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NEUTRALIZATION OF PHENOL-CONTAMINATED SOILS

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Abstract: *To eliminate the consequences of accidental spill of phenol, the results of neutralization of soils contaminated with phenol are presented. As for the analysis of soils by the geological-lithological section it was found that in areas of phenol contamination the soil has a surface soil-plant layer with a thickness of about 0.5m, then there is a heavy clay layer with a thickness of up to 7.0 m and finally a sand layer saturated with groundwater is observed. It revealed that according to physical and mechanical properties, the solid mineral phase of the soil corresponds to a hard plastic and semi-solid consistency of clays. It showed that the filtration of water through the bottom and walls on the area of the former burial of the tank is complicated because of closer to zero water permeability of soil strata due to clay rock. Mineralogical and chemical composition of soils contaminated with phenol is determined. An environmentally safe method of neutralizing phenol-containing soils is developed with a neutralizing composition based on quicklime and bentonite which simplifies the neutralization method of soils contaminated with phenol. Environmental safety was observed in the absence of phenol in water extracts from soils and the in treatment process permissible for the environment pH. Essence of proposed method lies in chemical inactivation of phenol based on its transformation into slow-moving water-insoluble compound - calcium phenolate. Decontamination product of phenol-containing soil is the smallest capsules comprising soil particles and immobilized phenol in the form of calcium phenolate. Material of the capsