляет большую устойчивость. В возрасте 8-10 лет она достигает высоты 1,8 -2,2 м и живет при систематической омолаживающей обрезке 30-40 и более лет. Колебания интенсивности и продолжительности вегетативного морфогенеза, индуцированного условиями влажности, являются основой изменчивости структурных элементов вегетативных органов. Фитонциды Ribes aureum Pursh. способны убивать и подавлять вирусы, бактерии, микроскопические грибы. По П. Б. Токину впервые в засушливых условиях г. Волгограда была определена фитонцидная активность листьев смородины золотистой (Табл. 10) (Tokin, 1974). В керамической ступке перетирались листья исследуемого вида. Через марлю отжимались 3 капли сока растения. В химический стакан к 50 мл дистиллированной воды вносилась суспензия микроорганизмов Paramécium caudátum Ehrenberg. На предметное стекло помещалась капля воды с микроорганизмами и на расстоянии нескольких миллиметров от нее – капля сока смородины. Было зафиксировано время жизнедеятеятельности с помощью микроскопа Микмед-5, а также отмечено время ответной реакции на воздействие фитонцидов для каждого исследованного вида

Таблица 10 – Сравнительные фитонцидные характеристики смородины золотистой, шиповника обыкновенного и липы сердцевидной и их влияние на реакцию инфузории туфельки (Paramécium caudátum Ehrenberg)

Вид	Время гибели Paramécium caudátum Ehrenberg.	Фитонцидная активность, %
R. aureumPursh.	1 минута 07 секунд	93,4
	2 минуты 15 секунд	46,5
	4 минуты 23 секунды	23,6
R. canina L.	3 минуты 45 секунд	28,9
	5 минуты 24 секунды	19,08
	6 минут 18 секунд	16,1
T. cordata Mill.	4 минуты 34 секунды	23,0
	6 минуты 09 секунд	16,4
	7 минут 55 секунд	13,2

Чтобы вырастить жизнеспособный вид в экстремальных условиях необходимы его разносторонние исследования – наблюдения, как отражаются на внутренней организации древесного организма высокие температуры и постоянный водный дефицит, как эти показатели сказываются на формировании вегетативных и репродуктивных органов и способности вида расти и развиваться в условиях напряженного гидротермического режима.

Характер адаптации растений к различным стрессовым воздействиям неспецифичен. У видов в ответ на стрессовые воздействия в разной степени изменяются физиологические функции, что отражает их уровень устойчивости, но в некоторых случаях может свидетельствовать и о специфичности реакции (Табл. 11) [2].

Таблица 11 – Водный режим листьев смородины золотистой в пунктах исследований

Пункт исследований	Дата	t воздуха, °C	Влажность, %	Водный дефицит, %	Тургоресцент-ность %
г. Волгоград	7.07	+36	25	19,24	81,02
г. Калач-на-Дону	18.07	+31,3	22	21,43	78,58
пос. Пятиморск	18.07	+31	32	57,78	42,23
г. Дубовка	3.08	+31	37	41,36	58,65

г. Камышин	24.08	+30	21	55,04	44,97
Дендрарий ФНЦ агроэкологии РАН	28.07	+33	30	29,41	70,58
Территория ФНЦ агроэкологии РАН	27.07	+32	20	38,35	61,64

Наилучший результат по водному дефициту показали отобранные образцы смородины в г. Волгограде, г. Калач-на-Дону и дендрарии ФНЦ агроэкологии РАН. Тургоресцентность наиболее выражена у образцов из г. Волгограда, г. Калач-на-Дону, и на участках ФНЦ агроэкологии РАН, что свидетельствует о высокой величине осмотического давления внутриклеточных вакуолей. Показатели водного дефицита и тургоресцентности – пропорциональны, поэтому у видов с низким значением водного дефицита отмечены высокие показатели тургоресцентности. У вида смородины из г. Волгограда под микроскопом были четко видны пульсирующие вакуоли, регулирующие осмотическое давление (увеличение 10,0 и 4,0), наблюдался ярко выраженный гомеостаз.

По данным водного режима можно сделать вывод, что смородина золотистая – типичный мезофит с широкой экологической амплитудой. Благодаря этому она может хорошо расти и плодоносить в ареале умеренно увлажненных местообитаний, положительно реагировать на некоторое увеличение влажности. Установлено, что представители одного и того же вида, произрастающие в разных условиях, отличаются типом строения. У первых усиливаются признаки ксероморфности, у последних – мезоморфности, что коррелирует с продуктивностью растений. Изменчивость листьев смородины варьирует в зависимости от места произрастания растений (таблица 12).

Таблица 12 – Метамерная изменчивость листьев смородины в пунктах наблюдений

Длина черешка, см	Длина листа, см	Ширина листа, см	Количество жилок, шт
г. Волгоград			
4,08	7,06	8,85	9,85
г. Калач-на-Дону			
3,90	9,35	7,99	12,3
пос. Пятиморск			
4,16	8,82	7,72	12,0
г. Дубовка			
2,35	3,49	4,11	12,3

Дендрарий ФНЦ агроэкологии РАН			
2,72	4,18	4,69	12,5
Территория ФНЦ агроэкологии РАН			
3,72	5,08	5,42	14,1
г. Камышин			
2,47	3,11	4,47	14,3

Наибольшей длиной черешка отличается вид из пос. Пятиморск, наименьшей – г. Дубовка, наибольшую длину листа имеет вид из г. Калач-на-Дону, наименьшую – из дендрария ФНЦ агроэкологии РАН. Ширина листа отличается наибольшим размером у вида из г. Волгограда, наименьшим – из г. Дубовка. Вид из г. Камышина имеет наибольшее количество жилок, наименьшее – вид из г. Волгограда. Листья нижней части кустарника и верхней части отличаются друг от друга большей степенью варьирования показателей. Генотипические особенности вида растения определяют параметры его листовой пластинки. Температура воздуха, количество осадков, влажность почвы влияют на модификационную изменчивость листовых параметров, расположение листьев на кусте и побеге. Если разница в параметре листовых пластинок устойчива, то данный факт говорит о видовых различиях растений.

Происхождение семян – основа для выращивания биологически стойкого посадочного материала, который способен противостоять неблагоприятным условиям. Количество семян для выращивания 1 тыс. сеянцев смородины золотистой составляет 0,06 кг.Плоды собирают в июле, различия их качественных и количественных признаков делает возможным отобрать наиболее перспективные виды для озеленения, использования для лекарственных и хозяйственных целей (таблица 13).

Таблица 13 – Показатели плодоношения смородины золотистой в опытной сети ФНЦ агроэкологии РАН

Показатели плодоношения	Калач-на-Дону	Дубовка	Дендрарий ФНЦ агроэкологии РАН
Вес плода, г	0,58	0,59	0,52
Ширина плода, см	0,80	0,65	0,71
Длина плода, см	1,04	0,86	0,68
Количество семян в плоде, шт.	24	22	22
Вес 10 шт. семян, г	0,15	0,09	0,07

Контроль питательной ценности, химического состава и показателей безопасности плодов является приоритетным для определения хозяйственной пригодности смородины (таблица 14). Детектирование проводилось в УФ-области спектра при длине волны 254 нм (GOST, 2010). Для прямого количественного определения триптофана без получения ФТК-производного регистрировалось поглощение при длине волны 219 нм.

Таблица 14 – Показатели аминокислотного состава смородины в 2020 году

Наименование показателя	Значение, мг %	
	г. Волгоград	г. Дубовка
Аргинин	162	113
Лизин	79	45
Тирозин	42	30
Фенилаланин	65	53
Гистидин	33	42
Лейцин+изолейцин	166	136
Метионин	30	49
Валин	65	21
Пролин	95	64
Треонин	64	42
Серин	68	43
Аланин	73	48
Глицин	109	72
Триптофан	59	75

Результаты и обсуждение. Результаты изучения содержания тяжелых металлов в плодах смородины представлены в Таблице 15 и могут быть использованы в биоиндикации экологического состояния смородины и имеют принципиальное значение для оценки последствий техногенного загрязнения природных и аграрных экологических систем (GOST, 2010; Tkachenko et al., 2012; Zhao et al., 2013).

Таблица 15 – Содержание тяжелых металлов

Пункт сбора плодов	Название элемента			
	Кадмий (Cd)	Цинк (Zn)	Свинец (Pb)	Медь (Cu)
г. Волгоград	0,04	12,07	0,84	8,19
г. Дубовка	0,05	5,20	0,10	2,10
ПДК*	0,03	10,0	0,40	5,0

*Примечание: в воздушно-сухой пробе, мг/кг

Смородина, как медоносное растение, является ценным для пчел, как основной источник нектара и цветочной пыльцы, и превосходит по медопродуктивности другие древесные растения сухостепной зоны.

Ведение пчеловодства в лесах Калачевского лесничества допускается на всей площади (Forestry regulations of the Kalachevsky forest area, 2019). Хороших медоносов под пологом леса в лесном фонде лесничества мало, а их постоянное размещение в лесу нецелесообразно. Насаждения из смородины способствуют улучшению базы медосбора и созданию лучшей кормовой базы пчеловодства (Табл. 16).

Таблица 16 – Мёдопродуктивность медоносных растений

Наименование медоносных растений	Мёдопродуктивность в переводе на полное покрытие нектар, кг/га
Груша обыкновенная Pyrus communis L.	30-50
Абрикос обыкновенный Prunus armeniaca L.	25-30
Яблонялесная Malus sylvestris (L.) Mill.	30-50
Вишня обыкновенная Prunus cerasus L.	30-40
Терн Prunus spinosa L.	15-20
Малина обыкновенная Rubus idaeus L.	50-70
Смородина золотистая Ribes aureum Pursh.	50-70

Конечным итогом отбора является массовое размножение и внедрение выделенных форм. На питомнике Нижневолжской станции по селекции древесных пород в г. Камышине саженцы смородины золотистой 1 и 2 года выращиваются по стандартам требований к качеству: ГОСТ Р 53135-2008 «Посадочный материал плодовых, ягодных, субтропических, орехоплодных цитрусовых культур и чая. Технические условия».

Число корней у саженцев смородины первого товарного сорта – не менее 4, второго – не менее 3. Длина корневой системы саженцев первого товарного сорта – не менее 15 см, второго – не менее 10 см. У однолетних саженцев первого и второго товарных сортов – не менее одного надземного побега, у двухлетних саженцев первого товарного сорта – не менее 3 надземных побегов, второго сорта – не менее 2.

Диаметр основания надземной части однолетних саженцев смородины первого товарного сорта – не менее 0,8 см, второго товарного сорта – не менее 0,6 см. Длина побегов саженцев первого товарного сорта – не менее 50 см, второго товарного сорта – не менее 40 см.

Для полива саженцев смородины в питомнике используется капельное орошение, капельные линии «NEO-DRIP», шаг 40-50 см, эмиттеры с расходом воды 2,4 л/час (Табл. 17).

Таблица 17 – Кратность и норма полива сеянцев смородины в питомнике на светло-каштановых почвах

<table>
<tr><td>Вид</td><td colspan="3">1 фаза – набухание и прорастание семян</td><td colspan="2">1 фаза - формирование всходов</td></tr>
<tr><td rowspan="5">Ribes aureum Pursh.</td><td>Длительность, дни</td><td>Число поливов</td><td>Норма поливов, м^3/га</td><td>Длительность, дни</td><td>Число поливов</td></tr>
<tr><td>5-20</td><td>3-4</td><td>100</td><td>15-20</td><td>2</td></tr>
<tr><td colspan="2">2 фаза – формирование всходов</td><td colspan="3">3 фаза – рост сеянцев</td></tr>
<tr><td colspan="2">Норма полива, м^3/га</td><td>Длительность, дни</td><td>Число поливов</td><td>Норма полива, м^3/га</td></tr>
<tr><td colspan="2">100-150</td><td>80-90</td><td>3</td><td>300-350</td></tr>
</table>

Выводы. На основе анализа и обобщения экспериментального материала выявлены закономерности и механизмы адаптации Ribes aureum Pursh. в засушливых условиях, с учетом комплексных исследований и критериев, характеризующих их биологический потенциал и хозяйственную пригодность для отбора адаптированного генофонда хозяйственно ценных видов, с целью создания экологически сбалансированных насаждений с многофункциональным действием: эстетическим, рекреационным, почвозащитным, почвоулучшающим, ремизным, обеспечивающим улучшение природной среды, получение хозяйственного сырья (лекарственного, медоносного, пищевого и т. д.).

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ENVIRONMENTAL ASSESSMENT OF SOIL CONTAMINATION OF THE OIL AND GAS ZONE INDUSTRY ZONE

Abstract. The oil and gas industry, the main industry operating in many OPEC countries, makes extensive use of radiation equipment, some of this equipment are potentially dangerous to human health and the environment if not controlled every time.

The goal of our work is to develop scientific-methodical foundations of radio-ecological and radiation safety at the enterprises of the oil and gas complex, to ensure safe living conditions for staff and the population living in adjacent territories. The article considered: the role of groundwater in the radionuclide contamination in oil fields. Depending on the chemical type of ground waters, enclosing rocks state, and relation in the oil-water-rock system, various anomalies formation is possible.

Gamma spectrometry analysis has investigated the nature of radioactivity and determined that the elements of uranium-radium are the main cause of radiation background. Based on this data, we estimated the radioactive background of the surrounding environment and made a map of where were indicated the most dangerous radioactive areas. The article describes the radiation background of the study field environment. The article is shown local fields of radionuclide contamination and the results of the investigations conducted for studying the radioisotope composition of technogenic anomalies and the mechanism of their formation.

In the end, the results of the study showed that regular radioecological monitoring is necessary in the territories of the Apsheron Peninsula oil fields to prevent radiation hazards.

Key words: environment**,** radionuclides, ionizing radiation, oil-gas, radionuclide pollution.

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МҰНАЙ-ГАЗ АЙМАҒЫ ТОПЫРАҒЫНЫҢ ЛАСТАНУЫН ЭКОЛОГИЯЛЫҚ БАҒАЛАУ

Аннотация. Мұнай және газ өнеркәсібі, көптеген елдерде жұмыс істейтін жаһандық сала сәуле шығару генераторлары мен жабық және ашық радиоактивті көздерді кеңінен пайдаланады, олардың кейбіреулері егер оларды тиісті түрде бақыламайтын болса адам денсаулығы мен қоршаған орта үшін ықтимал қауіпті. Бұдан басқа, өндіру, техникалық қызмет көрсету және пайдаланудан шығару кезінде коллектор жынысынан шығатын табиғи радиоактивті материалдың едәуір мөлшері кездеседі.

Жаһандық экологиялық проблемалардың ішінде радиоэкологиялық жағдай қоршаған радиоактивтіліктің адамның тіршілік ету ортасына әсерінің ең аз зерттелген саласы ретінде ерекше назар аударуды талап етеді. Соңғы уақытқа дейін атмосфераның және жер бетінің радиоактивті ластану көздері негізінен жасанды радиоизотоптар болып табылады деп есептелді.

Мақалада мұнай кен орындарының радионуклидтермен ластануындағы жер асты суларының рөлі көрсетілген.

Түйін сөздер: қоршаған орта, радионуклидтер, иондаушы сәулелену, мұнай-газ, радионуклидтің ластануы.

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ЭКОЛОГИЧЕСКАЯ ОЦЕНКА ЗАГРЯЗНЕНИЯ ПОЧВ НЕФТЕГАЗОВОЙ ЗОНЫ

Аннотация. Нефтяная и газовая промышленность, глобальная отрасль, действующая во многих странах, широко использует генераторы излучения, закрытые и открытые радиоактивные источники, некоторые из которых потенциально опасны для здоровья человека и окружающей среды, если их не контролировать должным образом. Кроме того, во время добычи, технического обслуживания и вывода из эксплуатации встречаются значительные количества естественного радиоактивного материала (НОРМ), происходящего из породы-коллектора.

Среди глобальных экологических проблем радиоэкологическая обстановка требует особого внимания как наименее изученная область влияния окружающей радиоактивности на среду обитания человека. До последнего времени считалось, что источниками радиоактивного загрязнения атмосферы и поверхности Земли являются в основном искусственные радиоизотопы. В статье показана роль подземных вод в загрязнении радионуклидами нефтяных месторождений. В зависимости от химического типа подземных вод, состояния вмещающих пород, соотношения в системе нефть-вода-порода возможны различные варианты формирования аномалий. Радиевые аномалии широко развиты на месторождениях эксплуатируемых нефтяных залежей верхней части продуктивной толщи.

По результатам наших анализов была составлена радиационная карта и выделены наиболее опасные участки по уровню радиоактивности изучаемой территории. Целью гамма-спектрометрического анализа исследовать природу радиоактивности химических элементов и определить, что именно элементы уран-радий являются основной причиной радиационного фона. На основе этих данных мы произвели оценку радиоактивного фона окружающей среды и составили карту, на которой были указаны наиболее опасные радиоактивные районы. В конечном итоге результаты, полученные в результате

этого исследования, показали, что на территориях нефтепромыслов Апшеронского полуострова необходимо проводить регулярный радиоэкологический мониторинг для предотвращения радиационной опасности.

Ключевые слова: радионуклиды, ионизирующее излучение, нефть-газ, окружающая среда, радионуклидное загрязнение.

Introduction. Correlation of elevated concentrations of natural radionuclides with oil fields known since the beginning of the 20th century. In preparation, this article was intended to demonstrate to readers as much as possible wide range of changes in background parameters and possible mechanisms for the formation of its local features, which, as a rule, have run into practitioners.

Radioactive pollutants mainly have natural origins and contents of the naturally radioactive elements K, U, and Th in rocks are reported in conventional units of % K, mg/kg U and mg/kg Th. Radium (Ra), thorium (Th), uranium (U) and are the most widespread pollutants among the naturally-occurring radionuclides. Following various technogenic processes, the naturally-occurring radionuclides can become a serious threat to the ecosystem (Aliyev, 2007:5).

The concentration of the gamma-emitting radionuclides, except for ^{40} K, inhuman is so small that none of them can be detected using normal whole-body counters available to measure any intakes of radionuclides by occupational workers (Abison, 2001:3).

Differentially, the 238-U/235-U ratio has increased over time due to the faster radioactive decay of 235-U (Hamlat et al., 2001:6).

The incompatibility of uranium implies that highly differentiated felsic rocks (igneous rocks that are rich in feldspar and silicon) tend to have higher contents of U: granitic rocks contain an average of 2 – 5mg/kg of U, depending on the magma source and the differentiation path (Wilson, 1992). Metamorphic and sedimentary rocks deriving from felsic materials will inherit the U concentration of their parent rocks, as the most abundant U-bearing minerals are typically resistant to weathering processes. Significant enrichment of U in sedimentary rocks can be achieved by densitydriven accumulation of these minerals, typical of placer deposits, as well as by absorption and/or adsorption of U in organic matter.

Thorium is a trace element in the Earth's crust (5.6 mg/kg) with a relative enrichment in the upper crust (10.5mg/kg) due to its strong lithophile metallic character. Concentrations in common rock types range from 1.6 to 20mg/kg.

Monazite sands are one of the main sources of thorium, containing about 6% thorium. Consequently, monazite sand deposits are one of the areas with unusually high natural radioactivity. At present, thorium has a major use in nuclear power as a potential source of fissile material.

Amongst the daughter products of 232-Th, the major radiological hazards come from the radium, radon, and polonium isotopes.

The natural radioactivity in rocks depends on their type and on how and where they were formed. Rocks can be classified into igneous, sedimentary, or metamorphic ones according to their formation process. Igneous rocks are formed from magma, either inside a magma chamber (thus forming magmatic rock like granite or diorite), inside intrusions (forming intrusive rock like dolerite), or from lava flows (forming volcanic rock such as basalt or rhyolite).

Materials and methods. Radioecological studies in Azerbaijan started in 1988. It was established that the natural radioactive background of the Absheron Peninsula, formed by weakly radioactive sedimentary rocks, fluctuates around 6-8 mcR/h.

The sites in question were chosen on the territory of Bibiheybat and Zykh-Hovsan oil fields of Absheron peninsula. The data considered here are the results obtained from 10 different points as follows: samples 1 from the center of Zykh lake, samples 2 and 3 from Duzlu lake, and three samples from surface runoffs. Produced water samples were collected out of onshore and offshore locations on the territory of the Bibiheybat field.

Experimental method. For our research we used different methods - were analyzed using gamma-spectrometer according to generally accepted methods for the assessment of the contribution of each element to radionuclide pollution. Based on such a favorable radioecological situation, within the limits of the given region, it was determined the presence of numerous local and area sites where, as a result of technogenic activity, radioactivity exceeds the acceptable radiation level by tens, hundreds, and more times.

For this research, we used ARL™ OPTIM'X WDXRF Spectrometer and this spectrometer provides all the benefits of wavelength dispersive x-ray fluorescence (WDXRF), one of the most versatile methods for elemental analysis of solids and liquids.

The analyzed sample is placed in a fixed position under the detector (fig. 1), then the spectral capture time is entered from the "Analysis" panel with the " Acquisition" tool $t_{Acquisition}$ = 86400 sec. From Genie 2000 program alpha-spectrum assembly is started by pressing the "Start" button (Kelsey et al., 2016:11).

Figure 1. ARL™ OPTIM’X WDXRF spectrometer

When the error of the analyzed peak area is less than 2σ (P = 95% confidence), spectrum accumulation stops and the gamma spectrum is saved with the same identification code (Brückner et al., 2003:108).

The sample analyzed by the alpha-spectrometric method, unlike the gamma-spectrometric method, is measured on the spectrometer when it is electrolyzed on stainless steel disks (Young et al., 2016:11). Preparation for alpha-spectrometric analysis of uranium isotopes in the sample is as follows.

Results and discussion. After our experiment in the spectrometer produced results are shown in the figure (2; 3).

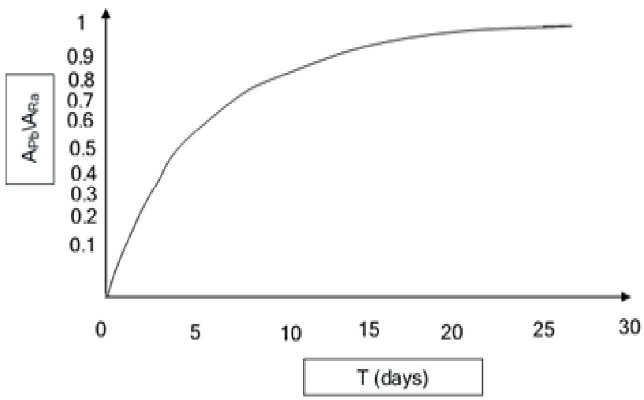

Figure 2.Regularity of radioactive balance with the isotope ^{214}Pb, a decay product of the isotope ^{226}Ra

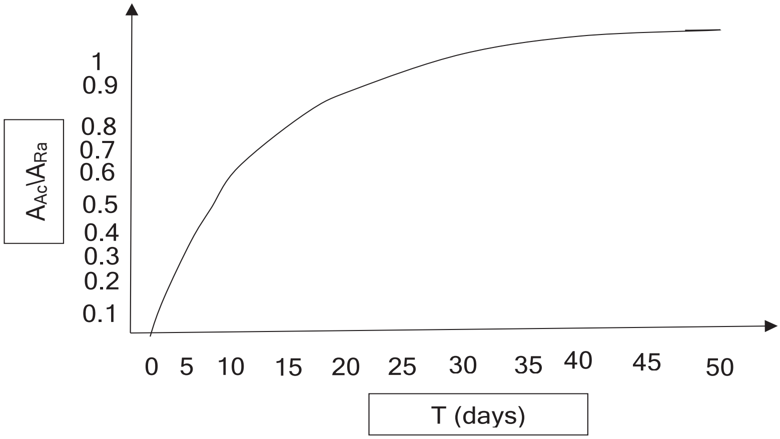

Figure 3. Regularity of radioactive balance with the isotope ^{228}Ac, a decay product of the isotope ^{228}Ra

A characteristic feature of radionuclide contamination of the territory of the Absheron Peninsula is that pollution occurs with radioactive isotopes of natural origin but as a result of technogenic processes.

Meet pollutions formed by artificial isotopes or large accumulations of potash fertilizers (Table 1). So, by developing the dynamics of pollution it is necessary to follow the solution of a particular task (Aliyev et al., 1996:5).

Table 1

Radionuclide composition of technogenic contamination of the Absheron Peninsula

Sampled area	U^{238}	Ac^{228} (MsTh II)	Ra^{228} (MsTh I)	Ra^{226}	Rn^{222}	Rn^{220} (Th)	Bi^{214} (RaC)	Tl^{208}	K^{40}
Bibi-Haybat	+	+	+	+	+	+	+	+	+
Gum adasi	+	+	+	+	+	+	+	+	+
Surakhani	+	+	+	+	+	+	+	+	+
East of the Hovsan	+	-	-	+	+	-	+	-	-
Zira	-	-	-	-	-	-	-	-	+

The dynamics of pollution of oil-field areas can be schematically modeled quite simply. In the process of interaction of water solutions with rocks and oil deposits, pollution happens as a result of the removal of radionuclides of the uranium-radium and thorium series from the depths to the surface (Khalilova, 2016:5). This is typical for hard waters of the upper layer of the productive series, characterized by high mineralization of chloride-sodium-calcium composition of sulfate-free with low content of bicarbonate ions.

These waters leach radium from rocks with normal dispersion of radioactive element content, where radium and its isotopes are in adsorbed form. The processes of radium leaching from rocks take place in the presence of corresponding cations of alkaline-earth elements in waters. In addition to these factors, a huge role in the formation of contaminated areas in the oil areas is played by the presence of mobile contact of water with rocks and oil, which takes place during its extraction (Cannon et al., 1971:123).

In comparison with radiıım uranium distribution in formation waters of oil, fıelds have an opposite character. If the maximal levels of radium isotopes content are typical of hard high-mineralized waters then uranium content m these waters is lower than in alkaline ones. In alkaline waters, the low limit of uranium concentration is not less than n $\times 10^{-6}$g/l, for hard waters it doesn't exceed n$\times$10-^{7} g/l. It was established that in the neutral and weak-alkane environment the uranium transition from rocks into solution increases with temperature, incidentaİly radium nearly is not leached. But as acidity increases the leaching of uranium and radium increases as well. At a low concentration of $CaCl_2$ uranium comes into the solııtion intensively, on a high concentration - uranium content in water decreases sharply. High concentrations of chloride (Na^+ Mg^+ Ca^+) act in the same way because at this time uranium precipitates as Ca [UO_2 $(CO_3)_3$], and owing to chloride presence radium comes into the solution easily (Zielinski, 1999).

However, these processes are much more complicated than their schematic representation. So, at the beginning of the research on the reasons for the high radium content of oil waters L.V. Komlev established that radium content in the water of the same well varies greatly over time. Further research showed that waters of the same reservoir, similar in chemical composition, sometimes contain sharply different concentrations of radium. The dynamics of this process (2) become clear if all peculiarities of interaction between rocks and waters with different salt compositions are taken into account (Heaton, 1995:5).

Typical concentrating ^{226}Ra for oil field waters is (3-8) 10-11%, the highest in the waters of the study area - 1.83 10-8%. This water is usually enriched with isotopes ^{226,228,224}Ra in times compared to sulfate and hydrocarbonate water.

For example, as has been shown above, at low concentrations of $CaCl_2$ the intensity of uranium leaching increases, while at high concentrations it drops sharply (3).

1. In contact of calcium-containing waters with carbonate rocks exchange reactions can occur over the surface:

$$Na_2CO_3 + Ca^{2+} + 2Cl^- {>}CaCO_3 + 2Na^+ + 2Cl$$
$$MgCO_3 + Ca^{2+} + 2Cl \rightarrow CaCO_3 + 2Cl^- + Mg^{2+}$$

Due to the formation of a hard-soluble compound $CaCO_3$ on the surface of the rock at high concentrations, uranium leaching becomes more difficult.

2. Uranium with calcium in the presence of carbonate ion forms a hard-soluble complex compound such as $Ca_2 [UO_2 (CO_3)_3]$. By the increasing concentration of $CaCl_2$ in the solution, the formation of this compound and precipitation of uranium in the precipitate is possible. The leaching of uranium from rocks by $CaCl_2$ solutions of various concentrations reflects the complex nature of this phenomenon. As the increasing of $CaCl_2$ concentration in the solution, the leaching first increases intensively and then decreases.

In this case, it is important to note that firstly decreasing radium leaching corresponds to the concentration of $CaCl_2$ in the solution, at which the leaching of uranium from rocks stops. This is explained by the fact that with the growth of calcium chloride concentration the percentage of precipitation of calcium in the solution increases. As a result, it can be concluded that uranium is extracted by waters in those cases where the water contains $NaHCO_3$ or at a moderate concentration of $CaCl_2$.

By the increasing concentration of Na+, Mg^{2+}, and Ca^{2+} chlorides in solutions, uranium leachability decreases, which is explained by its precipitation in the form of $Ca_2[UO_2(CO_3)_3]$.

An increasing concentration of these salts in solutions contributes to the leaching of radium. This may partially explain the genetic meaning of a regular distribution of radioactive elements in Plateau waters of oil fields.

Therefore, studying the nature and dynamics of pollution in various areas needs an individual approach in each case.

Dynamics of distribution of radioelements on depth in the system of rocks - reservoir waters - oil and in conditions of a terrestrial surface can be shown on an example of the concrete situation developed during the development of deposits and oil production. To begin with, it is necessary to take into account that waters are always accompanied by oil. Oil is in permanent contact with water both in the deposit and especially in the processes of migration or movement in space. Thus, it is necessary to take into account that oil and formation waters are sharply different both in composition and in the chemical type of waters.

Table 2 shows the coefficients of uranium or radium enrichment of waters depending on the hydro-chemical type, i.e., alkaline waters are enriched with uranium and radium respectively 2 and 700 times, and hard waters are depleted in uranium by a factor of 10 and enriched in radium by a factor of 4000.

The thorium-uranium relations show that the contents of thorium in waters and oils do not depend on the hydro-chemical composition of waters (Zielinski et al., 1999:240). Radon during the contact of the radium-containing solution with oil is strongly absorbed by it, thus violating all balanced relations in the uranium-radium and thorium series (Schmitz et al.,2003:16). Besides that, at the contact of waters with rocks of oil strata, it is necessary to take into account a variety of lithological differences - clays, sands, etc. that also influences on processes of redistribution of radioactive elements.

Table 2

Enrichment of reservoir waters of oil deposits with uranium and radium

Water	Uranium,%	Radium,%	Enrichment coefficient	
			uranium	radium
Ocean	2x10^{-7}	1x10^{-14}		
Reservoir waters of oil deposits				
Alkaline	4x10^{-7}	7x10^{-12}	2	700
Hard	4x10^{-8}	4x10^{-11}	0,2	4000

The whole process of the presented assessment shows that during the geological time in the process of migration and formation of deposits in reservoirs and as a result of constant contact with formation waters, as a consequence, probably, many times broken and established balance, distribution and redistribution of radioelements between oil and water takes place.

In such a process, depending on the chemical composition of oils, i.e. the presence of components capable of accumulating radioelements and depending on the hydro-chemical type of contacting waters, determining the forms of existence of radioelements in rocks and formation of water, oil, and formation water will be depleted or enriched with radioelements, not to the same extent.

This circumstance allows substantiating the reasons for “spotting” the polluted territories of oil fields and indicates the necessity of a detailed study of the distribution of increased radioactivity in different territories. In this lies the difficulty of cleaning up the oil fields from radioactive pollution (Webb, 1975; Dissanayake, 1984).

The pollution of the territories of the old Iodine plants and their surroundings occurs in a somewhat different way. Iodine-bromine waters exploited by these plants are distinguished by a high concentration of radium, for it is the hard waters of the upper part of the productive series that are rich in iodine and bromine (Aliyev, 1996).

The main cause of pollution of oil field areas and territories of iodine plants is the presence of radio-bearing water, which together with the extracted oil comes to the surface and contaminates the environment (table 3, 4).

It should be emphasized that the Iodine plant Ramana and Surakhani have been demolished and waste hazardous substances have been disposed of in special zones.

Table 3

Radionuclide composition and level of radioactive contamination of the Absheron Peninsula

Sampled area	Radiation level, mcR/h	Level of radio active contamination	Radiation zone on the map (figure 3)
Bibi-Haybat	9-9,5	High	I
Gum adasi	3,5-4,0	low	III
Surakhani	4,5-5,5	medium	II
East of the Hovsan	4,0-4,5	medium	II
Zira	3,5-4,0	low	III

Table 4.

The maximum permissible concentrations of trace elements in the body have been established

Nameofanelement	Blood (mkg/ml)	Urine (mkg/ml)
U^{238}	0,06	0,07
Ac^{228}	0,1	0,06
Ra^{228}	0,2	0,004
Ra^{226}	0,08	0,8
Rn^{222}	0,005	0,04
Rn^{220}	0,03	0,02
Bi^{214}	0,004	0,02
Tl^{208}	0,9	0,1
K^{40}	0,25	0,08

Conclusions. Water for iodine extraction is passed through activated carbon, on which radioactive elements are adsorbed along with iodine. During further processing of the coal, the iodine is extracted, and the uranium and radium are discharged together with the coal into the settling tanks, which are located in the open air. The radioactive elements are partly washed by atmospheric precipitation and carried far beyond the plants, polluting the environment, and partly carried by winds, also polluting the environment.

According to our analyses, was created a radiation map and were identified the most dangerous areas according to the level of radioactivity in the study area (fig.4).

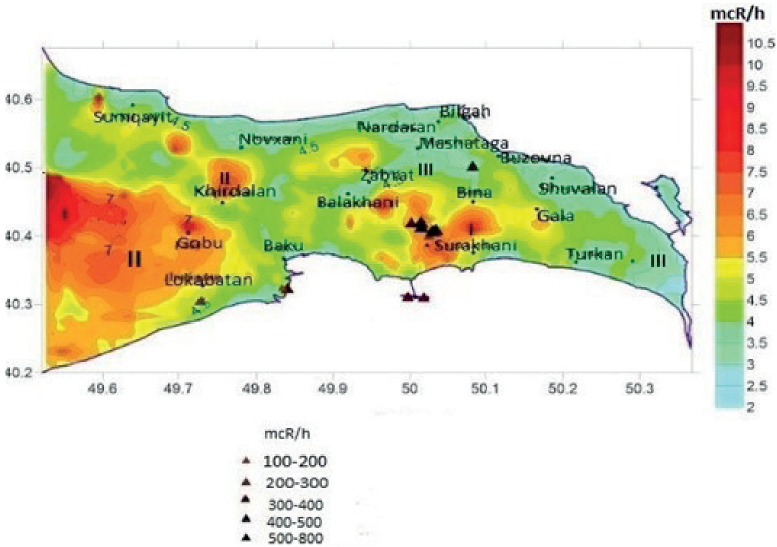

Figure 4. Map scheme of radioactivity environment in oil and gas industry zone.

Another mechanism of pollution of separate areas refers to the processes of separation of oil and water in tanks, for its subsequent transportation for processing. In this operation, oil and water are piped into tanks, where they are defended. Then, the water, together with the rocks flows into a lake (Zykh-Hovsan) or directly onto the surface of the ground (Gumadasi Island). Water and sand are heavily polluted with radionuclides which concentrate on the ground surface.

There are many more ways of polluting the territory of the Absheron Peninsula. In particular, during the operation of oil equipment at the fields with an increased concentration of radioactive elements, sediments highly enriched with radioactive elements are formed on the inner surfaces of the pipes. When pipes are cleaned, or sometimes just folded, dirty areas are formed, and near the working premises, sometimes in the territory of settlements.

It is possible to imagine the processes leading to pollution of the channel bed through which radioactive waters flow to the sea. Here the mechanism of sorption operates on all objects, which are washed by these waters. Thus, the pollution of the territory of the Absheron Peninsula with radioactive elements takes place in different ways.

Based on pollution lies technogenic processes associated with the development and exploitation of oil fields, iodine-bromine extraction, repair of equipment, oil processing, etc. Pollution in these processes occurs by radionuclides of natural origin. Pollution caused by artificial isotopes is local and confined mainly to landfills.

Finally, results derived from this study found that regular radio-ecological monitoring should be implemented on the territories of the Absheron peninsula oil fields to prevent radiation danger.

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TRANSITION OF A NEWTONIAN FLUID TO A VISCOPLASTIC STATE

Abstract. When a non-isothermal waxy oil flow in a main oil pipeline, a Newtonian fluid transits to a viscoplastic state. This is due to the fact that the rheological properties of waxy oil are highly dependent on temperature. When oil flow in the pipeline cools due to heat exchange with the environment, viscosity and yield stress begin to increase and lead to the appearance of a viscoplastic state of oil. In the zone of yield stress, the fluid transits to a viscoplastic state and is described by the Shvedov-Bingham rheological equation. Along the pipe cross-section, oil in the near-wall zone can be in a viscoplastic state, and in the central part it can be in a Newtonian fluid. In the zone of yield stress, oil does not flow, which causes an increase in flow velocity in the central part of the pipeline. Such a complex structure of a non-isothermal waxy oil flow is investigated using the RANS turbulence model. In numerical calculations, the distributions of averaged and pulsating flow characteristics are obtained. The calculated data are compared with the results of the DNS model and show the transition of a Newtonian fluid to a viscoplastic state in the pipeline.

Key words: waxy oil, Newtonian fluid, viscoplastic state, RANS turbulence model.

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НЬЮТОН СҰЙЫҚТЫҒЫНЫҢ ТҰТҚЫР ПЛАСТИКАЛЫҚ КҮЙГЕ АУЫСУЫ

Аннотация. Магистралды мұнай құбырындағы парафинді мұнайдың изотермиялық емес қозғалысы кезінде Ньютон сұйықтығы тұтқыр пластикалық күйге ауысады. Бұл парафинді мұнайдың реологиялық қасиеттері температураға қатты тәуелді екендігімен түсіндіріледі. Құбырдағы мұнай ағыны қоршаған ортамен жылу алмасуына байланысты салқындаған кезде тұтқырлық пен шекті ығысу кернеуі арта бастайды және тұтқыр пластикалық мұнай күйінің пайда болуына әкеледі. Шекті ығысу кернеуі аймағында сұйықтық вязкопластикалық күйге өтеді және Шведов-Бингамның реологиялық теңдеуімен сипатталады. Құбырдың көлденең қимасы бойынша қабырға аймағындағы мұнай тұтқыр пластикалық күйде, ал орталық бөлігінде Ньютон сұйықтығында болуы мүмкін. Шекті ығысу кернеуі аймағында мұнай ақпайды, бұл құбырдың орталық бөлігіндегі ағынның жылдамдығын арттырады. Парафинді мұнайдың изотермиялық емес қозғалысының мұндай күрделі құрылымы RANS турбуленттік моделінің көмегімен зерттелінді. Сандық есептеулерде ағынның орташа және импульстік сипаттамаларының таралуы алынды. Есептелген деректер модельдің DNS нәтижелерімен салыстырылды және құбырдағы Ньютон сұйықтығының тұтқыр пластикалық күйге ауысуы көрсетілді.

Түйін сөздер: парафинді мұнай, Ньютон сұйықтығы, вязкопластикалық күй, RANS турбуленттілік моделі.

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ПЕРЕХОД НЬЮТОНОВСКОЙ ЖИДКОСТИ В ВЯЗКОПЛАСТИЧЕСКОЕ СОСТОЯНИЕ

Аннотация. При неизотермическом движении парафинистой нефти в магистральном нефтепроводе происходит переход ньютоновской жидкости в вязкопластичное состояние. Это объясняется тем, что реологические свойства парафинистой нефти сильно зависят от температуры. При охлаждении потока нефти в трубе из-за теплообмена с окружающей средой вязкость и предельное напряжение сдвига начинает возрастать и приводит к появлению вязкопластичного состояния нефти. В зоне предельного напряжения сдвига жидкость переходит в вязкопластичное состояние и описывается реологическим уравнением Шведова-Бингама. По сечению трубы нефть в пристенной зоне может находиться в вязкопластичном состоянии, а в центральной части – ньютоновской жидкостью. В зоне предельного напряжения сдвига нефть не течет, что вызовет рост скорости потока в центральной части трубы. Такая сложная структура неизотермического движения парафинистой нефти исследована с помощью RANS модели турбулентности. В численных расчетах получены распределения осредненных и пульсационных характеристик течения. Расчетные данные сопоставлены с результатами DNS модели и показывают переход ньютоновской жидкости в вязкопластичное состояние в трубе.

Ключевые слова: парафинистая нефть, ньютоновская жидкость, вязкопластичное состояние, RANS модель турбулентности.

Introduction. Turbulent flows of non-Newtonian viscoplastic fluids in pipes are of great practical importance, since they are found in many industrial installations (pipelines, various heat exchangers, plain bearings, centrifuges, oil production, wastewater treatment systems, etc.).

As an example of such a fluid is waxy oil. A characteristic feature of such a fluid is the strong dependence of viscosity and yield stress (yield point) on its temperature (Evseeva et al., 2002; Barnes, 1999; Abu-Jdayil et al., 2012; Zhapbasbayev et al., 2021). At high temperatures, waxy oil obeys the laws of a Newtonian fluid, and as the temperature decreases, the viscoplastic properties of a non-Newtonian fluid appear (Aiyejina, 2011; Chala, 2018). Such oils have a high-pour-point (from 15 to 30^{0}C), which can be higher than the ambient temperature (Kulwant, 1995; Braga, 1997).

The appearance of yield stress in waxy oils can lead to a stagnant zone where the flow does not occur. This leads to a decrease in the pipeline flow area (Chala et al., 2018; Pakhomov et al., 2021; Gavrilov et al., 2016). The appearance of the stagnant zone can lead to a complex rheological fluid flow (Abu-Jdayil et al., 2012). In the case of the insufficient kinetic and thermal energy of the flow, the stagnant zone overlaps the working section of the pipeline and the section of the oil pipeline freezes (Hwang et al., 1998; Blackburn et al., 2006; Blackburn et al., 2004).

The non-isothermal turbulent flow of a non-Newtonian fluid has been little studied in the literature and only one recent paper has been found (Blackburn et al., 2017).

Materials and methods. The mathematical model of the problem. The non-isothermal waxy oil flows in an underground pipeline with an inner diameter D_1 = 0.2 m, length L = 3 m, and its depth to the pipe axis H = 2 m (see Fig. 1). The average velocity of the fluid flow at the pipe inlet is U_{m1} = 0.2 m/s and its initial temperature T_1 = 298 K. The ambient temperature, soil temperature, is T_S = 273 K. The paper assumes that the soil temperature is a constant value for a given depth and the pipe wall temperature on its outer side is equal to the soil temperature $T_W = T_S$ = 273 K. The fluid density in the inlet section is ρ_1 = 835 kg/m^3. The Reynolds number of the flow determined from the flow parameters at the inlet (for a Newtonian fluid) is $Re = U_{m1}D_1/\nu_{W1}$ = 8200. At the pipeline inlet, velocity and temperature profiles are assumed to be constant, equal to initial values. As the fluid flows, the heat transfer process takes place through the pipe wall with the environment, so oil temperature and velocity will vary both along the pipe length and along its cross-section.

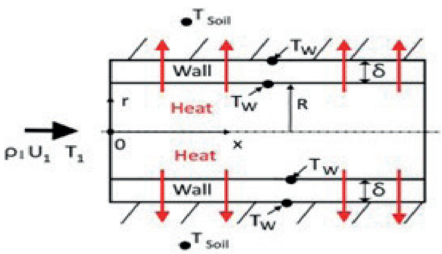


Figure 1. The flow and heat exchange diagram of an underground pipeline.

The rheological model of a viscoplastic Bingham-Shvedov fluid has the form (Barnes, 1999):

$$\mu_{eff} = \begin{cases} \mu_p + \tau_0 \left|\dot{\gamma}\right|^{-1}, & \text{if } |\tau| > \tau_0 \\ \infty, & \text{if } |\tau| \le \tau_0 \end{cases} \tag{1}$$

The system of averaged Reynolds equations for an incompressible fluid has the form (Pakhomov, 2021):

$$\nabla \cdot \mathbf{U} = 0 \tag{2}$$

$$\nabla \cdot (\rho \mathbf{U}\mathbf{U}) = -\nabla P + \nabla \cdot (2\mu_{eff}\mathbf{S}) + \nabla \cdot \left(-\rho\langle \mathbf{u}'\mathbf{u}'\rangle\right) + \nabla \cdot \langle 2\mu'_{eff}\mathbf{S}'\rangle \tag{3}$$

$$\nabla \cdot (\rho C_p T\mathbf{U}) = \nabla \cdot (\lambda \nabla T) + \nabla \cdot \left(-\rho C_p \langle \mathbf{u}'t'\rangle\right) + \boldsymbol{\tau} : \mathbf{S} \tag{4}$$

where S is the average strain rate tensor, $S = \sqrt{2S_{ij}S_{ij}}$ is the average strain rate tensor modulus. The turbulent characteristics $-\rho\langle \mathbf{u}'\mathbf{u}'\rangle$ and $-\rho C_p\langle \mathbf{u}'t'\rangle$ are in accordance with the Boussinesq hypothesis (Gavrilov et al., 2016). The expression $\nabla \cdot \langle 2\mu'_{eff}\mathbf{S}'\rangle$ in equation (3) is found according to the representation (Gavrilov et al., 2016). The last term in equation (4) considers the kinetic energy dissipation of the flow.

The system of equations (2)–(4) is considered together with the k–$\tilde{\varepsilon}$ model (Hwang et al., 1998):

$$\frac{\partial(\rho U_j k)}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_T}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] - 0.5\frac{\partial}{\partial x_j}\left(\mu \frac{k}{\varepsilon}\frac{\partial \hat{\varepsilon}}{\partial x_j}\right) + \rho\Pi_k - \rho\varepsilon + D_n + \Gamma_n \tag{5}$$

$$\frac{\partial(\rho U_j \tilde{\varepsilon})}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_T}{\sigma_\varepsilon}\right)\frac{\partial \tilde{\varepsilon}}{\partial x_j}\right] + \frac{\partial}{\partial x_j}\left(\mu \frac{\tilde{\varepsilon}}{k}\frac{\partial \tilde{\varepsilon}}{\partial x_j}\right) + \frac{\rho\tilde{\varepsilon}}{k}\left(C_{\varepsilon 1} f_1 \Pi_k - C_{\varepsilon 2} f_2 \tilde{\varepsilon}\right) + E_n \tag{6}$$

$$\mu_T = C_\mu f_\mu \frac{\rho k^2}{\tilde{\varepsilon}} \tag{7}$$

The problem is solved at the following boundary conditions. On the pipe wall, no-slip conditions are set for velocity, turbulence kinetic energy and the rate of its dissipation, and for temperature, conditions for heat transfer with the environment are:

r = R = D/2: $U = V = k = \tilde{\varepsilon} = 0$ and $-\lambda_W \left(\frac{\partial T}{\partial r}\right)_W = k(T_m - T_W)$ (8)

where λ_W is the fluid thermal conductivity coefficient, h is the heat transfer coefficient, $T_m = \frac{8}{U_1 D_1^2} \int_0^{D_1/2} T(r)U(r)rdr$ is the fluid mass average temperature, the subscript "W" is the parameter determined by the conditions on the pipe wall.

The boundary conditions on the pipe axis have the form:

$$r=0: \quad \frac{\partial U}{\partial r} = \frac{\partial V}{\partial r} = \frac{\partial T}{\partial r} = \frac{\partial k}{\partial r} = \frac{\partial \tilde{\varepsilon}}{\partial r} = 0 \tag{9}$$

In the inlet section (x = 0), the uniform distributions of velocity and temperature over the pipe cross-section were set, and for turbulence kinetic energy and the rate of its dissipation in the form are:

$$k_0 = 1.5\mathrm{Tu}^2 U_0^2; \quad \tilde{\varepsilon}_0 = C_\mu \frac{k_0^{3/2}}{0.06 R_1} \tag{10}$$

In the outlet section (x = L), the derivatives of all sought quantities in the axial direction are set equal to zero.

Numerical solution. The solution will be obtained using the finite volume method on staggered grids. For the convective terms of differential equations, the QUICK procedure of the third order of accuracy is used. For diffusion flows, it is planned to use the central differences of the second order of accuracy. The correction of the pressure field will be carried out according to the finite volume agreed the SIMPLEC procedure.

A computational grid was applied that was non-uniform both in axial and radial directions. The concentration of design nodes is done in the vicinity of the inlet section and solid walls. The first calculation node from the wall is located at the distance $y_+ = yu^*/\nu = 0.5 - 0.8$, where y is the distance from the pipe wall measured along the normal, u_* is the fluid friction velocity determined from flow parameters in the inlet section, and ν is the fluid kinematic viscosity. It was found that the calculation results of the averaged fields of axial velocity and temperature on grids 1500x100 and 1000x60 of the control volume differ by less than 0.01%.

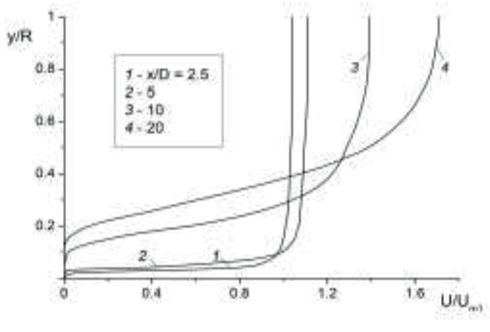
Results and discussion. The waxy oil flow, which is originally a Newtonian fluid, is cooled by heat exchange with the environment through the pipe wall. The profiles of the dimensionless averaged axial velocity U/U_{m1} (a), turbulence kinetic energy k/k_1 (b), temperature $\Theta = (T - T_{W1})/(T_1 - T_{W1})$ (c), and yield stress $\tau_0/\tau_{0,1}$ (d) are shown in Fig. 2. Here $\tau_{0,1}$ is the yield point at T =293 K.

The inlet profile of the averaged axial velocity is significantly deformed due to the process of heat exchange between the fluid and the environment (see Fig. 2a). On the wall, the axial velocity value is equal to zero, and it increases and reaches its maximum value in the near-axial zone. The average longitudinal fluid velocity value in the near-axial zone of the pipe increases by more than 1.6 times in comparison with the inlet velocity value. Fluid turbulence kinetic energy transverse profiles also undergo significant changes as the fluid flows along the pipe length (see Fig. 2b). There is an increase in the level of turbulence kinetic energy (TKE) in the near-axial zone of the pipe (more than 1.5 times) and its noticeable decrease in the near-wall region. This is associated with changes in the averaged axial velocity profile (see Fig. 2a).

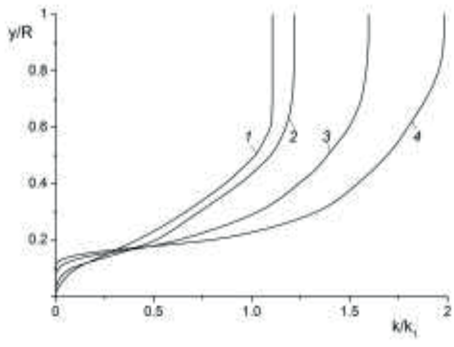
A decrease in fluid temperature (see Fig. 2c) leads to a change in its physicochemical properties and viscoplastic properties begin to appear (Evseeva et al., 2002; Barnes, 1999; Abu-Jdayil et al., 2012; Zhapbasbayev et al., 2021). At a temperature of $T \leq 293$ K, yield stress τ_0 appears in the near-wall zone, which leads to a deceleration of velocity and a stop of waxy oil (see Fig. 4d). The height of the near-wall section with low flow temperature increases towards the pipe axis and corresponds to the height of a decrease in fluid axial velocity.

It can be noted that the evolution along the pipe length of temperature and yield stress profiles show that waxy oil has a Newtonian fluid property in the central part of the pipe. Whereas in the near-wall zone, waxy oil has a viscoplastic Bingham-Shvedov fluid property.

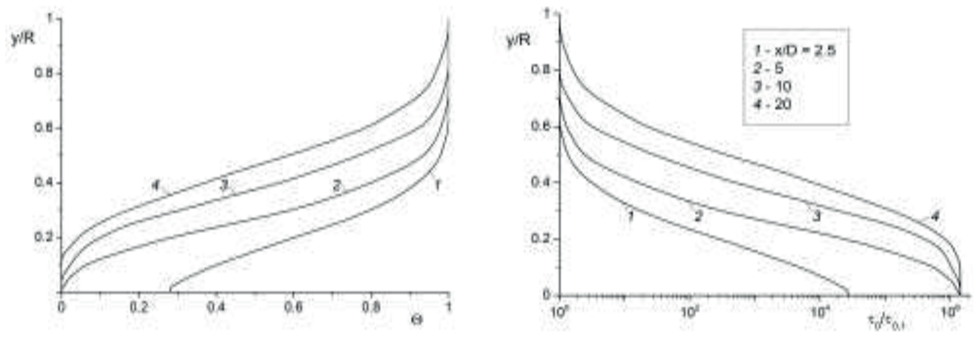
A decrease in the pipe flow area due to the appearance of yield stress leads to an increase in axial velocity (see Fig. 2a). This corresponds to the condition of conservation of fluid mass flow rate along the pipe length.



a)



b)



c) d)

Figure 2. Distributions of the dimensionless average component of axial velocity U/U_{m1} (a), turbulence kinetic energy k/k_1 (b), average temperature θ (c), yield stress $\tau_0 / \tau_{0,1}$ (d) along the pipe radius: Re = 8200, T_1 = 298 K, T_s = 273 K.

The comparison of the DNS data (Blackburn et al., 2006; Blackburn et al., 2004, Blackburn et al., 2017) and the calculations on axial velocity (a), TKE (b) for a Newtonian fluid (1 and 3) and a Shvedov-Bingham fluid (2 and 4) is presented in Fig. 3. Here, the dots are the DNS data (Blackburn et al., 2017), the lines are the authors' calculations. In viscous ($y_+ < 5$) and buffer ($5 < y_+ < 30$) zones, calculations for both fluids give practically the same values and there is good quantitative agreement with the data of (Blackburn et al., 2017) (see Fig. 3a).

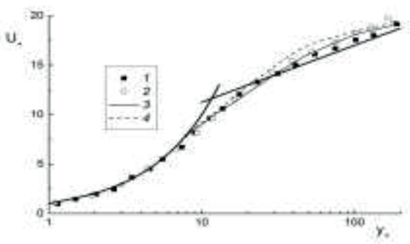
It can be concluded that a change in yield stress is practically not manifested within the viscous sublayer and the differences between non-Newtonian and Newtonian fluids are minimal.

According to the axial velocity distribution, it can be noted that the difference of our calculations in comparison with the DNS data in the logarithmic layer ($30 < y_+ < 200$) does not exceed 10%.

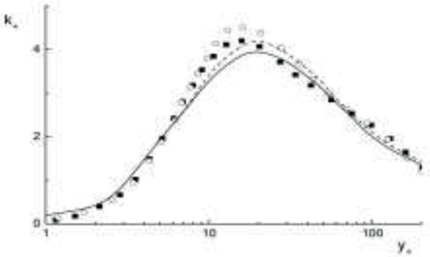
The distributions of TKE calculated using the RANS model also agree satisfactorily with the DNS calculation in the viscous sublayer and in the logarithmic zone (see Fig. 3b). In the logarithmic layer at y_+ = 10–55, an additional generation of turbulence in a Shvedov-Bingham fluid is shown in comparison with a Newtonian fluid.

Figure 4 shows the calculation data on the influence of the ambient soil temperature T_S on the distributions of axial velocity (a), TKE (b), and the Reynolds stress (c) along the pipe section. The viscoplastic properties in the distributions of axial velocity, TKE, and the Reynolds stress are most clearly manifested for the ambient temperature T_S=273 K (1).

It can be noted that the distribution of TKE for a Newtonian fluid differs significantly from the distribution of TKE for a Bingham-Shvedov fluid (see Fig. 4b).

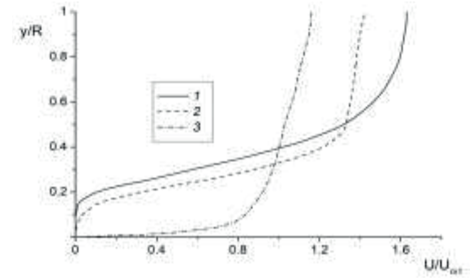


a)

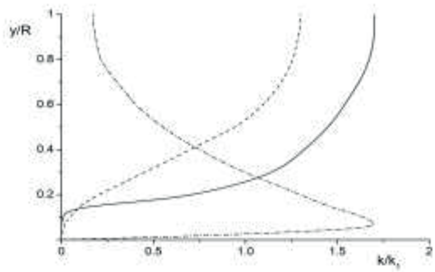


b)

Figure 3. Distributions of dimensionless axial velocity (a) and turbulence kinetic energy (b) in universal coordinates for a Newtonian fluid (1 and 3) and for a Shvedov-Bingham fluid (2 and 4), respectively.1 and 2 are the DNS calculation (Blackburn et al., 2017), 3 and 4 are the authors' RANS calculation. Re = 1.3×10^4, $Re_\tau = 323$, $\tau_0/\tau_W = 1.1$.



a)



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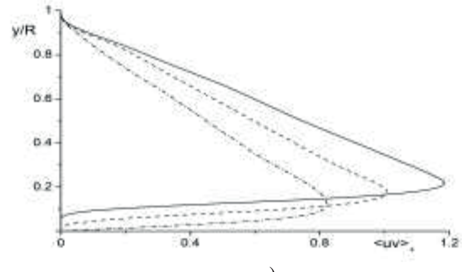

c)

Figure 4. Effect of the ambient temperature on the distributions of dimensionless averaged axial velocity (a), turbulence kinetic energy (b), and the Reynolds stress (c): 1 is the T_S = 273 K, 2 is the T_S = 288 K, 3 is the T_S = 298 K.

The characteristic distribution of TKE for a Newtonian fluid with a maximum in the near-wall zone (Pope, 2000) is transformed into the distribution of TKE with a maximum on the flow axis for a Bingham-

Shvedov fluid. This shows a qualitative rearrangement in the distribution of TKE in a non-isothermal waxy oil flow in the pipe with heat transfer on the wall.

The distribution of the Reynolds stress also shows a shift of a maximum towards the flow axis with the presence of a braking zone in the near-wall zone (see Fig. 4c).

Conclusion. 1. The RANS modeling of the transition of waxy oil from an initial Newtonian fluid to a viscoplastic state due to heat transfer between a heated fluid in the pipe with the cold environment was performed. The calculated data on the distribution of turbulence axial velocity and kinetic energy agree with the DNS data of other works.

2. The hydrodynamics and heat transfer structure of a non-isothermal turbulent waxy oil flow in the pipe has been studied. A significant increase in the level of turbulence kinetic energy in the axial zone and a decrease in the near-wall region of the pipe are shown. This differs from the well-known nature of the turbulence kinetic energy distribution of a Newtonian fluid along the pipe cross-section.

3. In the calculations, the boundary of the area of the manifestation of fluid viscoplastic properties is determined: 1) the shift of the position point of the maximum level of turbulence kinetic energy towards the pipe axis; 2) the stagnant zone height of a fluid flow is numerically predicted. In the area of the appearance of yield stress (in the near-wall area of the pipe), there is no fluid flow (the medium behaves like a solid body).

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CONSTRUCTION OF SOLITONS FOR INTEGRABLE NONLINEAR KAWAHARA EQUATION

Abstract. At present time the theory of solitons is widely investigated, because, concept of soliton is used in real science as nonlinear differential equations' systematic constant solution. This paper illustrates the application of the Hirota's bilinear method for construction of solitons for an integrable nonlinear equation. In particular, the evolution of solitons of Kawahara equation was considered. It is a dispersive partial differential equation and describes various wave phenomenos. Based on Hirota's bilinear method a substitution was applied and the Kawahara equation was transformed into a bilinear form. Then, by considering the formal series, one-soliton and two-soliton solutions were presented and graphs of the obtained soliton solutions were constructed. Furthermore, we have achieved new results, such as vector field, optimal system, solutions to reduce symmetry, convergence analysis and the laws of conservation of equations. In order to create a point symmetry of Kawahara equation, the Lie group with one parametric group of Lie transformations were introduced. Using Lee's symmetry analysis method, we created optimal systems and system symmetry. Later, with a new method of conservation introduced by N.H. Ibragimov, we obtained the law of conservation associated with the symmetry of Kawahara equation. Using approach that we apply one can obtain conservation law and the laws of symmetry of both higher order differential and soliton equations.

Key words: Hirota method, bilinear form, soliton solution, Kawahara equation, partial differential equation, Lie point symmetries, conservation laws.

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ИНТЕГРАЛДЫҚ СЫЗЫҚТЫ ЕМЕС КАВАХАРА ТЕҢДЕУІ ҮШІН СОЛИТОНДЫҚ ШЕШІМДЕРДІ ҚҰРУ

Аннотация. Қазіргі уақытта солитондар теориясы кеңінен зерттелуде, өйткені солитон ұғымы нақты ғылымда сызықты емес дифференциалдық теңдеулердің жүйелі тұрақты шешімі ретінде қолданылады. Бұл жұмыс интегралданатын сызықты емес теңдеу үшін солитондарды құру үшін Хиротаның екі сызықты әдісін қолдануды суреттейді. Атап айтқанда, Кавахара теңдеуінің солитондарының эволюциясы қарастырылды. Бұл әртүрлі толқындық құбылыстарды сипаттайтын дисперсиялық дербес туындылы дифференциалдық теңдеу. Хиротаның бисызықты әдісі негізінде алмастыру қолданылып, Кавахара теңдеуі бисызықты түрге ауыстырылды. Содан кейін формалды қатарларды қарастыра отырып, бір солитонды және екі солитонды шешімдер ұсынылып, алынған солитондық шешімдердің графиктері салынды. Сонымен қатар, біз векторлық өріс, оңтайлы жүйе, конвергенциялық талдау және теңдеулердің сақталу заңдары сияқты жаңа нәтижелерге қол жеткіздік. Кавахара теңдеуінің нүктелік симметриясын құру үшін Ли түрлендірулерінің бір параметрлік тобы бар Ли тобы енгізілді. Ли симметриясын талдау әдісін қолдана отырып, біз оңтайлы жүйелер мен жүйелік симметрияны құрдық. Кейінірек Н.Х. Ибрагимов енгізген жаңа сақталу әдісін қолдана отырып, біз Кавахара теңдеуінің симметриясына байланысты сақталу заңын алдық. Қолданып отырған тәсілді пайдалана отырып, солитондық және жоғары ретті дифференциалдық теңдеулер үшін сақталу заңы мен симметрия заңдарын алуға болады.

Түйін сөздер: Хирота әдісі, бисызықтық форма, солитондық шешім, Кавахара теңдеуі, дербес туындылы дифференциалдық теңдеу, Ли нүктесінің симметриялары, сақталу заңдары.

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ПОСТРОЕНИЕ СОЛИТОНОВ ДЛЯ ИНТЕГРИРУЕМОГО НЕЛИНЕЙНОГО УРАВНЕНИЯ КАВАХАРЫ

Аннотация. В настоящее время теория солитонов широко исследуется, поскольку понятие солитона используется в реальной науке как систематическое постоянное решение нелинейных дифференциальных уравнений. Настоящая работа иллюстрирует применение билинейного метода Хироты для построения солитонов для интегрируемого нелинейного уравнения. В частности, была рассмотрена эволюция солитонов уравнения Кавахары. Это дисперсионное дифференциальное уравнение частных производных, описывающее различные волновые явления. На основе билинейного метода Хироты была применена подстановка, и уравнение Кавахары было преобразовано в билинейную форму. Затем, рассматривая формальные ряды, были представлены односолитонные и двухсолитонные решения и построены графики полученных солитонных решений. Кроме того, мы достигли новых результатов, таких как векторное поле, оптимальная система, анализ сходимости и законы сохранения уравнений. Чтобы создать точечную симметрию уравнения Кавахары, была введена группа Ли с одной параметрической группой преобразований Ли. Используя метод анализа симметрии Ли, мы создали оптимальные системы и симметрию системы. Позже, используя новый метод сохранения, введенный Н.Х. Ибрагимовым, мы получили закон сохранения, связанный с симметрией уравнения Кавахары. Используя подход, который мы применяем, можно получить закон сохранения и законы симметрии как солитонных, так и дифференциальных уравнений более высокого порядка.

Ключевые слова: метод Хироты, билинейная форма, солитонное решение, уравнение Кавахары, дифференциальное уравнение частных производных, точечные симметрии Ли, законы сохранения.

Introduction. Nonlinear wave equations continue to attract considerable attention of researchers as they characterize common and important phenomena arising in various physical contexts, including optics, plasma and waves on water, Bose-Einstein condensates, acoustics. Often nonlinear partial differential equations (PDEs) describe nonlinear waves mathematically. PDEs admit many classes of exact solutions, including solitons. And also, these equations are interesting not only from a mathematical, but also important from a practical point of view, since they are the defining equations for many specific physical parameters. On the other hand, many important questions still remain open, and these equations are still the subject of considerable research. In this scientific paper we mainly focused on Kawahara equation.

The discovery of solitons by Martin Kruskal and Norman Zabuski, which led to the inverse scattering method (Ablovitz, et all, 1981), revived the modern theory of integrable systems. It became clear that in physics there are fully integrable systems having an infinite number of degrees of freedom, Korteweg-de Vries equation and some integrable lattice models, such as the Toda lattice. Nonlinear differential equations that describe various nonstationary processes can have both soliton-type solutions and nonsoliton-type solutions. Solitons are any localized nonlinear waves that interact with arbitrary local perturbations and always restore asymptotically their exact original shape with a possible phase shift (Ablovitz, et all, 1981). A soliton-type solution means a solitary wave localized in a small region, which rapidly tends to zero with distance from the localization region. It's profile does not change over time (Myrzakul, et all, 2021; Serikbayev et all, 2020).

Kawahara equation is important models in the theory of waves. In the normal sense, solitary waves are non-linear waves of regular shape that decompose rapidly in their lower regions. This rate of decomposition is usually exponential. However, under critical conditions in dispersion systems (eg, plasma magnetoacoustic waves, surface tension waves, etc.), weak non-local single waves appear unexpectedly. These waves consist of a central core similar to the classic single waves, but they are accompanied by oscillating tails that propagate indefinitely from the core with a constant amplitude of non-zero. To describe and clarify the properties of these waves, Kawahara introduced generalized nonlinear variance equations with the form KdV equation with an additional fifth-order derivative. This equation has been studied extensively from a variety of perspectives (Faminskii, et all, 2010). Kawahara equation describes long waves' propagation in a shallow liquid under ice, gravitational waves on the surface of heavy liquid, magnetoacoustic waves in a cold plasma (Iguchi, 2007). Some sources refer to this equation as singularly perturbed KdV equation (Kawahara, 1972). Analytical solution of special forms of the Kawahara equation in the case of solitary waves were studied by Sirendaoreji (2004), Yamamoto and Takizawa (1981). Kawahara Equation's numerical solution was also investigated. For finding an approximate solution to the Kawahara equation some other methods based on homotopy analysis have been proposed by Abbasbandy (2010), Wang (2011), Kashkari (2014).

In addition to the above aspects, the Kawahara equation has been extensively studied in terms of various other aspects of mathematics, including the validity, existence and stability of single waves, integration, long-term behavior, stabilization and control. etc. As for the boundary value problem, the Kawahara equation with homogeneous boundary conditions was studied by Doronin and Larkin (Doronin, et all 2008), and also by Faminsky and Opritova (Faminskii, et all, 2015). Also in connection with results on well-posedness in a weighted Sobolev space, one can mention in (Khanal, et all, 2008).

In this article, we investigated the evolution of solitons in the Kawahara equation. Using Hirota's method, one-soliton, two-soliton solution of the Kawahara equation in the following form was constructed:

$$u_t + uu_x + u_{3x} - u_{5x} = 0 \tag{1}$$

where $u = u(t, x)$ is a real-valued function of two real variables t and x.

Kawahara (Kawahara, 1972) introduced the dispersion partial differential equation describing the one-dimensional propagation of long waves of small amplitude in various problems of fluid dynamics and plasma physics, called the Kawahara equation. Divergent form of the equation (1) is written as:

$$u_t + \frac{\partial}{\partial x}\left(\frac{1}{2}u^2 + u_{xx} - u_{4x}\right) = 0 \tag{2}$$

Research materials and methods. It is known that the construction of explicit solutions of continuous or discrete integral systems plays an important role in the description and interpretation of nonlinear phenomena such as the effect of nonlinear optics, synthesis reactions in plasma physics, magnetohydrodynamic phenomena and superconductivity. In addition, the study of integrable systems and their associated properties has always been important and has become the focus of recent research. In particular, the creation of explicit solutions for differential equations is one of the most important topics. Methods, which find exact solutions are important for solving partial differential equations. So, in the theory of solitons, the following approaches are applicable: the use of the inverse scattering problem, the Hirota method, the method of Backlund transformations, etc. Most of them allow finding either a general or frequent solution. In recent decades, several approximate methods have been proposed or developed and then modified to find solutions to nonlinear evolutionary equations using motion waves. Solutions of various evolutionary equations were found by one or another of these methods. Thus, the Hirota method (Hirota, 1979) allows one to find soliton or soliton-like solutions of nonlinear partial differential equations. Its formalism almost always works for equations that have a Lax pair. That method is based on the following ideas (Hirota, 1976):

1. To change the dependent variable so that the new equation has a bilinear form, quadratic in the dependent variables.
2. To consider the formal series of perturbation theory for this equation. In the case of soliton solutions, these series are cut off.
3. To prove the assumed n-soliton form of the solution using this method.

In the article, Hirota method (Hirota, 1979) was developed in relation to the Kawahara equation. Hirota's bilinear method is especially useful when constructing multisoliton solutions. The idea behind Hirota's method is to bring the equation to the so-called bilinear form using some successful replacement for an unknown function. In order to make the bilinear form of the equation (2), it is necessary to introduce the following replacement:

$$u(x,t) = 2(\ln f(x,t))_{xx}. \tag{3}$$

Substituting (3) into (2) we get:

$$2(\ln f(x,t))_{xxt} + \frac{\partial}{\partial x}[((\ln f(x,t))_{xx})^2 + 2(\ln f(x,t))_{4x} - - 2(\ln f(x,t))_{6x}] = 0. \tag{4}$$

We express the values in the Kawahara equation by the function $f\ (x,\ t)$:

$$u_t = 2\frac{\partial}{\partial x}\left(\frac{f_{xt}}{f} - \frac{f_x f_t}{f^2}\right), \tag{5}$$

$$\frac{1}{2}u^2 = 2\frac{(f_{xx})^2}{f^2} - 4\frac{f_{xx}(f_x)^2}{f^3} + 2\frac{(f_x)^4}{f^4} \tag{6}$$

$$u_{xx} = 2\frac{f_{4x}}{f} - 8\frac{f_{3x}f_x}{f^2} + 24\frac{f_{2x}{f_x}^2}{f^3} - 6\frac{(f_{xx})^2}{f^2} - 12\frac{(f_x)^4}{f^4}, \tag{7}$$

$$u_{4x} = 2\frac{f_{6x}}{f} - 12\frac{f_{5x}f_x}{f^2} + 60\frac{f_{4x}f_x^2}{f^3} - 30\frac{f_{4x}f_{xx}}{f^2} - 240\frac{f_{3x}f_x^3}{f^4} + 240\frac{f_{3x}f_{xx}f_x}{f^3} -$$
$$-20\left(\frac{f_{3x}}{f}\right)^2 + 720\frac{f_{xx}f_x^4}{f^5} - 540\frac{f_{xx}^2f_x^2}{f^4} + 60\left(\frac{f_{xx}}{f}\right)^3 - 240\left(\frac{f_x}{f}\right).^6 \quad (8)$$

Expressing the values in the Kawahara equation by the function $f(x,t)$, putting these values in equation (1) and assuming that $f \neq 0$, following equation is obtained:

$$\begin{aligned} &12f^4f_{5x}f_x + (2f^5 + 30f^4f_{2x} - 60f^3f_x^2)f_{4x} + 20f^4f_{3x}^2 - \\ &-8f^2f_x(f^2 + 30ff_{2x} - 30f_x^2)f_{3x} - f_{6x} + 60f^3f_{2x}^3 2f^5 + \\ &(-4f^4 + 540f_x^2f^2)f_{2x}^2 + (20f^3f_x^2 - 720ff_x^4)f_{2x} + 2f^5f_{xt} - \\ &-2f^4f_xf_t - 10f^2f_x^4 + 240f_x^6 = 0. \end{aligned} \quad (9)$$

This is a bilinear form of equation (1).

Results. Using the results obtained in the previous section, we can construct soliton solutions to equation (1). For this, according to Hirota's method, we expand the function *f* into a formal series in the small parameter ε.

$$f = 1 + \sum_{i=1}^{\propto} \varepsilon^i f^{(i)} = 1 + \varepsilon f^{(1)} + \varepsilon f^{(2)} + \cdots \quad (10)$$

At the same levels of ε we obtain the following equations for the formula (9) using the appropriate coefficients:

$$\begin{aligned} &\varepsilon^1: \quad f_{xt}^{(1)} + f_{4x}^{(1)} - f_{6x}^{(1)} = 0, \\ &\varepsilon^2: \quad f_{xt}^{(2)} + f_{4x}^{(2)} - f_{6x}^{(2)} = 5f^{(1)}f_{6x}^{(1)} - 5f^{(1)}f_{xt}^{(1)} - 5f^{(1)}f_{4x}^{(1)} - 6f_{5x}^{(1)}f_x^{(1)} \\ &\dots \\ &+f_x^{(1)}f_t^{(1)} + +4f_x^{(1)}f_{3x}^{(1)} - 15f_{2x}^{(1)}f_{4x}^{(1)} + 2\left(f_{2x}^{(1)}\right)^2 - 10\left(f_{2x}^{(1)}\right)^2, \\ &\varepsilon^{N+1}: \quad f_{xt}^{(N+1)} + f_{4x}^{(N+1)} - f_{6x}^{(N+1)} = \cdots\left(f^{(1)}, \dots f^{(N)}\right) = 0. \end{aligned} \quad (11)$$

According to the structure of the right parts of the system, you can break the line (10) in any number of *N*(10) assuming that $f^{(N+1)} = 0$, we can equate the numerical equations $N+2,\ N+3, \dots$ to zero , therefore

$$f^{(N+2)} = f^{(N+3)} = \cdots \equiv 0. \quad (12)$$

According to Hirota's method for constructing *N*-soliton solutions of a nonlinear equation, the solution is sought in the following form:

$$f^{(1)} = \sum_{i=1}^{N} e^{\theta_i}, \tag{13}$$

where:

$\theta_i = a_i(x - a_i^2 t) + \delta_i$;

$a_i, \delta_i = const.$

One-soliton solution. To find one-soliton solution of equation (1), we take the case when $N = 1$ in (8). Then

$$f = 1 + f^{(1)}. \tag{14}$$

and one-soliton solution of Kawahara equation is equal to:

$$u = \frac{a_1^2}{2} \frac{1}{cosh^2\left(\frac{\theta}{2}\right)}, \tag{15}$$

here

$\theta_1 = a_1(x - a_1^2 t) + \delta_1.$

Graphs of one-soliton solution of the Kawahara equation are shown in Figures 1 a, 1 b, 1 c:

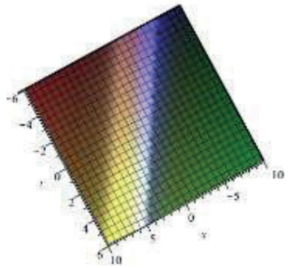

Figure 1a. Solution of the Kawahara equation with the values $a_1 = 1$ and $\delta_1 = 0{,}01$.

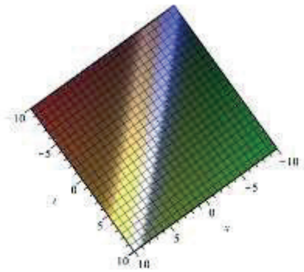

Figure 1b. Solution of the Kawahara equation with the values $a_1 = 1$ and $\delta_1 = 3$.

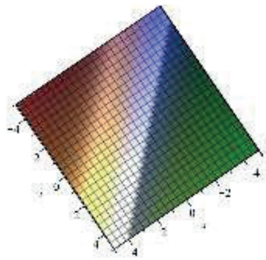

Figure 1c. Solution of the Kawahara equation with the values $a_1 = 1$ and $\delta_1 = 8$.

Two-soliton solution. In order to find the two-soliton solution of equation (1), it is necessary to consider the case where $N = 2$ from the formula (11):

$$f = 1 + f^{(1)} + f^{(2)}, \tag{16}$$

where

$$f^{(1)} = e^{\theta_1} + e^{\theta_2}, \quad f^{(2)} = Ae^{\theta_1 + \theta_2}.$$

The two-soliton solution of the Kawahara equation has the following form:

$$u = \frac{\partial}{\partial x}\frac{a_1e^{\theta_1}+a_2e^{\theta_2}+A(a_1+a_2)e^{\theta_1+\theta_2}}{1+e^{\theta_1}+e^{\theta_2}+Ae^{\theta_1+\theta_2}} \tag{17}$$

here

$$\theta_2 = a_2(x - a_2^2t) + \delta_2,$$

$$A = \frac{(26a_1^6 - 5a_1^4)e^{2\theta_1} + (26a_2^6 - 5a_2^4)e^{2\theta_2}}{(a_1^4 + 4a_1^3a_2 + 6a_1^2a_2^2 + (4a_2^3 - 3a_2)a_1 + a_2^4)e^{\theta_1+\theta_2}(a_1+a_2)^2} -$$
$$-\frac{5e^{\theta_1}e^{\theta_2}\left(a_1^6 - 1{,}2a_1^5a_2 - 3a_1^4a_2^2 + a_1^3(-4a_2^3 + 0{,}6a_2)\right)}{(a_1^4 + 4a_1^3a_2 + 6a_1^2a_2^2 + (4a_2^3 - 3a_2)a_1 + a_2^4)e^{\theta_1+\theta_2}(a_1+a_2)^2} -$$
$$-\frac{5e^{\theta_1}e^{\theta_2}\left((-3a_2^4 + 0{,}8a_2^2)a_1^2 + \left(-1{,}2a_2^5 + 0{,}6a_2^3\right)a_1 + a_2^6\right)}{(a_1^4 + 4a_1^3a_2 + 6a_1^2a_2^2 + (4a_2^3 - 3a_2)a_1 + a_2^4)e^{\theta_1+\theta_2}(a_1+a_2)^2}.$$

Graphs of the two-soliton solution of the Kawahara equation are shown in Figures 2a, 2b, 2c:

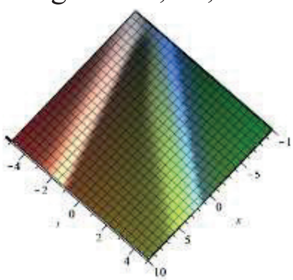

Figure 2a. Two-soliton solution of the Kawahara equation with values α_1=1,65; α_2=1,25; and δ_1 = 1,25; δ_2 = 9.

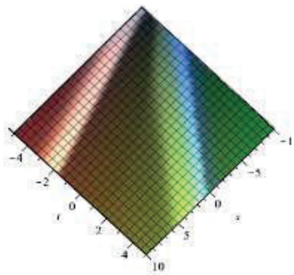

Figure 2b. Two-soliton solution of the Kawahara equation with values α_1=1,65; α_2=1,25; and δ_1 =1,25; δ_2 =10;

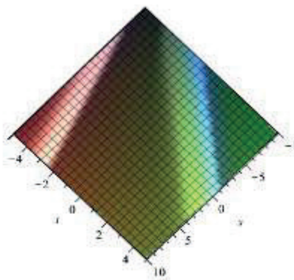

Figure 2c. Two-soliton solution of the Kawahara equation with values α_1=1,65; α_2=1,25; and δ_1 =1,25; δ_2 =1,25;

Lie point symmetries. In the last decade, there has been a revival of interest in the analysis of differential equations and their solutions from the point of view of their invariance properties with respect to a type of surface transformation called the Bäcklund transformation (Hirota, et all, 1976). S. Lie and A. V. Bäcklund considered these and general transformations of surfaces as indirect transformations for differential equations of higher orders. In this section, the Lie point symmetry for the nonlinear Kawahara equation (1) will be analyzed.

First, to create a point symmetry of equation (1), we introduce a Lie group with one parametric group of Lie transformations,

$$x \to x + \varepsilon\xi(x,y,t,u,v) + O(\varepsilon^2),$$
$$t \to t + \varepsilon\tau(x,y,t,u,v) + O(\varepsilon^2), \quad (18)$$
$$u \to u + \varepsilon\eta(x,y,t,u,v) + O(\varepsilon^2),$$

where ε means the group parameter ξ, τ and η and are infinitesimal generators. The vector field corresponding to the above transformation group is represented as follows:

$$V = \xi(x,t,u)\frac{\partial}{\partial x} + \tau(x,t,u)\frac{\partial}{\partial t} + \eta(x,t,u)\frac{\partial}{\partial u}, \quad (19)$$

Thus for the system (1) there is an operator pr^2, then the condition for the invariance of this operator is as follows:

$$pr^2V(\Delta)|_{\Delta=0} = 0. \quad (20)$$

Based on Lie's theory, the operator pr^2 of the equation can be written in the following form for the real and imaginary parts of the equation

$$pr^2V = \eta\frac{\partial}{\partial u} + \eta^t\frac{\partial}{\partial u_t} + \eta^x\frac{\partial}{\partial u_x} + \eta^{3x}\frac{\partial}{\partial u_{3x}} + \eta^{5x}\frac{\partial}{\partial u_{5x}}, \quad (21)$$

Thus, using condition (21), we obtain the following equivalent condition

$$\eta^t + \eta u_x + \eta^x u + \eta^{3x} - \eta^{5x} = 0. \quad (22)$$

where the functions of the coefficients are as follows

$$\eta^x = D_x(\eta - \xi u_x - \tau u_t) + \xi u_{xx} + \tau u_{xt},$$

$$\eta^t = D_t(\eta - \xi u_x - \tau u_t) + \xi u_{xt} + \tau u_{tt},$$

$$\eta^{3x} = D_{3x}(\eta - \xi u_x - \tau u_t) + \xi u_{4x} + \tau u_{xxxt}, \quad (23)$$

$$\eta^{5x} = D_{5x}(\eta - \xi u_x - \tau u_t) + \xi u_{6x} + \tau u_{xxxxxt}.$$

Now, by setting the coefficient functions (23) to (22), we obtain the following equivalent condition

$$\eta^t+\eta u_x+\eta_x u+\eta_{3x}-\eta_{5x}-\xi_t u_x-\tau_t u_t-\xi_x u u_x-\tau_x u u_t-\xi_{3x}u_x-$$
$$-2\xi_{xx}u_{xx}-3\xi_x u_{3x}+\xi_{5x}u_x+3\xi_{4x}u_{xx}+8\xi_{3x}u_{3x}+9\xi_{xx}u_{4x}+5\xi_x u_{5x}=0$$

So we get the values of the sub-operators as follows

$$\xi_{5x}=0,\quad \xi_{4x}=0,\quad \xi_{3x}=\frac{3}{8}\xi_x,\qquad \tau_x=-\frac{\tau_t}{u},$$
$$\xi_t=0,\quad \eta_t=-\frac{8}{3}\tau,\quad \eta_x=u\xi,\quad \eta=\frac{3\tau_x u u_x+(8u-3)\tau_x u_t-(8u-3)\eta_x}{8}.$$

Lie's algebra of infinitely small symmetry of equation (1) is covered by the following four linear independent operators:

$$V_1=\frac{\partial}{\partial t},\qquad V_2=\frac{\partial}{\partial x},$$
$$V_3=\frac{3}{8}ux\frac{\partial}{\partial x}-t\frac{\partial}{\partial t}-u\frac{\partial}{\partial u},\quad V_4=\left(\frac{3}{8}xu+1\right)\frac{\partial}{\partial x}+(1-t)\frac{\partial}{\partial t}+u\frac{\partial}{\partial u}. \tag{24}$$

Based on the commutator operator $[V_k,V_j]=V_kV_j-V_jV_k$, we obtain the commutator function of system (1) (see Table 1)

Table 1. The commutator function of system (1)

Lie	V_1	V_2	V_3	V_4
V_1	0	0	V_1-V_3	V_1-V_4
V_2	0	0	$-V_2$	$-V_2$
V_3	V_3-V_1	V2	0	V_3-V_4
V_4	V_4-V_1	V_2	V_4-V_3	0

Conservation laws. The general theorem on conservation laws for higher order differential equations is proved. The theorem is also valid for any system of differential equations, where the number of equations is equal to the number of dependent variables. The new theorem does not require the existence of Lagrangian and is based on the concept of conjugative equations for nonlinear equations recently proposed by the author. It is proved that the conjugative equation includes all the symmetries of the original equation. Accordingly, the law of conservation can be associated with Lie, Lie- Bäcklund or any group of non-local symmetries and find the laws of conservation for differential equations without classical Lagrangeans (Barut, et all, 1977).

In this section, if we want to derive the law of conservation of equation (1), we must first find the law of conservation of the system (22). Therefore, in order to construct conservation law of the system (22) we use Lie's point symmetry (28).

$D_t(C^t) + D_x(C^x) = T$,

here, $C = (C^x, C^t)$ conservation vectors.

N.H. Ibragimov (Ibragimov, 2007) proposes to create a new conservation theorem, ie the law of conservation of magnitude without Lagrange in the differential equation. To write the laws of conservation, we first write Lagrangean. Now, to write the Lagrangian of this equation, we multiply the equation by some function $\phi(x, y, t)$

$$L = \phi(x, y, t)(u_t + uu_x + u_{3x} - u_{5x}). \quad (25)$$

In the above system (25), we replace ϕ with u so we write the conservation vector formula $C = (C^1, C^2, C^3 \dots)$ as follows [28]:

$$C^n = \xi^n L + W^\alpha \left[\left(\frac{\partial L}{\partial {u^\alpha}_n} \right) - D_j \left(\frac{\partial L}{\partial {u^\alpha}_{nj}} \right) + D_j D_k \left(\frac{\partial L}{\partial {u^\alpha}_{njk}} \right) - \cdots \right] + \\ + D_j(W^\alpha) \left[D_j \left(\frac{\partial L}{\partial {u^\alpha}_{nj}} \right) - - D_j D_k \left(\frac{\partial L}{\partial {u^\alpha}_{njk}} \right) + \cdots \right] + D_j D_k (W^\alpha) \\ \left[\frac{\partial L}{\partial {u^\alpha}_{njk}} - \cdots \right], \quad (26)$$

where $W^\alpha = \eta^\alpha - \xi^j u_j^\alpha \ (\alpha = 1, 2, \dots, m)$ - Lie characteristic function. Using the above formula, we can write an additional conservation vector

$$C^t = \xi^t L + W^u \frac{\partial L}{\partial u_t},$$

$$C^x = \xi^x L + W^u \left(\frac{\partial L}{\partial u_x} - D_x^2 \frac{\partial L}{\partial u_{3x}} - D_x^4 \frac{\partial L}{\partial u_{5x}} \right) + D_x(W^u) \left(\frac{\partial L}{\partial u_x} D_x^2 \frac{\partial L}{\partial u_{3x}} - D_x^4 \frac{\partial L}{\partial u_{5x}} \right).$$

Now we can use generators of symmetry V_1, V_2, V_3 and V_4 as an example to obtain the vector of conservation of the system (1).

Case 1. Thus, the following characteristics can be obtained for the generator $V_1 = \partial / \partial t$. Lie characteristic functions are

$$W = -u_t. \quad (27)$$

Now, by introducing (27) into (26), we obtain the following conservation vectors

$$C_1^t = uu_x + 1 - u_t,$$

$$C_1^x = uu_x + 1 - uu_t - uu_{tx}.$$

After the calculation we can find the following equation

$$D_t(C_1^t) + D_x(C_1^x) = u_{tx}(u - u_x - 1) - u_t u_x - uu_{txx}.$$

Case 2. Thus, the following characteristics can be obtained for the generator $V_2 = \partial/\partial x$. Lie characteristic functions are

$$W = -u_x. \tag{28}$$

Now, by introducing (28) into (26), we obtain the following conservation vectors

$C_2^t = uu_x + 1 - u_x,$

$C_2^x = 1 - uu_{xx}.$

After the calculation we can find the following equation

$D_t(C_2^t) + D_x(C_2^x) = uu_{tx} + u_x u_t - u_{xt} - uu_{3x} - uu_{xx}.$

Case 3. The following characteristics can be obtained for the generator $V_3 = \frac{3}{8}ux\frac{\partial}{\partial x} - -t\frac{\partial}{\partial t} - u\frac{\partial}{\partial u}$. Lie characteristic functions,

$$W = u + t - \frac{3}{8}ux. \tag{29}$$

Now, by introducing (29) into (26), we obtain the following conservation vectors,

$C_3^t = uu_x + 1 - \frac{3}{8}ux + t + u,$

$C_3^x = 3uu_x + 1 + u^2\left(1 - \frac{3}{8}x\right) - \frac{3}{8}u(xu_x + u).$

After the calculation we can find the following equation,

$$D_t(C_3^t) + D_x(C_3^x) = u_t u_x + uu_{xt} + (u_t + u_x^2)\left(1 - \frac{3}{8}x\right) + 3uu_{xx} + \left(\frac{13}{8} - \frac{3}{4x}\right)uu_x - \frac{3}{8}u^2.$$

Case 4. Thus, the following characteristics can be obtained for the generator $V_4 = \left(\frac{3}{8}xu + 1\right)\frac{\partial}{\partial x} + (1 - t)\frac{\partial}{\partial t} + u\frac{\partial}{\partial u}$. Lie characteristic functions

$$W = t - 2 - u\left(1 + \frac{3}{8}x\right). \tag{30}$$

Now, by introducing (29) into (26), we obtain the following conservation vectors

$C_4^t = u\left(u_x - \frac{3}{8}x - 1\right) + t - 1,$

$$C_4^x = uu_x + u\left(1 + \frac{3}{8}x\right)\left(u_x - u - t - \frac{13}{8}\right).$$

After the calculation we can find the following equation,

$$D_t(C_4^t) + D_x(C_4^x) = u_x^2(u_t + 2) + uu_{xt} + (\,uu_{xx} - u_x u_t)\left(\frac{3}{8}x + 1\right) + \frac{3}{8}u\left(t - \frac{13}{8}\right).$$

Discussion. We constructed solutions of the Kawahara equation. For completeness, graphical representation of them is shown in Figures 1a, 1b, 1c and 2a, 2b, 2c, which clearly indicates that solutions are bright solitons because their waves are under the flat non-vanishing plane. Such wave processes play an extremely important role in modern physics and are the subject of study in hydrodynamics, nonlinear optics, plasma physics, field theory, elementary particle physics, biophysics, etc. This equation, called the Kawahara equation, occurs in plasma dynamics when a wave propagates at a certain angle to a magnetic field, in nonlinear electrical circuits, and for internal waves in a two-layer fluid, taking into account the surface tension between layers in a stratified fluid. Within the framework of this equation, solitons have oscillating tails and can be attracted to each other. This situation is realized for internal waves in a two-layer ocean, when one layer is thin and the other is thick (compared to the wavelength).

N.H. Ibragimov developed a theorem on the laws of their conservation, based on the symmetry of Lie-Becklund, ie the symmetry of higher order differential equations. N.H. Using Ibragimov's theorem on new conservation laws, we obtain the conservation laws, ie the conservation laws of the particle, for Equation (1) without the Lagrange system. This method we use is effective for finding the laws of symmetry and conservation of both soliton and higher order differential equations without Lagrange's character.

Conclusion. In this article the application of Hirota's bilinear method for constructing solitons for an integrable lattice model was illustrated. In particular, the evolution of solitons of the Kawahara equation, an equation of the Korteweg-de Vries type of the fifth order, is considered. The Hirota method is developed in relation to the Kawahara equation. Based on Hirota's bilinear method, a substitution was applied and the Kawahara equation was converted to a bilinear form. Then, one-soliton and two-soliton solutions were presented, by considering the formal series. Furthermore, graphs of the obtained soliton solutions were constructed.

As mentioned above, we have achieved new results, such as vector field, optimal system, solutions to reduce symmetry, convergence analysis and the laws of conservation of equations. Using Lee's symmetry analysis method, we created optimal systems and reduced system symmetry. Later, using a new method of conservation introduced by N.H. Ibragimov, we obtained the law of conservation associated with the symmetry of equation (1). The new results presented in this paper can be used to describe the dynamics of solitons in nuclear physics and other optical experiments. Therefore, all the results of this study can be used to improve the dynamic operation of Kawahara equations in engineerin**g and mathematical physics.**

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MODIFIED TEXTILE FABRIC-BASED WEARABLE TRIBOELECTRIC NANOGENERATOR

Abstract. Triboelectric nanogenerators (TENG) are gaining huge interest due to their mechanical energy harvesting ability and active sensing applications. Especially, development of wearable TENG is of high importance allowing harvesting the energy of human motions to autonomously power small-scale personal devices. TENG would be useful for biomechanical energy harvesting if the triboelectric materials used in the nanogenerator fabrication are non-toxic, comfortable for wearing, and scalable. Common textile fabrics with improved triboelectric properties can be applied for fabricating wearable TENG to harvest the energy of human motions. In this work, we developed unique fabric triboelectric pair by chemically modifying cotton fabric with 3-aminopropyltriethoxysilane (APTES) and perfluorodecyltrichlorosilane (FDTS) to obtain tribo-positive and tribo-negative materials, respectively. The TENG fabricated from corresponding materials exhibits remarkable triboelectric energy harvesting during testing with peak-to-peak open-circuit voltage (V_{oc}) of about 4 V and short-circuit current (I_{sc}) 250 nA and, in addition, we demonstrated the ability to charge capacitor.

Key words: triboelectric effect, nanogenerator, textile electrode, chemical functionalization.

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МОДИФИЦИРЛЕНГЕН ТОҚЫМА МАТА НЕГІЗІНДЕГІ КИІЛЕТІН ТРИБОЭЛЕКТРЛІК НАНОГЕНЕРАТОР

Аннотация. Трибоэлектрлік наногенераторлар (ТЭНГ) механикалық энергия жинау қабілетіне және белсенді сезу қолданбаларына байланысты үлкен қызығушылық тудырады. Әсіресе, шағын көлемді жеке құрылғыларды автономды түрде қуаттандыру үшін адам қозғалысының энергиясын жинауға мүмкіндік беретін киілетін ТЭНГ-ті дамытудың маңызы зор. Егер наногенератор өндірісінде қолданылатын трибоэлектрлік материалдар зиян емес, киюге ыңғайлы және масштабталатын болса, ТЭНГ биомеханикалық энергияны жинау үшін пайдаланылатын еді. Жақсартылған трибоэлектрлік қасиеттері бар қарапайым тоқыма маталары адам қозғалысының энергиясын жинау үшін киілетін ТЭНГөндіру үшін қолданылуы мүмкін. Бұл жұмыста біз трибо-оң және трибо-теріс материалдарды алу үшін мақтаматасын 3-аминопропилтриетоксисиланмен (АПТЭС) және перфтородецилтрихлорсиланмен (ФДТС) химиялық түрлендіру арқылы бірегей матадан трибоэлектрлік жұп жасадық. Сәйкес материалдардан жасалған ТЭНГ ашық тұйықталу кернеуі (V_c) шамамен 4 В-қа және қысқа тұйықталу тогы (I_{sc}) 250 нА-ге көрсеткіштеріне ие болып, сынақтар кезінде керемет трибоэлектрлік энергия жинау және оған қоса, конденсаторды зарядтау қабілетін көрсетті.

Түйін сөздер: трибоэлектрлік эффект, наногенератор, тоқыма электроды, химиялық модификация.

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НОСИМЫЙ ТРИБОЭЛЕКТРИЧЕСКИЙ НАНОГЕНЕРАТОР НА ОСНОВЕ МОДИФИЦИРОВАННОЙ ТЕКСТИЛЬНОЙ ТКАНИ

Аннотация. Трибоэлектрические наногенераторы (ТЭНГ) привлекают большой интерес вследствие их способности сбора механической энергии и применения в качестве активных сенсоров. Особенно высокую важность имеет разработка носимого ТЭНГ, дающая возможность сбора энергии движений человека, с целью автономного питания мелких персональных устройств. ТЭНГ был бы полезен для биомеханического сбора энергии, если бы трибоэлектрические материалы, используемые при изготовлении наногенератора, были бы нетоксичными, удобными для ношения и масштабируемыми. Обычные текстильные ткани с улучшенными трибоэлектрическими свойствами могут применяться для изготовления носимого ТЭНГ для сбора энергии движений человека. В этой работе мы разработали уникальную текстильную трибоэлектрическую пару путем химической модификации хлопчатобумажной ткани 3-аминопропилтриэтоксисиланом (АПТЭС) и перфтордецилтрихлорсиланом (ФДТС) для получения трибо-положительного и трибо-отрицательного материалов, соответственно. ТЭНГ, изготовленный из соответствующих материалов, демонстрирует значительный сбор трибоэлектрической энергии во время испытаний с двойным амплитудным напряжением около 4 В и током короткого замыкания 250 нА и, более того, мы продемонстрировали способность для зарядки конденсатора.

Ключевые слова: трибоэлектрический эффект, наногенератор, текстильный электрод, химическая модификация.

Introduction. Scientists and engineers have been devoting efforts towards the development of the new energy sources alternative to fossil fuels (Fan et al., 2016). In recent years, mechanical energy harvesting has attracted attention not only to deal with the global energy crises, but also to develop energy supply for micro-sensors and portable personal electronic devices (Song et al., 2021, Wang, 2013). Several energy harvesting devices have been demonstrated to transform mechanical energy into the electrical energy based on different effects, including electromagnetic (Ahmad et al., 2018), piezoelectric (Manchi et al., 2021) and triboelectric (Wu et al., 2019) effects. Among these proposed technologies triboelectric nanogenerators (TENGs) based on triboelectric effect and electrostatic induction successfully demonstrate efficiency in transforming ambient mechanical energy into electrical energy. The TENG has demonstrated a collection of excellent merits such as a flexible structure, lightweight, environmental friendliness, relatively low cost, wide-range of materials choices and ability to drive low-power electronics via converting biomechanical energy into electricity (Lin et al., 2016).

Materials and methods. The conjunction of contact electrification and electrostatic induction is the basic principle behind the TENG and the primary model of TENG, made of two different materials separated by a gap can be considered as a capacitor with varying capacitance, was based on Maxwell's displacement current (Wang, 2017). Based on this principle, TENG operates in four different modes; generally, sliding motion and vertical contact-separation motion are two main motions that can be used in a TENG to convert mechanical energy into electrical energy (Figure 1) (Dharmasena et al., 2019). When two triboelectric materials with different electron affinities come into physical contact, tribo-charges are separated and transferred from one material to the other. The surface of the material with higher electron affinity becomes negatively charged, while the other surface becomes positively charged with an equal amount. When the two materials separate, the tribo-charges in the interfacial regions too are separated, inducing an electrical potential difference between electrodes, and driving free electrons to flow back and forth in the external circuit to maintain the electrostatic equilibrium.

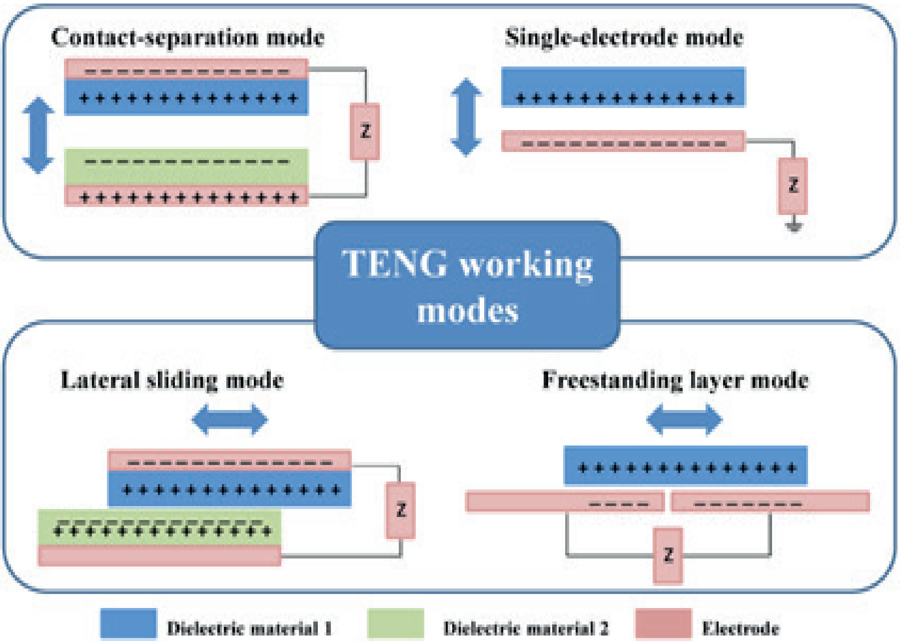

Figure 1. Four basic operation modes for TENG

The materials used as triboelectric layers are diverse and include natural and synthetic polymers, metals, and inorganic materials (Zhang et al., 2020). The material choices are of great importance for TENGs since the triboelectric effects of the materials are fundamental for TENGs. Higher output performance and additional functionalities can then be realized by physical and chemical modifications. Chemical modification of triboelectric layer surface has attracted interest because the modification can tune the surface triboelectricity, which can boost the output of the TENGs (Nurmakanov et al., 2021, Wang et al., 2020). This approach has great importance in future studies since it offers a way to tune the triboelectric effect of materials. Moreover, to design a TENG for a particular application, apart from choosing appropriate pair of materials, several parameters need to be considered, such as power density, stability, flexibility, wearability and sustainability.

In particular, a triboelectric textile can be a unique source of energy in which the energy can be harvested from human motions. Textile provides intrinsic porous structure and high surface roughness, traditionally used for protection, warming. Considering the rapid growth in small-scale portable and wearable electronics, realizing textiles with additional functionalities is of great significance, such as energy harvesting and energy storage. Several approaches, such as nanopatterning and chemical modification, have been reported to transform various textiles into triboelectric materials (Liu et al., 2019, Zhang et al., 2016).

So far, many studies have mainly focused on coating fibers and textiles using PDMS and nanoparticles. However, these require multi-coating processes, complex procedures and special equipment, which limit their scalable production. In this work textile triboelectric nanogenerators based on cotton fabric were developed by using facial chemical functionalization process utilizing silane-based self-assembled monolayer (SAM) molecules. The triboelectric properties of the cotton cloth were modulated by introducing amino- and fluoro- groups on its surface. Moreover, textile conductive electrode based on Ppy was developed to realize fully textile TENGs. Chemical modulation was proven to improve the triboelectrification and thus output electrical signal. The proposed textile fabric TENG fabricated from modified cotton fabric demonstrated an electrical output while tapping with a human hand. The output electrical characteristics of TENGs with different tribo-pairs were examined, further the possibility of charging capacitor was shown which is vital for application.

Experimental. Design of the textile TENGs. The structure of the typical developed textile TENG is depicted in Figure 2. First, as triboelectric pair cotton and polyester fabrics were chosen, these fabrics were attached to a conductive textile electrode by using special adhesive textile glue. Then triboelectric fabrics with attached electrodes were stacked to arch-shaped polyethyleneterephtalate (PET) using double-sided adhesive tape.

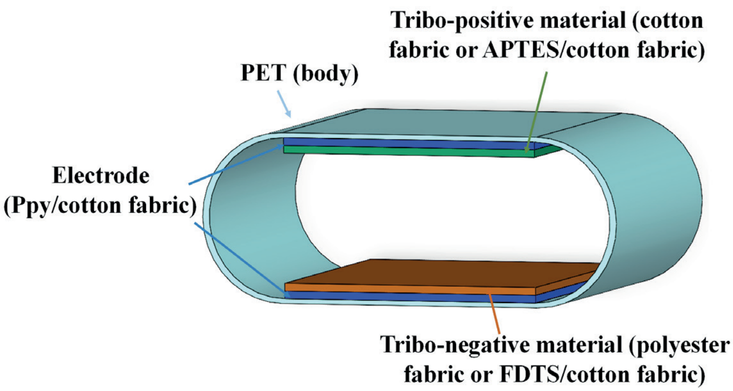

Figure 2. Schematic of the arch-shaped TENG

Conductive fabric electrode preparation. An experimental part of the conductive fabric electrode preparation has been carried out by the well-known in situ polymerization process which is an easy, cost-effective, large-scale, single-step, and low-temperature process technique. The preparation of the conductive fibers has included fibers pretreatment (removing impurities) and polymerization. Here pristine cotton fabric was coated with Ppy by immersing fabrics in a 0.5 M pyrrole solution and then $FeCl_3$,p-toluene sulfonic acid were added to this solution. Subsequently, the resulting solution and the impregnated fabric were then left for 20 min at 0-4°C for polymerization. Subsequently, the cotton fabric was cleaned with deionized water and dried in an oven at 60°C for 2 h and then Ppy coated conductive cotton electrode was obtained.

Preparation of triboelectric materials.

Cotton fabric contains a cellulose content of up to 90%,thus, the hydroxyl groups of the cellulose in cotton can react with silanes that have different polarities, leading to materials that have different surface energies and tribo-polarities (positive or negative surfaces).

A facile method to transform cotton into positive and negative tribo-material was applied where the cleaned cotton fabric was soaked in 3-aminopropyltriethoxysilane (APTES)/isopropyl alcohol (5% v/v) in perfluorodecyltrichlorosilane (FDTS)/hexane solution (1%v/v), respectively, followed by rinsing it in isopropyl alcohol and drying in air.

Characterization and Measurements.

The morphology of the fibers was studied with scanning electron microscopy (Zeiss Crossbeam 540) and the surfaces of the silane grafted textiles were investigated using Fourier-transform infrared (FTIR) and X-ray photoelectron (XPS) spectroscopies.

The output short-circuit current and open-circuit voltage of the textile TENGs were measured by a Stanford low-noise current preamplifier (SR570) and a digital oscilloscope (Tektronix 2002C), respectively.

Results and Discussion. First, the surface morphology of the cotton fabric before and after coating with Ppy was investigated by using SEM. Figure 3a shows the SEM image of bare cotton fabric revealing that it was composed of the intertwined micro-fibrous framework. In contrary, SEM image of Ppy coated cotton fabric as shown in Figure 3b clearly demonstrated that the conducting polymer (i.e., Ppy) was grown on each micro-fiber and also indicated that the nanoparticles-like Ppy was uniformly distributed on the surface of micro-fiber. Such nano-architectures of Ppy on the micro-fibrous framework of cotton fabric can offer high conductivity for an electrode.

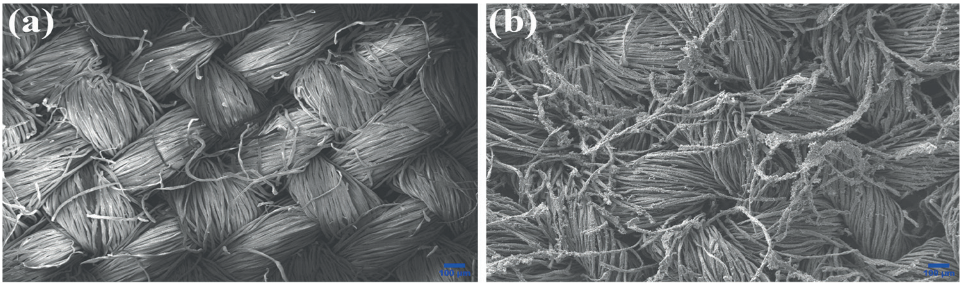

Figure 3. SEM images of the a) initial and b) coated with Ppy cotton fabric surfaces

Further, the surface morphologies of pristine cotton, APTES and FDTS grafted cotton fabrics were investigated by SEM as shown in Figure 4. Figure 4a shows the SEM images of cotton before grafting with silanes showing the intertwined micro-fibrous framework, but after treatment with APTES there is no big difference between the morphology of micro-fibrous framework of pristine and APTES-grafted cotton fabrics. However, after treating the cotton fabric with FDTS, the presence of fluoroalkylsiloxane film on the cotton fibers was clearly seen as demonstrated in Figure 4c.

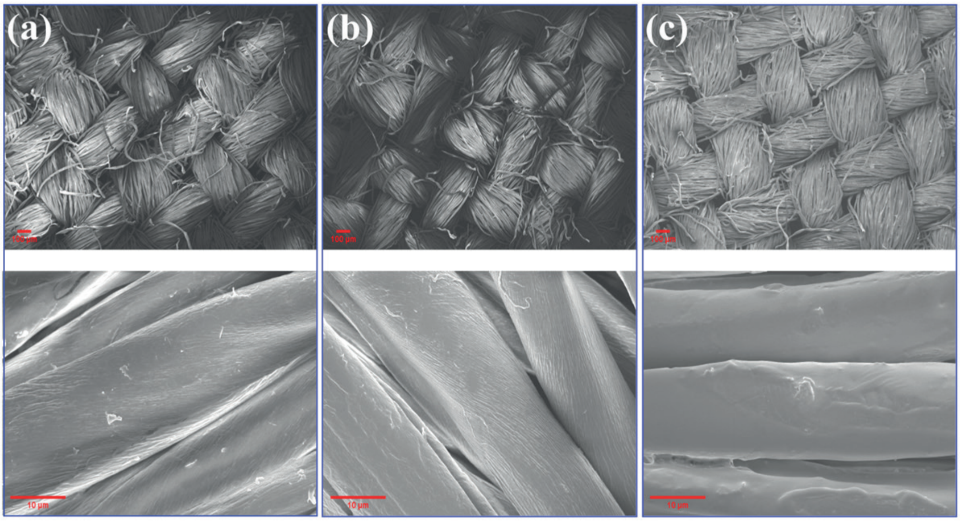

Figure 4. SEM images of a) pristine, b) 3-aminopropyltriethoxysilane (APTES) and c) perfluorodecyltrichlorosilane (FDTS) coated cotton fabric

Functional group modification of the cotton surface was investigated by Fourier transform infrared spectroscopy in attenuated total reflectance mode (ATR-FTIR) with a frequency range of 500-4000 cm^{-1}. The ATR FTIR spectra of the pristine cotton fabric and functionalized with APTES and FDTS fabric samples are presented in Figure 5. Pristine cotton and functionalized cotton spectra display the typical cellulose absorption bands at around 3280-3330 cm^{-1} (OH stretching vibrations) which blurred the characteristic N-H asymmetric and symmetric vibrations in the primary amine group from the APTES. Stretching vibrations at around 2890 $cm^{-1}$was attributed to -CH_2vibration, 1250-1470 cm^{-1} (CH), and multiple peaks around 1025-1160 cm^{-1} corresponds to C-O-C vibrations from cellulose absorption bands. The appearance of amine N-H bending vibration at 1571 cm^{-1} present in the spectrum of APTES modified cotton fabric confirmed the presence of the APTES on the cotton fabric surface. On the other hand appearance of -CF stretching vibrations at 1141 cm^{-1} in the spectrum of FDTS modified cotton fabric confirmed the presence of the FDTS on the cotton fabric surface.

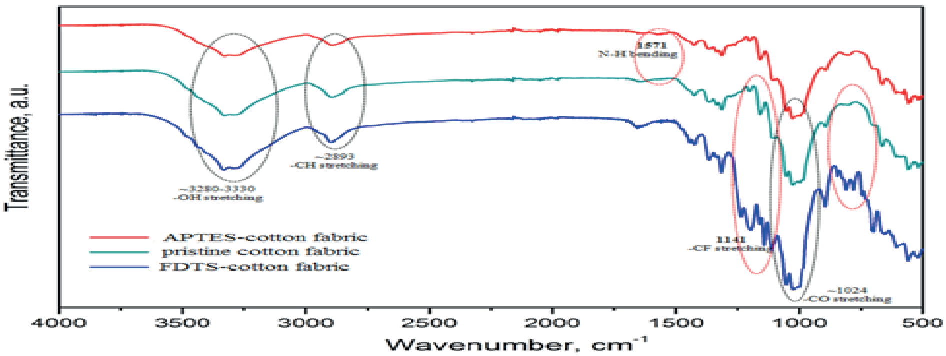

Figure 5. FTIR spectra of the pristine cotton fabric, APTES and FDTS functionalized cotton fabrics

Moreover, the surface elemental composition of APTES and FDTS functionalized cotton fabrics were investigated by XPS. Figure 6 depicts the wide-scan spectra of the functionalized with APTES and FDTS cotton fabrics. Bands at around 532.1, 399.8, 285 and 102.7 eV of APTES modified cotton fabric represent O1s, N1s, C1s and Si2p, respectively. The binding energy peaks for N1s and Si2p has shown the successful grafting of APTES on the cotton fabric surface. XPS spectrum of FDTS modified cotton revealed characteristic four bands at around 689, 533.1, 291.4 and 103.2 eV represent F1s, O1s, C1s and Si2p, respectively. The binding energy peaks for F1s and Si2p has shown the successful grafting of FDTS on the cotton fabric surface. Results of FTIR and X-ray photoelectron spectroscopies show that silanes were successfully introduced on the surface of cotton fabric.

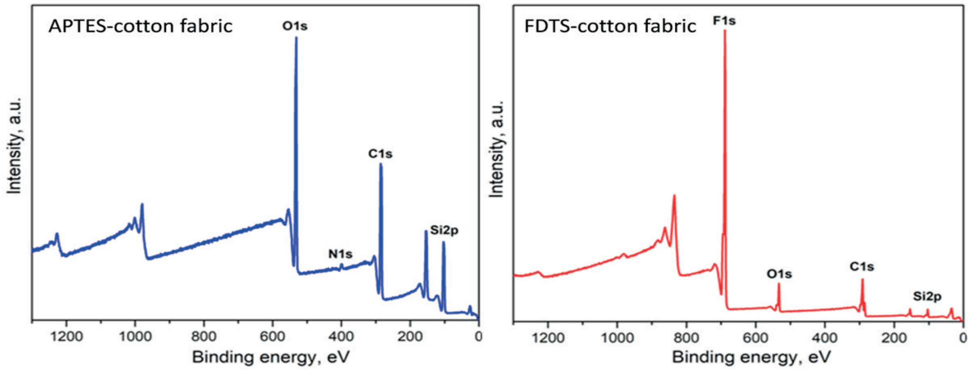

Figure 6. XPS survey spectra of functionalizedwith APTES and FDTS cotton fabrics

The output voltage and current of developed textile triboelectric nanogenerators are shown in Figure 7 and Figure 8, respectively. The output performance of TENGs fabricated from pristine polyester and cotton fabrics (polyester-cotton), i.e., without any chemical functionalization, APTES-cotton against polyester fabric (polyester-APTES/cotton) and APTES/cotton fabric - FDTS/cotton fabric was also measured. Here, the output peak-to-peak open-circuit (V_{oc}) voltage of the TENG fabricated from pristine polyester and cotton fabrics was about 1.5 V, while TENG fabricated from APTES/cotton fabric and polyester fabric demonstrated a slightly higher output voltage close to 2.5 V. Notably, the combination of FDTS/cotton and APTES/cotton fabrics triboelectric pair exhibited the highest output voltage of 4 V.

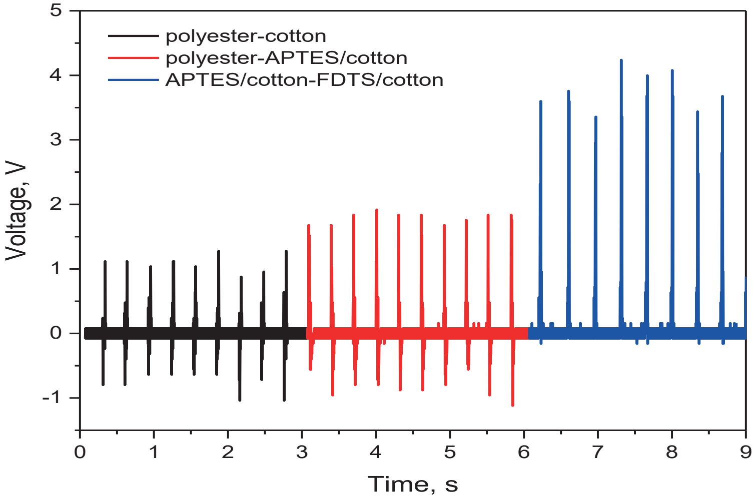

Figure 7. The output voltage of polyester-cotton, polyester-APTES/cotton fabric and APTES/cotton fabric-FDTS/cotton fabric-based TENGs

The peak-to-peak output current follows the same trend as the output voltage. The triboelectric nanogenerator constructed from the pair of pristine cotton and polyester fabric demonstrated the output short-circuit current (I_{sc}) equal to 50 nA, whereas the TENG made of cotton modified by APTES and polyester showed higher output current compared to TENG based on pristine cotton and polyester fabrics and it was equal to 200 nA. The highest output current demonstrated the TENG where as tribo-surfaces served chemically functionalized cotton fabric. Particularly, the tribo-negative and tribo-positive surfaces obtained by FDTS and APTES functionalization of cotton, respectively. The corresponding TENG demonstrated the maximum peak-to-peak short-circuit output current of 250 nA. This enhanced electrical performance of APTES/cotton fabric-FDTS/cotton fabric TENG is due to chemical functionalization of the material, where the presence of amino- and fluoro- functional groups on the surface enhanced its triboelectric properties.

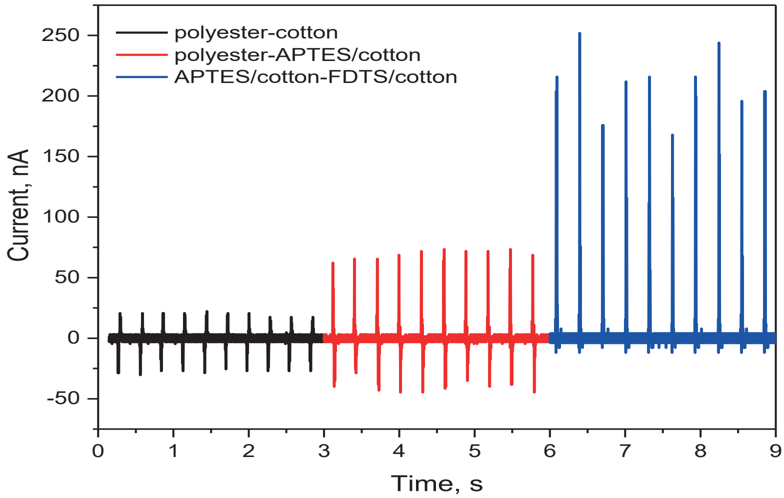

Figure 8. The output current of polyester-cotton, polyester-APTES/cotton fabric and APTES/cotton fabric-FDTS/cotton fabric-based TENGs

The electrical energy from the TENG is usually alternating, while a direct current is needed to derive most of the electronic devices. Hence, energy storage devices are required to store energy from the textile fabric TENG. The capability of the APTES/cotton fabric-FDTS/cotton fabric TENG to charge the capacitor is shown in Figure 9. Here, a circuit integrating the TENG with a full-wave bridge rectifier and a capacitor was constructed. The charge-discharge curve under periodic motion is illustrated in Figure 7a, where a 0.1μF capacitor was charged up to about 0.7 V in 4.5 seconds.

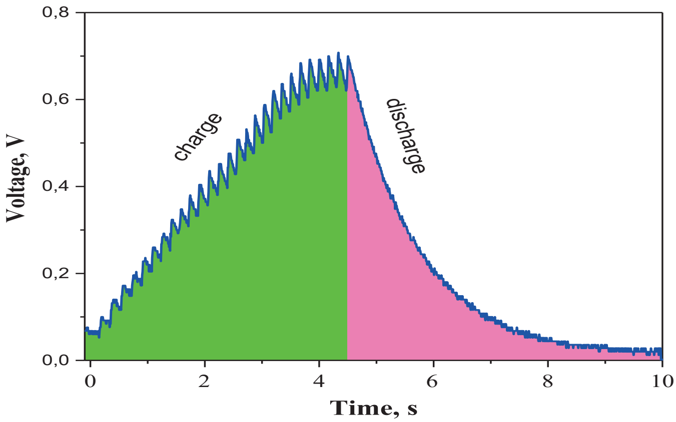

Figure 9. Charging a 0.1 μF capacitor by APTES/cotton fabric-FDTS/ cotton fabric TENG

The proposed TENG based on cotton fabric modified with APTES and FDTS proved to be a potential candidate for mechanical energy harvesting for small scale electronic applications. Furthermore, corresponding fabric TENG can be further studied to scavenge energy from different human parts.

Conclusion. In conclusion, an inexpensive and easily fabricated wearable TENG on the base of natural textile fabric functionalized with APTES and FDTS was demonstrated. Herein, the tribo-positive and tribo-negative surfaces were obtained by introducing functional groups containing amine and fluorine, respectively. Corresponding TENG exhibited maximum V_{oc} and I_{sc} values of 4 V and 250 nA, respectively. The developed TENG can be applied for upcoming wearable electronic applications because of its potential to harvest small mechanical energies of human motion.

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FORECAST OF SURFACE WATER QUALITY IN RIVER BASINS USING PHYSICAL AND CHEMICAL INDICATORS OF NATURAL SYSTEMS

Abstract. To carry out a quantitative and qualitative assessment of activities in the catchment areas of river basins using a variety of principles and methods, long-term systematic objective hydrological, hydrogeochemical and economic information and analytical materials are needed. At the same time, the scientific and practical feasibility of this problem is also determined by the fact that the validity and reliability of forecasts of the geoecological state of the catchment areas of river basins largely depend on the correct chosen principle and method, which require the need for a structural analysis of complex hydrochemical indices for assessing surface water pollution, based on the laws nature, principles and properties of natural processes.

Mathematical models have been developed to improve the tools for assessing the quality of surface waters in catchment areas of river basins, based on the solution of differential equations of hydrochemical processes of natural systems, corresponding in physical and mathematical terms to practical problems of hydrochemistry and the principles of nonlinearity of natural processes, are a consequence of the use of classical mathematical methods for constructing models and their analytical analysis.

Key words: water quality, mathematical model, surface water, non-linearity of natural processes, differential equations, hydrochemical processes.

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ӨЗЕНДЕРДІҢ АЛАБЫНДАҒЫ ЖЕР ҮСТІ СУЛАРЫНЫҢ САПАСЫН ТАБИҒИ ЖҮЙЕНІҢ ФИЗИКАЛЫҚ ЖӘНЕ ХИМИЯЛЫҚ КӨРСЕТКІШТЕРІН ПАЙДАЛАНУ АРҚЫЛЫ БОЛЖАУ

Аннотация. Әртүрлі қағидалар мен әдістерді пайдалана отырып өзеннің сужинау алабының аймағының қызметін сандық және сапалық бағалауды жүзеге асыру үшін ұзақ мерзімді жүйеленген мақсатық гидрологиялық, гидрохимиялық және шаруашылық саласының ақпараттық-талдау мәліметтері қажет. Сонымен қатар, бұл мәселенің ғылыми және практикалық қажеттілігі, өзеннің сужинау алабының геоэкологиялық жай-күйін бағдарлаудың сенімділігі және негізділігі көп жағдайда дұрыс таңдалған қағидаға және әдіске тікелей байланысты болғандықтан, жер беті суларының ластануын бағалаудың кешенді көрстеткіштерін құрылымдық талдауды талап етеді.

Жұмыста табиғи жүйелердің гидрохимиялық жүргілерінің дифференциалдық теңдеулерін шешуге негізделген, гидрохимияның практикалық есептеріне физикалық- матиматикалық белгілеріне және табиғи жүргілердің сызықтық емес қағидасына сәкес келетін, өзеннің сужинау алабының жер үсті суларының сапасын бағалау құралдарын жетілдірудің матиматикалық моделі әзірленген және ол моделдерді құруға және оны аналитикалық талдауға қағидалық математикалық әдістерді қолданудың салдары болып табылады.

Түйін сөздер: судың сапасы, математикалық модель, жер үсті сулары, табиғи жүргілердің сызықты еместігі, дифференциалдық теңдеулер, гидрохимиялық жүргілер.

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ПРОГНОЗ КАЧЕСТВА ПОВЕРХНОСТНЫХ ВОД РЕЧНЫХ БАССЕЙНОВ С ИСПОЛЬЗОВАНИЕМ ФИЗИЧЕСКИХ И ХИМИЧЕСКИХ ПОКАЗАТЕЛЕЙ ПРИРОДНЫХ СИСТЕМ

Аннотация. Для осуществления количественной и качественной оценки деятельности на водосборных территориях речных бассейнов с использованием разнообразных принципов и методов необходимы многолетние систематизированные объективные гидрологические, гидрогеохимические и хозяйственные информационно-аналитические материалы. При этом научная и практическая целесообразность этой проблемы определяется еще и тем, что от правильного выбранного принципа и метода во многом зависит обоснованность и достоверность прогнозов геоэкологического состояния водосборных территорий речных бассейнов, которые требуют необходимости структурного анализа комплексных гидрохимических индексов оценки загрязнения поверхностных вод, на основе законов природы, принципов и свойств природных процессов.

В работе разработаны математические модели для совершенствования инструментария оценки качества поверхностных вод водосборов речных бассейнов, на основе решения дифференциальных уравнений гидрохимических процессов природных систем, соответствующих по физическому и математическому признаку практических задач гидрохимии и принципов нелинейности природных процессов, являются следствием использования классических математических методов построения моделей и их аналитического анализа.

Ключевые слова: качество воды**,** математическая модель, поверхностные воды, нелинейность природных процессов, дифференциальные уравнения, гидрохимические процессы.

Relevance. The catchment area of river basins is a multi-component geosystem with the unity of hydrogeochemical flows that perform important environment-forming and ecological functions and are spatial bases for nature management and environmental management with various purposes of use, within which the possibility of a comprehensive assessment of the state of water bodies opens up. To carry out a quantitative and qualitative assessment of activities in the catchment areas of river basins using a variety of principles and methods, long-term systematic objective hydrological, hydrogeochemical and economic information and analytical materials are needed. At the same time, the scientific and practical feasibility of this problem is also determined by the fact that the validity and reliability of forecasts of the geoecological state of the catchment areas of river basins largely depend on the correct chosen principle and method, which require the need for a structural analysis of complex hydrochemical indices for assessing surface water pollution, based on the laws nature, principles and properties of natural processes. The solution of this problem of the catchment areas of river basins is facilitated by the monitoring system, the data of which serve as an information and analytical basis for making managerial decisions in water management, managing the quality of water resources, predicting the ecological state and assessing the impact of anthropogenic activities on them.

Purpose of the study – on the basis of the genetic theory of hydrochemical processes of the natural system, the development of mathematical models to improve the tools for assessing the quality of surface waters in catchment areas of river basins.

Materials and methods of research. The study is based on the use of the apparatus of mathematical modeling of surface water quality, which involves the use of classical approaches based on differential equations of hydrochemical processes in natural systems and modern experience in creating and studying models for assessing the quality of surface water in the watersheds of river basins.

Water quality monitoring programs have become the most important for developing a clear understanding of water quality processes for decision makers to understand, interpret and use this information in the development of strategies for the conservation of water resources in the world, which has become a prerequisite for improving the methodology for determining the pollution index (Nicb et all.,2004; Tirupathi et all., 2019), using the Shannon entropy (Shannon, 1963; Shannon et all.,1963) as a tool for the development of an entropy-weighted water quality index (EWQI) (Kunwar et all, 2019), as well as the possibilities of wide use of the water quality index (WQI) (Sipra et.all, 2017; Godwin et all, 2019), as a method for assessing water quality in various river basins around the world.

There are a large number of works, among which one of the most common complex indicators of water quality is the hydrochemical water pollution index (WPI) (Temporary guidelines for a comprehensive assessment of the quality of surface and sea waters by hydrochemical indicators, 1986), as an integral characteristic of surface water pollution, water quality classes are used, which for surface waters are carried out only for a strictly limited number of ingredients according to the formula

$$\mathrm{WPI} = (1/6) \cdot \sum(C_{i-6}/MAC_{i-6}) \text{ or } \mathrm{WPI} = (1/N)\sum_i^N(C_i/MAC_i), \quad (1)$$

where п - a strictly limited number of indicators (ingredients) taken for calculation that have the highest value, regardless of whether they exceed MAC_i ornot, including the dissolved oxygen index BOD_5, which for land surface waters п = 6; C_1 – concentration ofipollutant in water; MAC_i – maximum allowable concentration of the i pollutant; N – is the number of ingredients for which the calculation was carried out.

However, anthropogenic pollution of watersheds in river basins and their depletion as a result of economic activity leads to independent changes in the qualitative composition and volume of water, which reshape the habitat of aquatic organisms. In such conditions of the life of river basins, it is desirable to have an integral indicator that takes into account water pollution.

V.V. Shabanov proposes to assess the pollution of waste and natural waters using the limiting water pollution coefficient ($K_{пз}$), which is a modification of the water pollution index (WPI) widely used in practice. Its essence boils down to the following, that is, the water quality indicator is introduced into the water balance equation (WMB) expressed in units of water volume ($WK_{пз}$) (Shabanov et all., 2009):

$$W_{пз} = W_p \cdot K_{пз}, \quad (2)$$

where W_p - the actual volume of river runoff, taking into account the volume of irretrievable water consumption.

In this case, the equation of the water management balance, taking into account the indicator of water quality in river basins, will take the following form:

$$W_p \cdot C_п + W_в \cdot C_p = (W_p + W_c) \cdot MAC \quad (3)$$

or

$$W_в = W_p \cdot (C_n - MAC)/(MAC - C_p), \quad (4)$$

whence we obtain an expression for determining the virtual volume of water ($W_п$):

$$W_п = (W_в/W_р) = (C_п - MAC)/(MAC - C_р), \quad (5)$$

where $C_п$ – background concentration of a substance in the river; $C_р$ - concentration of pollutant in the river after wastewater discharge.

The ratio on the right side of the equation for determining the virtual volume of water ($W_п$), is a coefficient (limiting pollution coefficient), which shows the multiplicity of excess pollution of the river (Shabanov et all., 2009):

$$К_{пз} = (C_п - MAC)/(MAC - C_р). \quad (6)$$

If the catchment area of the river basin is polluted by a substance that does not occur in water under natural conditions, then the limiting pollution coefficient has the following form:

$$К_{пз} = (C_п - MAC)/MAC \quad (7)$$

or, in some cases, they can be represented by the even simpler formula:

$$К_{пз} = C_п/MAC \quad (8)$$

The physical meaning ($К_{пз}$) is the averaged multiplicity in excess of the normative excess of the concentration of a pollutant $(C_п - MAC)$ over the permissible pollution of the natural river background $(MAC - C_р)$, or, in fact, the multiplicity of exceeding the MAC.

Thus, V.V. Shabanov and V.N. Markin (Shabanov et all., 2009), for practical water management calculations, it is recommended to use a simplified equation for the limiting pollution coefficient ($К_{пз}$):

$$К_{пз} = (1/N)\sum_i^N[(C_i - MAC_i)/MAC_i] \text{ or}$$
$$К_{пз} = (1/N)\cdot\sum_i^N(C_i/MAC_i) - 1 = WPI - 1. \quad (9)$$

Thus, the ever-increasing number of methods for assessing the quality of surface waters in river basins, the growing variety of principles and methods for their construction require a comprehensive structural and system analysis and their compliance with the laws of nature and natural processes.

Research results and discussion. The law of the limiting (limiting) factor or Liebig's law of the minimum is one of the fundamental laws in ecology, stating that the most significant factor for the body is the one that most deviates from its optimal value and allows you to determine the limiting sign of the harmful effect on the human body of water quality in watersheds river basin (Popov, 1997).

Rationing of substances according to the limiting sign of harmful effects on the human body under conditions of anthropogenic pollution of water bodies can be determined by two criteria, that is, by the totality of the water content coefficient (K_b), as the ratio of the actual water consumption (Q_i, m^3/c) to the average annual water consumption (Q_{cp}, m^3/c) and the limiting pollution factor ($K_{пз}$) or the water pollution index (WPI), which is calculated as the sum of the actual values of the main indicators of water quality (C_i) reduced to MAC_i.

At the same time, to characterize the physical meaning of the coefficient of limiting water pollution ($K_{пзi}$) by several substances (N) through the index of the multiplicity of excess pollution ($C_i - MAC_i$), defined as the water pollution index (MPI) minus 1, is the multiplicity of excess MAC.

According to the law of the limiting factor, the coefficient of maximum permissible water pollution ($K_{ПДЗi}$) can be expressed by the following mathematical relationship (Popov, 1997):

$$K_{пдзi} = K_{bi} \cdot K_{пзi}\ , 1 \geq K_b \geq 0\ ,\ 1 \geq K_{пзi} \geq 0. \qquad (10)$$

At the same time, the concentration of substances (C_i) in the water of a reservoir or river basins directly depends on the mass of substances (MM), entering the river basins annually and back from the actual water discharge (Q_i, $м^3/c$), which shows that between the water content coefficient (K_b) and the coefficient of maximum permissible pollution ($K_{ПДЗi}$) there is a direct linear relationship (Alimov, 1990).

The construction of any model is to some extent connected with the simplification of reality, which causes the presence of limitations in the scope of its application and, at the same time, makes it possible to obtain reliable results, which is the main goal of mathematical modeling of hydrochemical processes in the watersheds of river basins, that is, the development of reliable methods forecasting the quality of river waters, applicable to solve both scientific and practical problems (Mustafayev et all., 2009).

The main assumptions made in achieving the above goal is as follows, the change in the concentration of a substance in the water of rivers is approximately described by a differential equation that has the following form (Mustafayev et all., 2009):

$$dC_i/dt = I(C_i), \qquad (11)$$

where $I(C_i)$ – function of the concentration value C_i.

At the same time, the concentration of a substance is a function of time and water flow in river basins, that is $C_i = C(t, Q, H)$, where H – a characteristic of the influence of other factors on the concentration. Then the differential equation describing multifactorial hydrochemical processes, i.e. $C(t, Q, H)$, can be written in the following form:

$$dC_i/dt = (dC_i/dt) + (dQ/dt) \cdot (dC_i/dQ). \qquad (12)$$

The change in water discharge in the watersheds of river basins can be described by the following expression:

$$(dQ/dt) = \lambda \cdot Q, \qquad (13)$$

where λ - the specific rate of change in water consumption in river basins, in the general case, has the following form: $\lambda = \lambda(t, Q)$.

Based on the dependence on the ratio of the values dC_i/d and $(dQ/dt) \cdot \cdot (dC_i/dQ)$ one of the variants of schematization of the processes of change in hydrochemical parameters characterizing the change in the concentration of a substance, associated mainly with the fluctuation water content of the catchment area of river basins (Savichev, 1999):

$$dC_i/dt = (dQ/dt) \cdot (dC_i/dQ). \qquad (14)$$

Taking into account the dependence (dQ/dt), we transform the equation $dC_i/dt = I(C_i)$ to the form:

$$dC_i/dQ = I(C_i)/(\lambda \cdot Q). \qquad (15)$$

In the field of mathematics and mathematical modeling, the solution to this equation is determined by the choice of an analytical expression for $I(C_i)$ and λ.

At the first stage, to solve the equation $dC_i/dQ = I(C_i)/(\lambda \cdot Q)$ linear dependences on the concentration value were used, which make it possible to obtain a number of calculation formulas under the condition $k/\lambda = const$:

- analytical solution of the equation $dC_i/dQ = I(C_i)/(\lambda \cdot Q)$ for $I(C_i) = k \cdot C_i$ has the following form: $C_i = C_o \cdot (Q/Q_o)^{-(k/\lambda)}$;
- analytical solution of the equation $dC_i/dQ = I(C_i)/(\lambda \cdot Q)$ for $I(C_i) = k \cdot (S - C_i)$ has the following form: $C_i = S - (S - C_0) \cdot (Q/Q_o)^{-(k/\lambda)}$, where S - concentration

of a substance in the medium in contact with water masses in the watersheds of river basins; C_0- initial concentration of a substance in the water of river basins.

It should be noted that the equation $C_i = C_o \cdot (Q/Q_o)^{-(k/\lambda)}$; correspond in physical and mathematical terms to the empirical dependences of the $y = a \cdot X^b$ type, widely used in the practice of hydrological, hydrochemical and water management calculations, and the equation $C_i = S - (S - C_0) \cdot (Q/Q_o)^{-(k/\lambda)}$, in its structure is a modification of the empirical dependence of the type $y = C + a \cdot X^b$ (Savichev , 1999).

It should be noted that the equation $dC_i/dQ = I(C_i)/(\lambda \cdot Q)$, $C_i = C_o \cdot (Q/Q_o)^{-(k/\lambda)}$ and $C_i = S - (S - C_0) \cdot (Q/Q_o)^{-(k/\lambda)}$ is consistent with the ideas of A.I. Perelman, according to which the change in the amount of a substance in nature is proportional to its content and intensity of migration (Perelman A.I., 1975), that is, the change in concentration is determined by the intensity of biochemical transformations, the interaction of water with underlying rocks, organic and suspended matter, and the influence of the water content of river basins affects the flow rate chemical reaction:

$$dC_i/dt \gg (dQ/dt) \cdot (dC_i/dQ). \qquad (16)$$

Based on these regularities of geochemical, biochemical and hydrochemical processes in river basins, to solve the equation $dC_i/dt = I(C_i)$ exponential dependences on the concentration value are used, which make it possible to obtain a number of calculation formulas under the condition $k = const$:

- analytical solution of the equation $dC_i/dt = I(C_i)$ for $I(C_i) = k \cdot C_i$ has the following form: $C_i = C_o \cdot \exp(-k \cdot t)$;
- analytical solution of the equation $C_i/dt = I(C_i)$ for $I(C_i) = k \cdot (S - C_i)$ has the following form: $C_i = S - (S - C_0) \cdot \exp(-k \cdot t)$.

At the same time, the influence of water exchange on the rate of chemical and biochemical reactions of the exponential function $\exp(-k \cdot t)$ occurring in the watersheds of the river basin can be reduced to the expression:

$$\exp[-k \cdot f(Q)], \qquad (17)$$

where $f(Q)$ - some function of the water discharge of the watersheds of river basins, corresponding to the time of arrival of water masses along the length of the river or its section.

Based on this circumstance, the equations $C_i = C_o \cdot \exp(-k \cdot t)$ and $C_i = S - (S - C_0) \cdot \exp(-k \cdot t)$, can be transformed to the form $У = a \cdot \exp(-b \cdot Q^x)$.

Thus, the system of differential equations $dC_i/dt = I(C_i)$, which describes the hydrochemical process in the watersheds of river basins, can also be used to predict their hydrochemical characteristics and water quality.

Watersheds of river basins, as a variety or elements of a geosystem, have system-wide properties, that is, the nonlinearity of natural processes, where the transformation and exchange of energy and matter always proceeds at a decelerating rate, which show that the intensity of the harmful effect on a living organism in the face of an increase in anthropogenic pollution of water bodies slows down due to adaptation, that is, the degree of harmful effects is proportional to the product of the concentration of the substance in the water of the river basins.

Mathematical modeling of hydrochemical processes, to a certain extent, is associated, on the one hand, with a simplification of reality, which causes the presence of limitations in the scope of its application and, on the other hand, makes it possible to obtain reliable results, that is, based on this assumption, the change in the limiting water pollution coefficient ($K_{пзі}$) from the reduced water pollution index (WPI) is approximately described by the equation (Mustafayev Zh.S. et. al., 2021):

$$dK_{пзі}/dWPI = k \cdot (K_{пзі}). \qquad (18)$$

The solution of this equation is determined by the choice of the analytical expression $k \cdot (K_{пзі})$, which is widely used in the practice of hydrochemical estimations, taking into account the principles of nonlinearity of natural processes in assessing the harmful effects of water quality on a living organism, which is described by an exponential function, having the following form:

$$K_{пзі} = (1/N) \cdot \sum_{i=1}^{N}[1 - \exp(-WPI_i)] = (1/N) \cdot$$
$$\cdot \sum_{i=1}^{N}\{1 - \exp[-(C_i/MAC_i)]\}. \qquad (19)$$

Thus, the coefficient of maximum permissible water pollution ($K_{пДзі}$) can be represented as the product of the coefficient of water content (K_b) and the coefficient of maximum water pollution ($K_{пзі}$), which has the following form:

$$К_{пдзi} = К_b \cdot К_{пзi} = \left(Q_{ср}/Q_i\right) \cdot \frac{1}{N}\sum_{i=1}^{N}[1 - \exp(-WPI_i)], \quad (20)$$

where $К_{пДзi}$ – concentration limit factor; $К_b$ - water content ratio; $К_{пзi}$ - coefficient of limiting water pollution; Q_i - actual water consumption (m³/s); $Q_{ср}$ - average annual water consumption (m³/s); WPI - water pollution index: $WPI = C_i/MAC$; C_i – actual concentration of the i ingredient; MAC_i – maximum allowable concentration of the ingredient corresponding to the purpose of the water body.

Based on the current classification developed for the water quality index (WPI), he coefficient of maximum water pollution ($К_{пз}$) and the Shannon trophic index (H), разработана a classification was developed according to the coefficient of maximum permissible water pollution ($К_{пДзi}$) (Table 1).

Table1 - Classification of water quality and the state of water resources according to hydrochemical and hydrobiological indicators

Indicator	Water quality class					
	I	II	III	IV	V	VI
WPI	<0,2	0,20-1,0	1,00-2,00	2,00-4,00	4,00-6,00	>6,00
$К_{пз}$	≤-0,80	-0,8-0,0	0,0-1,0	1,0-3,0	3,0-5,0	>6.0
$К_{пДзi}$	<0,20	0,20-0,60	0,60-1,60	1.60-3,60	3,60-5,60	>5,60
H	3,06-2,30	2,30-1,89	1,89-1,52	1,52-1,25		1,25-1,11
Water quality	Very clean	clean	Moderately polluted	polluted	dirty	Very dirty
Trophicity	oligotrophic	mesotrophic		eutrophic		hypert-rophic

At the same time, the mathematical model for determining the coefficient of maximum permissible water pollution ($К_{пДзi}$) has a number of advantages, that is, firstly, it takes into account one of the main properties of the geosystem - the nonlinearity of natural processes, and secondly, with the possibility of assessing the quality through the WPI indicator, thirdly, genetic similarity with the Shannon index ($H = -\sum(n_i/N) \cdot \ln(n_i/N)$ where H – isthe species diversity; n_i - is the number of individuals of each species in all samples; N- is the total number of individuals of all species in all samples) is borrowed from information theory and is a parameter for assessing the complexity and content of information for any type of system, fourthly, it allows you to clarify the pollution limit of the maximum permissible concentration of pollutants, and fifthly, the water content of the catchment area of river basins.

Conclusions. The reliability of the developed mathematical models for assessing the quality of surface waters in catchment areas of river basins based on the solution of differential equations of hydrochemical processes of natural systems and practical problems of hydrochemistry and the principles of nonlinearity of natural processes that correspond in physical and mathematical terms, is a consequence of the use of classical mathematical methods for constructing models and their analytical analysis.

The proposed approach to assessing the quality of surface waters in catchment areas of river basins, in conjunction with geographic analysis, can be used for complex geoecological studies that allow developing recommendations for the rational management of water resources under the conditions of anthropogenic activity.

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THE GENERAL PICTURE OF CHANGES IN THE GEOMAGNETIC FIELD PARAMETERS ACCORDING TO THE ALMATY GEOMAGNETIC OBSERVATORY FOR THE PERIOD 1963-2021

Abstract. The secular variation of the geomagnetic field parameters is presented and an estimate of the state of the geomagnetic field is given according to the experimental data of the Almaty geomagnetic observatory [43.25°N; 76.92°E] Institute of the Ionosphere, Almaty, RK, for period 1963-2021. The characteristics are given of the temporal course and spatial distribution of the values of the parameters of the geomagnetic field for geomagnetic declination D, horizontal component H, full vector of geomagnetic field strength F, northern component X, eastern component Y, and vertical component Z. The conducted studies of the secular variation of the geomagnetic field parameters according showed inconstancy and change over time in their magnitude and direction. Over 58 years, D increased by about 28 min, H decreased by 980 nT, F increased by 1081 nT, X decreased by about 1000 nT, Y increased by about 135 nT, Z increased by about 1700 nT. On average, H decreases by (-28.5) nT/year, the average change in F is 88.6 nT/year. Y changed unevenly over time, during the period of time 1963-1966 there was an increase in Y, from 1966-1988 the Y has decreased, since 1988-2021 there has been an increase in the Y. The average value of the change in Z is 112.6 nT/year.

Key words: geomagnetic field parameters, experimental data, secular course.

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АЛМАТЫ ГЕОМАГНИТТІ ОБСЕРВАТОРИЯСЫНЫҢ 1963-2021 ЖЫЛДАР АРАЛЫҒЫНДАҒЫ ДЕРЕКТЕРІ БОЙЫНША ГЕОМАГНИТТІ ӨРІС ПАРАМЕТРЛЕРІНІҢ УАҚЫТ ӨЗГЕРІСТЕРІНДЕГІ ЖАЛПЫ КӨРІНІСІ

Аннотация. Геомагниттік өріс параметрлерінің ғасырлық барысы ұсынылған. Алматы геомагниттік обсерваториясында алынған [43.25°N; 76.92°E] Ионосфера институтының, Алматы қ., Қазақстан Республикасының 1963-2021 жылдар кезеңіндегі эксперименттік деректері бойынша геомагниттік өріс параметрлерінің ғасырлық барысы ұсынылды және геомагниттік өріс параметрлері мәндерінің уақытша жүрісінің және кеңістікте таралуының сипаттамасы берілді. Жұмыста геомагнитті өрістің мынадай параметрлері зерттелді: геомагнитті ауытқу D, көлденең құраушы H, геомагнитті өрістің кернеулігінің толық векторы F, Солтүстік құраушы X, Шығыс құраушысы Y, тік құраушы Z. 1963-2021 жылдар кезеңіндегі Алматы геомагнитті обсерваториясының деректері бойынша геомагнитті өріс параметрлерінің ғасырлық жүрісінің жүргізілген зерттеулері уақыт өте келе олардың шамасы мен бағытының өзгермейтіндігін және өзгергендігін. Сонымен, 58 жыл ішінде обсерваториядағы геомагниттік ауытқу D шамамен 28 минутқа артты, көлденең құраушы H компонентінің мәні 980 нТл-ға азайды, геомагниттік өрістің кернеу векторы F 1081 нТл-ға өсті, Солтүстік компонент X шамамен 1000 нТл-ға азайды, Y Шығыс компоненті шамамен 135 нТл-ға өсті, тік компонент Z шамамен 1700 нТл өсті. Орташа алғанда, көлденең құраушы H компонентінің (-28.5) нТл/жылына азаяды, F компонентінің өзгерісінің орташа мәні жылына 88.6 нТл құрайды. Y компоненті уақыт бойынша біркелкі емес өзгерді, 1963-1966 жылдар аралығында Y компонентінің ұлғаюы болды, 1966-1988 жылдар. Y компоненті азайды, 1988-2021 жылдар. Y компонентінің ұлғаюы байқалады. Z компонентінің өзгерісінің орташа мәні жылына 112.6 нТл құрайды.

Түйін сөздер: геомагнитті төмендеу, эксперименттік деректер, ғасырлық барысы.

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ОБЩАЯ КАРТИНА ИЗМЕНЕНИЙ ПАРАМЕТРОВ ГЕОМАГНИТНОГО ПОЛЯ ПО ДАННЫМ АЛМАТИНСКОЙ ГЕОМАГНИТНОЙ ОБСЕРВАТОРИИ ЗА ПЕРИОД 1963–2021 ГГ.

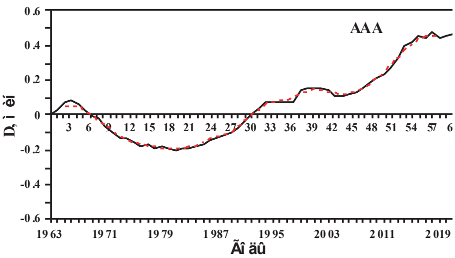
Аннотация. Представлен вековой ход параметров геомагнитного поля и дана оценка состояния геомагнитного поля по экспериментальным данным, полученным на Алматинской геомагнитной обсерватории [43.25°N; 76.92°E] Института ионосферы, г. Алматы, Республики Казахстан, за период 1963-2021 гг. Даны характеристики временного хода и пространственного распределения значений параметров геомагнитного поля. В работе исследованы такие параметры геомагнитного поля, как геомагнитное склонение D, горизонтальная составляющая H, полный вектор напряженности геомагнитного поля F, северная составляющая X, восточная составляющая Y, вертикальная составляющая Z. Проведенные исследования векового хода параметров геомагнитного поля по данным Алматинской геомагнитной обсерватории за период 1963-2021 гг. показали непостоянство и изменение со временем их величины и направления. Так, за 58 лет геомагнитное склонение D по данным обсерватории увеличилось на величину порядка 28 мин, величина горизонтальной составляющей H уменьшилась на 980 нТл, вектор напряженности геомагнитного поля F увеличился на 1081 нТл, северная составляющая X уменьшилась на величину порядка 1000 нТл, восточная составляющая Y увеличилась на величину порядка 135 нТл, вертикальная составляющая Z увеличилась на величину порядка 1700 нТл. В среднем H уменьшается на величину -28.5 нТл/год, средняя величина изменения F составляет 88.6 нТл/год. Y изменялась неравномерно по времени, за период времени 1963-1966 гг. произошло увеличение Y, с 1966-1988 гг. Y составляющая уменьшилась, с 1988-2021 гг. происходит увеличение Y составляющей. Средняя величина изменения Z составляет 112.6 нТл/год.

Ключевые слова: параметры геомагнитного поля, экспериментальные данные, вековой ход.

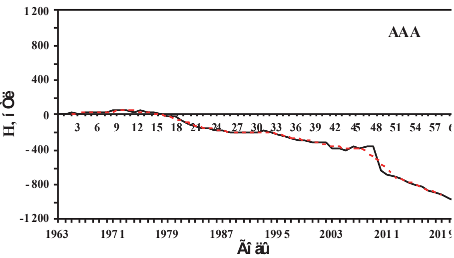
Введение. За последние 100 лет геомагнитное поле ослабло примерно на 5%. Как правило, ослабление геомагнитного поля ведет к инверсии северного и южного магнитных полюсов Земли (переполюсовке). Подтверждают общую тенденцию ослабления величины магнитного поля данные, передаваемые спутником Swarm, запущенным Европейским космическим агентством (European Space Agency, ESA). По данным спутника Swarm, в 2014г. наибольший уровень снижения геомагнитного поля произошел в Западном полушарии (Finlay, 2010: 1216) Наблюдаемое на поверхности Земли геомагнитное поле является важным источником информации о динамике магнитосферы. Магнитосфера и все пространство вокруг нее заполнены плазмой, в которой легко возбуждается электрический ток. Поэтому происходящие в магнитосфере процессы обуславливают проявление возмущений в геомагнитном поле. Следовательно, геомагнитные данные являются источником ценных сведений, необходимых для понимания процессов, протекающих в отдаленных областях космического пространства. Такие основные понятия, как магнитосфера, солнечный ветер, захваченная радиация были введены в научный обиход при анализе геомагнитных данных еще до появления спутников. Измерения геомагнитного поля, которые проводят на спутниках и в обсерваториях показывают, что магнитное поле Земли постоянно меняется. Эти изменения можно поделить на длиннопериодные (вековые) и короткопериодные вариации. Вековые вариации проявляются за длительный промежуток времени (десятилетия, столетия), а короткопериодные (быстрые) вариации сказываются в течение дня, часа, минут и секунд. При исследовании геомагнитных вариаций принято квалифицировать их по определенным признакам: по интенсивности, продолжительности, пространственному распределению, по физическим механизмам. Так называемый вековой ход геомагнитного поля (медленные вариации параметров геомагнитного поля с периодами несколько лет) мы можем исследовать при помощи многолетних измерений параметров геомагнитного поля в геомагнитных обсерваториях, которые находятся в разных точках Земли (Fournier, 2010:247, Friis-Christensen, 2006: 351, Love, 2008 a: 31, 2011 b: S07001, Matzka, 2010: 29, Mayaud, 1980, Nosé, 2012: S08002, Peltier, 2010: e5, Reay, 2005: 3081, Yumoto, 2012).

Материалы и основные методы. Все измерения параметров геомагнитного поля в геомагнитной обсерватории «Алма-Ата» (IAGA код AAA) [43.25°N; 76.92°E] ДТОО «Институт ионосферы» АО «НЦКИТ», г. Алматы, РК проводят в реальном времени с помощью специализированного измерительного комплекса по стандартным методикам (Kryakunova, 2015: 177, Гордин, 2004: 9). Комплекс состоит из двух цифровых магнитовариационных станций на базе феррозондовых магнитометров (LEMI-008 и LEMI-018) и вариационной станции с протонным магнитометром (POS-1), а также феррозондовым деклинометром Lemi-203 на базе теодолита 3Т2КП (Sokolova, 2016: 76, Нечаев, 2006: 35). Работа POS-1 основана на принципе динамической поляризации ядер (эффект Оверхаузера). Основой датчика служит Оверхаузеровский ядерно-прецессионный преобразователь на стабильном рабочем веществе. По сравнению с протонными преобразователями он обладает меньшим энергопотреблением, большей чувствительностью и градиентоустойчивостью. Используемый в составе датчика микропроцессор позволяет: обрабатывать и пересчитывать частоту свободной ядерной прецессии непосредственно в величину модуля измеряемого поля; адаптировать обработку сигнала ядерной прецессии в зависимости от условий измерения; контролировать качество и условия измерения; управлять датчиком по порту с внешнего блока управления, например с компьютера; проводить автоматическую внутреннюю настройку датчика, а также «ручную» настройку с внешнего блока управления; выводить результаты измерений и дополнительную информацию в цифровом виде через порт автоматически или по запросу. LEMI-008(LEMI-018) изготовлены на основе феррозондовых датчиков, электронные блоки которых обеспечивают преобразование, обработку и накопление информации о вариациях магнитного поля, передачу этой информации в компьютер через интерфейс RS 232. Встроенный GPS-приемник корректирует время внутренних часов и определяет координаты расположения магнитометра. Диапазон измерения магнитного поля ±65000 нТл, разрешающую способность по цифровому входу 0.1 нТл, диапазон измерения вариаций магнитного поля ±2600 нТл, разрешающую способность при измерении вариаций 0.01нТл. При помощи блоков программного обеспечения системы сбора и накопления данных можно управлять магнитометрами, собирать и хранить секундные данные, привязывать данные к точному единому времени; создавать суточные файлы минутных данных; графически выводить на монитор в реальном времени вариации геомагнитного поля; производить автоматическую и ручную коррекцию системных часов. Феррозондовый магнитометр LEMI-203 состоит из однокомпонентного феррозонда и блока электроники, соединенного сигнальным кабелем. Данный феррозондовый магнитометр используется как деклинометр и инклинометр. Феррозонд закреплен на зрительной трубе немагнитного астрономического теодолита. Феррозондовый магнитометр нужен для нахождения магнитного меридиана на круге теодолита, а зрительная труба служит для определения на этом круге географического меридиана благодаря наведению на миру с известным азимутом. Угол между плоскостью магнитного меридиана и плоскостью географического (астрономического) меридиана и есть склонение D (Sokolova, 2020: 142). В феррозондовом деклинометре магнитная ось устанавливается перпендикулярно меридиану. При использовании магнетометра в качестве инклинометра зрительную трубу с феррозондом устанавливают в плоскости магнитного меридиана и поворачивают ее вокруг горизонтальной оси до совмещения нормали датчика с направлением полного вектора F. Это положение определяется по нулевым показаниям магнитометра. Величина погрешности компонентных измерений с помощью феррозондового инклинометра зависит от местоположения обсерватории. При погрешности процессорного магнитометра 0.1 нТл и инклинометра имеющего цену деления вертикального лимба 1′′, ошибка составит 0.2-0.5 нТл.

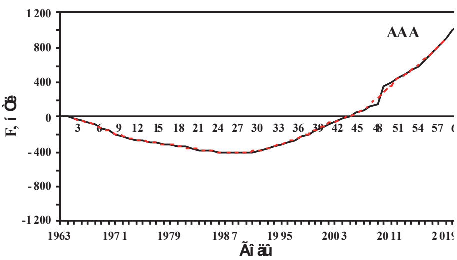
Результаты и обсуждение В обсерватории (AAA) проводят наблюдения геомагнитного поля с 1963 г. таких параметров, как геомагнитное склонение D, горизонтальная составляющая H, полный вектор напряженности геомагнитного поля F, северная составляющая X, восточная составляющая Y, вертикальная составляющая Z. Из наблюдаемых значений D и вариационных значений X, Y, Z, F были вычислены среднемесячные и среднегодовые абсолютные значения D, X, Y, Z, F за период 1963-2021 гг. H-составляющая была вычислена из северной составляющей X и восточной составляющей Y. Были построены графики вековых вариаций параметров геомагнитного поля по данным обсерватории (AAA) за период 1963-2021 гг. рисунок 1. На рисунке 1а показан вековой ход геомагнитного склонения D за период 1963-2021 гг. в обсерватории (AAA). Из рисунка видно, что в интервале времени 1988-2021 гг. хорошо виден рост D и имеется тенденция увеличения величины геомагнитного склонения D в восточном направлении. Наибольшее изменение D приходится на периоды 1986-1989 гг. и 1996-2000 гг., что соответствует 22 и 23 солнечным циклам. Было получено, что за 58 лет геомагнитное склонение D в обсерватории (AAA) увеличилось на величину порядка 28 мин. На рисунке 1 б приведен вековой ход горизонтальной составляющей H в обсерватории (AAA) за период 1963-2021 гг. Из графика видно, что H уменьшается со временем. За 58 лет в обсерватории (ААА) величина Н составляющей уменьшилась на 980 нТл. В среднем Н уменьшается на величину (-28.5) нТл/год. На рисунке 1 в приведен вековой ход полного вектора напряженности геомагнитного поля F в обсерватории (ААА) за период 1963-2021 гг. Из графика видно, что F увеличивается со временем. За 58 лет в обсерватории (ААА) вектор напряженности F увеличился на 1081 нТл. Средняя величина изменения F составляет 88.6 нТл/год. На рисунке 1 г приведен вековой ход северной составляющей X в геомагнитной обсерватории (ААА) за период 1963-2021 гг. Из графика видно, что X уменьшается со временем. За 58 лет в обсерватории (ААА) X составляющая уменьшилась на величину порядка 1000 нТл. На рисунке 1 д приведен вековой ход восточной составляющей Y в обсерватории (ААА) за период 1963-2021 гг. Из графика видно, что величина Y изменялась неравномерно по времени. Так за период времени 1963-1966 гг. произошло увеличение Y, с 1966-1988 гг. Y составляющая уменьшилась, с 1988-2021 гг. происходит увеличение Y составляющей. За 58 лет в обсерватории (ААА) Y составляющая увеличилась на величину порядка 135 нТл. На рисунке 1 е приведен вековой ход вертикальной составляющей Z на геомагнитной обсерватории (ААА) за период 1963-2021 гг. Из графика видно, что со временем Z составляющая увеличилась. За 58 лет в обсерватории (ААА) Z увеличилась на величину порядка 1700 нТл. Средняя величина изменения Z составляет 112.6 нТл/год.



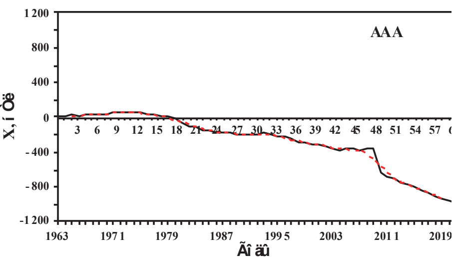
а



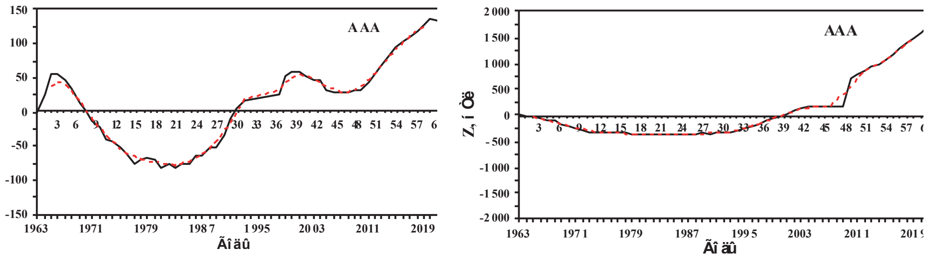
б



в



г



д е

Рисунок 1. Вековые вариации параметров геомагнитного поля по данным геомагнитной обсерватории ААА за период 1963-2021 годы: а - геомагнитное склонение D, б - горизонтальная составляющая H, в - полный вектор напряженности F, г - северная составляющая X, д - восточная составляющая Y, е - вертикальная составляющая Z

Заключение. Таким образом, проведенные исследования векового хода параметров геомагнитного поля, по данным обсерватории ААА за период 1963-2021 гг., показали непостоянство и изменение со временем их величины и направления. Так, за 58 лет геомагнитное склонение D в обсерватории (ААА) увеличилось на величину порядка 28 мин, величина горизонтальной составляющей H уменьшилась на 980 нТл, вектор напряженности геомагнитного поля F увеличился на 1081 нТл, северная составляющая X уменьшилась на величину порядка 1000 нТл, восточная составляющая Y увеличилась на величину порядка 135 нТл, вертикальная составляющая Z увеличилась на величину порядка 1700 нТл. Наибольшее изменение D приходится на периоды 1986-1989 гг. и 1996-2000 гг., что соответствует 22 и 23 солнечным циклам. В среднем H уменьшается на величину (-28.5) нТл/год, средняя величина изменения F составляет 88.6 нТл/год. Величина Y изменялась неравномерно по времени, за период времени 1963-1966 гг. произошло увеличение Y, с 1966-1988 гг. Y составляющая уменьшилась, с 1988-2021 гг. происходит увеличение Y составляющей. Средняя величина изменения Z составляет 112.6 нТл/год.

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SPECTROPHOTOMETRIC STANDARDS 8^m- 10^m. V. ZONES +61°, +20° and -16°

Abstract. The article is the result of the following stage of the creation of net of intermediate brightness spectrophotometric standards. In paper the absolute energy distribution in visual region of spectra for 16 B9-A2-stars 8^m-10^m was presented. The five investigated stars are located in zone with declination δ =+20° and five in zone with δ =-15°. The reduced data for 6 stars from the previous work of this cycle are also given, for which an error was found when taking into account the attenuation of radiation in the Earth’s atmosphere. The distribution of energy is studied in the range of 340 - 660 nm, spectral resolution is 5 nm, the relative root-mean-square error of the received data is from 3 to 6%. By prime standards served 8 stars, for which the energy distribution in their spectra given in first paper of this cycle. The energy scale of the primary standards is based on energy distribution in spectra of the main prime spectrophotometric standard α Lyr, which D. Hayess brought out. Observations were made on the telescopes of AZT-8 and Zeiss-600 using a diffraction spectrograph equipped with a CCD-cameras ATIC-490. The reliability of the results is estimated by comparing the calculated and directly observed magnitudes of the stars in UBV-system. One can used the investigated stars as spectrophometric standards at observations on medium-sized telescopes, including space ones.

Key words: stars, energy distribution, spectrophotometric standards, comparison with photometry.

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8^m-10^m СПЕКТРОФОТОМЕТРЛІК СТАНДАРТТАР. V. +61°,+20° ЖӘНЕ -16° АУМАҚТАРЫ

Аннотация. Мақала, аралық жарқырау бойынша спектрофотометрлік стандарттар желісін құрудың кезекті сатысының қорытындысы көрсетілген. Мұнда, спектрдің көрінерлік аймағындағы 8^m-9^m шамадағы B9V-A2V класстарының 16 жұлдыздарының абсолютті энергия таралуы берілген. Бес ауысу +20°-а және бес δ = -16˚ ауысуында орналасқан жұлдыздар зерттелген. Сонымен қатар, осы цикл бойынша алдыңғы жұмыстағы 6 жұлдыз үшін жұлдыздардың сәулеленуінің жер атмосферасынан өтуін есепке алып анықталған редукцияланған мәліметтер келтірілген. Энергияның таралуы 340 - 660 нм аралығында зерттелді, спектрлік рұқсат ету 5 нм құрайды, алынған мәліметтердің салыстырмалы орташа еселік қателігі -3 тен 6% дейін. Осы циклді бірінші жұмыста берілген энергия таралуы үшін 8 жұлдыз стандарт ретінде қолданылды. Алғашқы стандарттардың энергиялық шкалалары, Хейс шығарған, Вега – спектріндегі энергия таралуының алғашқы спектрофотометрлік стандартына негізделген. Бақылаулар АЗТ-8 және Цейсс-600 телескоптарында ATIK-490 ЗБА-камерасымен жабдықталған дифракциялық спектрограф көмегімен орындалды. Зерттелген жұлдыздарға алынған энергияның таралуы туралы мәліметтер алғашқы болғандықтан, олардың нәтижелерін бағалау және дәлелдеу UBV жүйесінің фотометрлік мәліметтерімен салыстыру арқылы жүргізілді. Зерттелген жұлдыздарға орташа өлшемді және сонымен қатар ғарыштық телескоптармен бақылаулар жүргізгенде спектрофотометрлік стандарттар ретінде қолдануға болады.

Түйін сөздер: жұлдыздар, энергияның таралуыспектрофотометрлік стандарттар, фотометрлік мәліметтермен салыстыру.

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СПЕКТРОФОТОМЕТРИЧЕСКИЕ СТАНДАРТЫ 8^m-10^m. V. ЗОНЫ +61°,+20° и -16°

Аннотация. Статья является итогом очередного этапа создания сети спектрофотометрических стандартов промежуточного блеска. В ней представлено абсолютное распределение энергии в видимой области спектра для 16 B9V-A2V-звезд 8^m-9^m. Пять исследованных звезд расположены в зоне со склонениями +20° и пять – со склонениями δ = -16˚. Также приведены редуцированные данные для 6 звезд из предыдущей работы данного цикла, для которых обнаружена ошибка при учете ослабления излучения в земной атмосфере. Распределение энергии исследовано в интервале 340 - 660 нм, спектральное разрешение составляет 5 нм, относительная с.к.о. полученных данных - от 3 до 6%. Стандартами служили 8 звезд, для которых распределение энергии приведено в первой работе данного цикла. Энергетическая шкала первичных стандартов основана на распределении энергии в спектре основного первичного спектрофотометрического стандарта – Веги, выведенного Хейессом. Наблюдения выполнены на телескопах АЗТ-8 и Цейсс-600 с помощью дифракционного спектрографа, оснащенного ПЗС-камерой ATIK-490. Ввиду того, что данные о распределении энергии для исследованных звезд получены впервые, оценка их достоверности сделана путем сравнения с фотометрическими данными в системе UBV. Исследованные звезды могут использоваться в качестве спектрофотометрических стандартов при наблюдениях на телескопах среднего размера, в том числе и космических.

Ключевые слова: звезды, распределение энергии, спектрофотометрические стандарты, сравнение с фотометрией.

Введение. В работе (Tereschenko, 2018) была анонсирована программа создания сети спектрофотометрических стандартов промежуточного блеска. Программа предусматривает поэтапное исследование внеатмосферного распределения энергии в спектрах более пятидесяти А-В-звезд 8^m - 9^m в интервале длин волн 340-660 нм и спектральным разрешением 5 нм. В настоящей работе приводится распределение энергии для пяти A-B-звезд, расположенных вдоль параллели +20° и пяти звезд, имеющих склонение -16°±1°. Последние находятся вблизи Млечного Пути и могут использоваться для стандартизации спектрофотометрических наблюдений объектов, расположенных в направлении ядра нашей Галактики. Кроме двух упомянутых зон, мы также приводим редуцированные данные для шести звезд, опубликованные нами в работе [2] (зона +61°). Приведенные в (Tereschenko, 2021) данные о распределении энергии оказались частично искаженными из-за допущенной ошибки при вычислении ослабления света в земной атмосфере.

Как известно (Mironov, 2008, Burnashev et al., 2016), звезды с хорошо изученным распределением энергии в их спектрах часто используются для калибровки приемно-регистрирующей аппаратуры и стандартизации спектрофотометрических наблюдений самых разных небесных тел. Актуальность создания стандартов промежуточного блеска обусловлена, прежде всего, массовым вводом в эксплуатацию телескопов среднего размера, при наблюдениях на которых требуются стандарты именно промежуточного блеска. На сегодня стандартов промежуточного блеска (8^m - 9^m) насчитывается всего несколько десятков (Hamuy at al., 1992, Hamuy at al., 1994, Biryukov et al., 1998, Borisov et al., 1998), поэтому пополнение их списка даже одним десятком звезд для наблюдателей-потребителей является существенным. Для крупных телескопов диаметром более 3м требуются стандарты слабее 12 величины. Задачу их создания решили в специально созданной для этого лаборатории в Институте Космического телескопа (STSI, Baltimore). При этом спектральная область калибровок была расширена и охватила интервал от 1150 А до 2,5 мк, а диапазон звездных величин – от 7^m до16^m. Процесс их создания занял более десяти лет. Обратим внимание, что численные значения потоков для слабых стандартов получены полуэмпирическим способом. Наряду с наблюдениями на космическом телескопе «Хаббл» были привлечены теоретические модели атмосфер белых карликов (Oke et al., 1983, Oke, 1990, Bohlin et al, 2001, Bohlin et al., 2004).

Список и основные характеристики исследованных и редуцированных звезд–стандартов приведены в Таблице 1. Во второй и третьей колонках приводятся номера звезд по каталогам «HIPPARCOS» и HD, в четвертой и пятой – экваториальные координаты на 2000 год, в шестой и седьмой – звездные величины V и показатели цвета (B - V) в системе UBV, в восьмой – спектральный класс, приводимый в SIMBAD.

Таблица 1

Список и основные характеристики исследованных звезд

№	Hip	HD	RA_{2000}	DE_{2000}	V_J	$(B-V)_J$	Sp
				δ = (61° ± 1°)			
1	4437	5409	$00^h56^m46^s$	60° 01' 59	$7^m.84$	$0^m.018$	A0
2	19122	25427	04 05 58	61 37 58	7.91	0.096	A0
3	41180	70177	08 24 12	62 18 01	7.68	-0.034	B9
4	60796	108518	12 27 37	61 09 10	8.00	0.203	A2
5	81940	151554	16 44 18	60 58 14	7.88	0.145	A0
6	100944	195391	20 28 00	59 44 04	7.98	-0.021	A0
				δ = (20° ± 2°)			
7	48521	85660	09 53 44	18 56 40	8.21	0.078	A0
8	59911	106858	12 17 20	22 12 31	8.13	0.124	A2
9	76060	138526	15 32 00	20 56 28	8.33	0.294	A2
10	90925	171233	18 32 51	20 24 19	8.40	0.095	A0
11	104638	201861	21 11 45	19 22 22	8.41	0.033	A0
				δ = (-16°± 2°)			
12	29966	43954	06 18 30	-14 35 54	8.37	0.002	A0
13	40661	69772	08 1801	-14 58 30	7.58	-0.03	B9.5
14	42822	74409	08 43 33	-14 02 31	7.65	-0.05	B9
15	84190	155503	17 32 35	-15 09 49	7.94	0.135	B9
16	95884	183430	19 30 02	-15 58 32	7.70	0.109	B9

Методы наблюдений и обработки. Результаты измерений. Методика получения абсолютного распределения энергии в спектрах звезд-стандартов промежуточного блеска подробно описана в первой работе данного цикла (Tereschenko, 2018). Напомним только основные моменты.

Наблюдения выполняются дифференциальным методом (методом равных высот), что позволяет использовать в редукциях среднее значение коэффициента прозрачности для места наблюдения. Первичными стандартами служат 8 звезд, список, характеристики и распределение энергии в спектрах которых приведены, в частности, в статье (Tereschenko, 2018). Энергетическая шкала первичных стандартов и, соответственно, наших данных основана на распределении энергии в спектре Веги. Для нее взято распределение, которое получил Д. Хейесс путем компиляции шести лучших калибровок. Наблюдения выполнены в обсерватории на Каменском плато (h = 1400м над у. м.) на двух телескопах: АЗТ-8 (D = 70cm) и Цейсс-600 (D = 60cm). Использовался безщелевой дифракционный спектрограф низкого разрешения, изготовленный нами специально для абсолютных наблюдений (Tereschenko at al., 2017). Диспергирующим элементом в нем служит тороидальная дифракционная решетка, а приемником излучения - ПЗС-камера ATIK-490.

Полученные кадры спектров обрабатывались в пакете «MaxIm DL-6». Процедура обработки кадров подробно описана в работе (Tereschenko, 2018). Численные редукции за поглощение в атмосфере и разные экспозиции выполнены по формуле:

$$E^*(\lambda) = E_{st}(\lambda) \cdot [I^*(\lambda) / I_{st}(\lambda)] \cdot [\tau_{st} / \tau^*] \times p_{av}(\lambda)^{-\Delta M}, \qquad (1)$$

где $E^*(\lambda)$ и $E_{st}(\lambda)$ – внеатмосферные значения спектральных плотностей энергетических освещенностей, создаваемых звездой и стандартом;

$I^*(\lambda)$ и $I_{st}(\lambda)$ - усредненные в интервале 5нм отсчеты на звезду и стандарт;

τ_{st} и τ^* - длительность экспозиций на стандарт и звезду;

$p_{av}(\lambda)$ – среднее значение коэффициента прозрачности;

$\Delta M = M^* - M_{st}$ - разность воздушных масс между звездой и стандартом.

Для вторичных стандартов мы брали значения освещенностей и отсчетов для квазинепрерывного спектра. Значения освещенностей в области спектральных линий для них было получено заранее путем графической интерполяции кривых распределения энергии. Аналогично интерполировались отсчеты на регистрограммах стандартов. Калиброванные и с вычтенным фоном регистрограммы распечатывались и по распечаткам выполнялась интерполяция. Полученные отсчеты вновь заносились в компьютер. Эту процедуру можно было выполнять численно с помощью компьютера, однако мы использовали «ручной» метод. Такой «гибридный» метод измерений более длителен и субъективен, однако, учитывая многолетний опыт наших измерений, оказывается более надежным. Для исследуемых звезд и стандартов берутся интегральные отсчеты внутри интервалов с теми же номерами пикселей (длин волн центров 50А интервалов). Репером при разбивке спектрограмм на 50-ангстремные интервалы усреднения служила линия водорода H□. Результаты наблюдений – распределение энергии в спектрах наблюдавшихся звезд, представлены в таблице 2.

Таблица 2

Распределение энергии в спектрах исследованных звезд (единицы: 10^{-7} ватт $м^{-2}$ $м^{-1}$)

№	1	2	3	4	5	6	7	8
λ/ HD	5409	25427	43954	69772	70177	74409	855660	106858
3425	293	199	163	337	324	311	119	151
3475	281	211	212	374	307	388	94	144
3525	310	190	180	379	293	346	101	165
3575	316	194	170	364	293	367	109	155
3625	286	196	161	374	315	360	98	161
3675	283	195	170	366	338	365	106	150
3725	297	231	199	395	360	375	122	166
3775	350	257	215	449	420	446	159	196
3825	418	333	279	548	535	545	218	250
3875	494	405	320	672	652	679	271	301
3925	490	403	330	690	662	680	290	313
3975	533	453	362	723	724	717	323	345
4025	592	528	398	827	777	809	380	412
4075	534	453	371	732	697	751	354	373
4125	503	435	346	696	656	710	324	343
4175	529	480	350	745	694	713	358	384
4225	512	468	339	709	671	682	350	382
4275	489	440	327	680	634	664	339	367
4325	431	372	294	581	564	598	285	308
4375	434	395	293	585	565	595	286	313
4425	457	431	299	619	605	598	312	350
4475	439	416	291	588	581	570	302	352
4525	431	404	280	577	566	555	294	342
4575	418	397	273	558	547	536	287	333
4625	407	385	263	549	527	522	281	322
4675	397	373	257	532	525	506	277	315
4725	387	358	244	516	496	494	271	303
4775	368	339	235	489	472	467	258	288
4825	328	294	217	432	412	431	228	249
4875	304	271	202	398	389	411	209	225
4925	332	311	213	441	423	428	229	258
4975	335	315	215	438	421	419	233	269
5025	325	306	207	424	407	405	224	262
5075	319	307	206	418	391	391	223	262
5125	312	293	200	407	376	380	218	252
5175	300	286	192	395	357	370	208	243
5225	299	287	191	387	351	364	208	239
5275	289	269	181	375	343	351	204	232
5325	280	267	178	361	331	337	196	227
5375	278	258	173	356	324	333	192	222
5425	270	258	169	351	323	330	187	222
5475	264	256	165	339	318	313	176	220
5525	260	253	170	336	302	322	184	221
5575	259	238	163	331	295	308	177	203
5625	254	233	157	319	291	301	173	195
5675	243	226	149	307	282	290	166	196
5725	236	225	148	300	278	280	163	196

5775	228	218	142	289	266	271	160	187
5825	226	211	142	279	257	259	156	187
5875	219	206	137	272	253	252	153	181
5925	215	202	135	271	244	252	147	177
5975	214	201	133	268	241	249	146	176
6025	210	197	129	262	236	242	145	173
6075	206	194	126	257	228	237	142	167
6125	206	188	124	250	225	231	141	167
6175	199	184	122	245	215	224	136	161
6225	193	182	118	238	209	218	133	161
6275	183	177	116	226	206	207	127	158
6325	179	172	114	220	196	203	126	150
6375	177	168	111	219	190	205	124	144
6425	174	160	106	212	184	197	121	139
6475	172	159	107	207	181	190	117	138
6525	163	147	95	189	167	175	105	125
6575	145	130	89	142	145	158	110*	114
6625	162	146	103	190	149	170	112	125
3425	176	94	210	234	139	166	316	132
3475	151	90	197	239	130	187	295	123
3525	166	100	196	243	123	191	279	117
3575	169	105	189	250	124	181	296	124
3625	153	106	196	263	112	187	291	151
3675	197	103	191	280	123	194	275	124
3725	201	108	199	300	123	213	296	162
3775	218	133	233	321	145	251	349	199
3825	271	159	302	341	184	313	448	252
3875	317	197	380	386	233	391	464	302
3925	308	208	400	416	265	434	482	328
3975	344	230	442	427	290	481	532	355
4025	414	272	507	459	316	527	598	383
4075	363	250	465	412	291	468	522	349
4125	345	237	445	408	272	460	499	323
4175	383	259	478	443	296	480	540	345
4225	374	261	473	438	296	465	534	327
4275	353	252	458	394	277	430	492	321
4325	305	218	402	337	239	378	428	272
4375	322	226	408	348	242	388	427	277
4425	356	252	438	364	263	409	457	302
4475	345	248	429	353	253	397	439	286
4525	336	247	424	356	243	386	424	274
4575	331	238	409	334	236	374	410	265
4625	328	236	401	344	229	363	405	265
4675	320	228	393	336	227	359	391	258
4725	310	218	367	315	216	339	376	244
4775	297	211	357	299	202	315	354	231
4825	259	186	315	264	178	281	315	205
4875	240	173	293	250	168	265	290	191

4925	272	195	315	282	186	292	322	211
4975	280	198	320	291	194	301	324	216
5025	269	191	314	286	185	292	314	208
5075	270	191	311	289	185	288	307	205
5125	260	189	304	280	187	279	299	202
5175	250	185	299	275	178	270	290	196
5225	254	183	292	275	173	259	282	190
5275	241	177	284	266	168	254	271	184
5325	242	173	275	263	165	247	265	176
5375	231	172	266	259	162	238	260	172
5425	232	169	267	258	160	236	253	173
5475	225	164	262	256	144	230	248	159
5525	225	161	260	252	150	220	236	160
5575	217	160	252	257	152	220	236	161
5625	214	157	243	251	142	215	230	158
5675	210	155	232	254	144	207	224	146
5725	207	152	235	247	141	207	214	146
5775	201	149	225	239	131	199	210	141
5825	196	146	221	232	133	196	209	140
5875	193	141	213	234	130	193	203	138
5925	192	139	208	234	128	190	199	133
5975	189	134	204	228	125	180	194	131
6025	188	135	201	227	125	180	187	127
6075	183	130	195	225	123	174	180	129
6125	179	128	189	216	115	169	176	122
6175	172	124	183	208	113	164	173	117
6225	172	125	180	212	110	164	167	113
6275	169	122	176	209	109	161	163	113
6325	165	116	168	201	109	151	155	105
6375	160	117	167	198	110	147	152	107
6425	158	112	161	194	107	145	150	103
6475	155	107	158	189	107	142	145	99
6525	141	101	146	167	94	131	133	91
6575	130	90	137	156	83	119	116	71
6625	150	100	142	180	100	135	139	84

Как отмечалось выше, данные о внеатмосферном распределении энергии в спектрах B-A-звезд широко используются при наблюдениях самых разных небесных объектов: от астероидов до гамма-всплесков, см., например, (Kondratyeva at al.,2015, Gaysina et al., 2015, Kondratyeva at al., 2019).

Сравнение с фотометрией. Данные о распределении энергии в спектрах представленных в таблице звезд получены впервые и поэтому нет возможности сравнить их с аналогичными данными других авторов. Как и в предыдущих работах, для проверки их достоверности, пусть и грубой, мы использовали метод синтетической фотометрии (Straijys, 1977) и фотометрические данные в системе UBV. Соответствующие вычисления были выполнены по формулам (2) - (4):

$$V = -2.5\log\Sigma[E(\lambda)*S_V(\lambda)]\Delta\lambda + C_V \quad (2);$$

$$B\text{-}V = -2.5\log[\Sigma(E(\lambda)*S_B(\lambda)] / \Sigma[E(\lambda)*S_V(\lambda)] + C_{B\text{-}V} \quad (3);$$

$$\delta V = V_{cal} – V_{obs} \quad (4);$$

где E(λ) – среднее внеатмосферное значение энергии излучения в длине волны λ, $S_V(\lambda)$ и $S_B(\lambda)$ – кривые реакции системы UBV, C_V и C_B – константы.

Кривые реакции системы UBV взяты согласно (Straijys, 1977), а константы определены по звезде HD221525. Результаты вычислений и сравнений представлены в таблице 3.

Таблица 3.

Сравнение вычисленных звездных величин V и B с наблюдаемыми в системе UBV

1	HD	Vobs	δV	Bobs	δB	n
			δ = +61°			
1	5409	7.843	0.027	7.862	0.080*	5
2	25427	7.910	0.023	8.006	0.051	5
3	70177	7.685	0.007	7.643	0.010	6
4	108518	8.022	0.022	8.235	0.037	3
5	151554	7.905	-0.006	8.056	-0.020	5
6	195391	7.977	-0.032	7.749	0.002	4
			δ = +20°			
7	85660	8.215	0.053	8.294	0.093*	3
8	106858	8.140	-0.038	8.313	-0.035	4
9	138526	8.330	0.061	8.624	0.039	4
10	171233	8.400	0.003	8.495	0.055	5
11	201861	8.410	-0.035	8.443	-0.024	4
			δ = -15°			
12	43954	8.373	0.001	8.374	0.013	3
13	69772	7.556	0.043	7.544	0.065	5
14	74409	7.645	0.025	7.573	0.056	3
15	155503	7.960	-0.048	80.109	0.052	2
16	183430	7.998	0.022	8.069	0.003	4

n – число наблюдений, вошедших в вычисление кривых распределения энергии E(λ).

Из таблицы следует, что для абсолютного большинства звезд сходимость вычисленных и непосредственно наблюдаемых звездных величин удовлетворительная, но для трех звезд данные о распределении энергии несколько завышены, особенно в полосе B. Причины завышения выяснить не удалось. Одной из основных причин может быть неустойчивость земной атмосферы, в частности, азимутальный эффект. Небо на Каменском плато с каждым годом явно ухудшается и проведение здесь фотометрических наблюдений становится проблематичным. По этой причине более трети выполненных нами наблюдений пришлось «выбросить в корзину». Тем не менее, программу создания сети звезд-стандартов промежуточного блеска, ввиду ее актуальности, необходимо завершить.

В заключение выражаю искренную благодарность Бобряшовой Т.А. за огромную помощь в обработке спектрограмм.

Исследование финансируется Комитетом науки Министерства образования и науки Республики Казахстан (программа № AP08855631).

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К 110-летию ученого

У.М. АХМЕДСАФИН – ОСНОВАТЕЛЬ ГИДРОГЕОЛОГИЧЕСКОЙ НАУКИ В КАЗАХСТАНЕ

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У.М. Ахмедсафин – крупнейший ученый-энциклопедист, гидрогеолог, географ, эколог, Герой Социалистического Труда, пионер гидрогеологии в Казахстане, один из самых ярких представителей блестящей когорты ученых, с его именем связан расцвет казахстанской науки. Он является автором уникальной методики поиска подземных вод в зоне засушливых пустынь.

Его труды, научные открытия намного пережили ученого, и актуальность их в условиях дефицита пресной воды на планете чрезвычайно возрастает. Работая в сложных климатических условиях, он обследовал огромные пространства знойных песчаных пустынь Казахстана и Средней Азии, считавшиеся совершенно безводными, исходя из научных предпосылок, открыл многочисленные подземные моря, озера, реки, расшифровал и объяснил их происхождение, определил ресурсы и наметил широкие перспективы их использования на благо человечества.

После успешной защиты кандидатской диссертации в Московском геологоразведочном институте им. С. Орджоникидзе в 1940 году, по согласованию с вице-президентом АН СССР, академиком О.Ю. Шмидтом, был направлен в казахстанский филиал Академии наук СССР в г. Алма-Ате, где им впервые был создан Сектор гидрогеологии и инженерной геологии.

В годы Великой Отечественной войны (1941-1945 гг.) У.М. Ахмедсафин организовал и возглавил комплексную экспедицию в пустынные районы республики для выявления возможностей нахождения и содержания эвакуированных на восток заводов, предприятий и скота: предстояло выяснить, имеется ли в пустынях достаточное количество подземных вод. Оказалось, что в обследованных районах Южного Казахстана песчаные пустыни не безводны и в них широко распространены доброкачественные подземные воды, пригодные для использования.

В 1947 г. У.М. Ахмедсафин защитил докторскую диссертацию в Москве. В 1951 году выпустил большую монографию «Подземные воды песчаных массивов южной части Казахстана». В этой работе и в ряде статей впервые в отечественной и зарубежной гидрогеологии всесторонне освещается инфильтрационное происхождение, накопление, распространение региональных ресурсов подземных вод, методов их определения. Выявленные при этом ресурсы доброкачественных подземных вод дали мощный импульс к развитию аридной гидрогеологии.

В годы освоения ценных земель У. Ахмедсафин возглавил гидрогеологические исследования в Северном Казахстане. Здесь были определены перспективные водоносные горизонты, содержащие значительные запасы подземных вод, за счет которых решена проблема водообеспечения 400 целинных совхозов, колхозов, многих районных центров, железнодорожных станций и т.д.

Более четверти века У. Ахмедсафин изучал глубинную гидрогеологию аридных районов. При этом им были установлены научные положения, имеющие первостепенное значение не только для Казахстана, но и для многих засушливых развивающихся стран. Они позволили ему впервые в истории гидрогеологических исследований у нас и за рубежом создать и опубликовать фундаментальные прогнозные карты артезианских бассейнов (с монографиями), выявить 70 артезианских бассейнов, оценить содержащиеся в них огромные вековые запасы доброкачественных подземных вод, равные 7,5 триллионам кубометров (соизмеримые с объемом 70-и озер Балхаш), ежегодно возобновляющиеся в размере 48 млрд.куб. метров.

В 1951 году У. Ахмедсафин избирается членом-корреспондентом, а в 1954 – академиком Академии наук Казахской ССР. В 1965 г. впервые организовал единственный в системе Академий наук СССР Институт гидрогеологии и гидрофизики.

Его крупные научные достижения позволили обеспечить подземной водой около 69 городов Казахстана, 4 тысячи населенных пунктов, обводнить 115 млн.га пастбищ, оросить до 60 тысяч га земель.

Обладая даром научного предвидения и большим практическим опытом, У. Ахмедсафин выступал против создания некоторых гидротехнических сооружений, могущих вызвать экологические катастрофы. Во многом его прогнозы подтвердились. Он единственный не подписал заключение правительственной комиссии о строительстве Кызылкумского канала, т.к. это привело бы к уменьшению притока реки Сырдарьи в Аральское море и тем самым способствовало бы усыханию Аральского моря.

Важным вопросом проблемы охраны окружающей среды была охрана озера Балхаш в связи со строительством Капчагайского водохранилища на реке Или. Строительство и забор значительного количества воды из реки Или на его заполнение могли привести озеро Балхаш к участи Аральского моря, т.е. к усыханию его крупной дельты. Ему потребовались большие усилия, научные доказательства, в том числе и на правительственном уровне, чтобы показать нецелесообразность строительства водохранилища и, уж во всяком случае не до проектной отметки. В результате удалось отстоять минимальную отметку заполнения водохранилища и нерасширения рисовых плантаций в низовьях реки Или. Таким образом удалось спасти озеро Балхаш хотя бы на период заполнения водохранилища.

Он также обосновал положение, что строительство гидротехнических сооружений на реках, протекающих в пустынных районах, может повлечь за собой усыхание водных бассейнов (озер), в которые они впадают. В зонах с повышенной сейсмической активностью – усиливать балльность землетрясений. В то же время правильное использование подземных вод в этих районах снижает балльность землетрясений.

У.М. Ахмедсафин являлся рьяным противником переброски Сибирских рек в Казахстан и Среднюю Азию. Совместными усилиями с учеными других Республик СССР принятие этого решения было приостановлено.

У.М. Ахмедсафин является основателем гидрогеологической науки и создателем школы аридной геологии в Казахстане. Им было подготовлено более 60 кандидатов и докторов наук. Кроме научной работы, занимался преподавательской деятельностью, заведовал кафедрой гидрогеологии и инженерной геологии в Казахском горно-металлургическом институте. В 1949 году ему было присвоено звание профессора.

У.М. Ахмедсафин был государственным деятелем. В 1955-59 годах избирался депутатом и членом Президиума Верховного Совета Казахской ССР IV созыва.

В 1955-60 гг. У.М. Ахмедсафин был членом Гидрогеологической секции Национального комитета геологов ЮНЕСКО. Он неоднократно оказывал помощь через ЮНЕСКО в гидрогеологических исследованиях во многих странах мира, в августе 1960 г. он сделал доклад на гидрогеологической секции Международного геологического конгресса в Копенгагене. В 1979 г. проводил международные курсы по линии ЮНЕП в Москве, Алма-Ате и Чимкенте по экологии пастбищ мира, на которых присутствовали представители африканских, арабских стран и Аргентины, неоднократно консультировал по вопросам орошения засушливых земель представителей Австралии, Израиля, Венгрии, Франции и Кувейта.

У.М. Ахмедсафин награжден многими правительственными наградами СССР. В 1969 году он был награжден высшей наградой СССР, ему было присвоено звание Героя Социалистического Труда.

У.М. Ахмедсафин опубликовал около 500 печатных работ: из них 18 монографий и 18 гидрогеологических карт.

Учитывая заслуги ученого, после его смерти его имя было присвоено созданному им Институту гидрогеологии и гидрофизики, одной из улиц Алма-Аты, учебному заведению на его родине в Северо-Казахстанской области.

100-летие ученого проводилось под эгидой ЮНЕСКО.

Светлой памяти

САДЫКОВОЙ АЛЛЫ БАЙСЫМАКОВНЫ

1 июля 2022 года на 76-м году жизни после непродолжительной болезни скончалась **Садыкова Алла Байсымаковна** – доктор физико-математических наук, академик Международной Евразийской академии наук (IEAS), заведующая лабораторией региональной сейсмичности ТОО Института сейсмологии МЧС Республики Казахстан.

Алла Байсымаковна – известный ученый, научный руководитель Программы «Оценка сейсмической опасности территорий областей и городов Казахстана на современной научно-методической основе», один из авторов карт сейсмического районирования территории Казахстана разной детальности и сейсмического микрорайонирования территории г. Алматы, входящих в перечень нормативных документов, регламентирующих проектирование и строительство в сейсмоактивных регионах Казахстана.

Алла Байсымаковна родилась в семье служащего в городе Шымкенте Южно-Казахстанской области 14 мая 1946 года, сразу после окончания Ленинградского вуза начала работать в секторе сейсмологии при Институте геологии Академии наук КазССР, на базе которого в 1976 г. был сформирован Институт сейсмологии. Здесь она защитила кандидатскую диссертацию в 1992 г., а затем в 2010 г. – докторскую на тему «Сейсмологические и геолого-геофизические основы вероятностной оценки сейсмической опасности Казахстана».

Алла Байсымаковна – автор более 160 научных и научно-методических работ, в т.ч. 7 монографий (в соавторстве) в области изучения особенностей проявления землетрясений, разработки методики долго- и среднесрочного прогноза землетрясений и оценки сейсмической опасности. Ее монография

«Сейсмическая опасность территории Казахстана» (Алматы, 2012, 267 с.) является фундаментальным трудом, где изложены результаты многолетних исследований особенностей сейсмичности и сейсмического режима территории Казахстана. Книга «Землетрясения Казахстана: причины, последствия и сейсмическая безопасность» (в соавторстве, Астана, 2019, 290 с.) является научно-популярным изданием о современном состоянии проблемы изучения землетрясений в Казахстане, где отмечены все трудности прогноза землетрясений и отведено место научным и общественным мерам противостояния стихии – сейсмозащите.

На протяжении многих лет Алла Байсымаковна была ученым секретарем межведомственной комиссии по прогнозу землетрясений и представляла нашу страну в международных организациях. Она активно сотрудничала со всеми сейсмологическими учреждениями, была членом различных республиканских комиссий, читала курс лекций по специальности «сейсмология» на кафедре геофизики КазНТУ им. Сатпаева. Ее неоднократные выступления по радио и телевидению, многочисленные интервью в средствах массовой информации были направлены на изложение знаний о землетрясениях – причинах их возникновения, связанных с ними опасностями, методах их изучения и возможностями прогноза.

Любовь к сейсмологии Алла Байсымаковна сохранила до конца жизни. До последнего дня она оставалась на работе, вкладывая в нее все физические и душевные силы, являя собой пример преданного и самоотверженного служения науке, высочайшей работоспособности и ответственности, целеустремленности, чуткости и бескорыстия, неравнодушного отношения к любой жизненной ситуации. Заслуги Садыковой А.Б. отмечены медалью за вклад в науку в честь 30-летия Независимости РК, грамотами, дипломами.

Благодаря высоким профессиональным и личным качествам Алла Байсымаковна пользовалась безусловным авторитетом среди казахстанских и зарубежных специалистов. Она прожила достойную жизнь уважаемого человека, глубокого мыслителя и преданного своему делу ученого. Более 45 лет она была вместе с мужем Е.Т. Садыковым, имея сына и четверых внуков.

1 июля 2022 перестало биться сердце этой удивительной женщины, но в наших сердцах всегда будет жить светлая память о ней. Мы будем помнить Аллу Байсымаковну как глубоко интеллигентного, отзывчивого, жизнерадостного, необычайно деятельного человека и талантливого ученого. Ее уход – большая потеря для науки Казахстана. Аллы Байсымаковны Садыковой больше нет с нами. Но осталось ее богатейшее научное наследие, ученики, которые будут продолжать дело своего наставника. Осталась добрая память об этом светлом, душевно щедром человеке.

От имени соратников и коллег по работе
профессор А. Нурмагамбетов

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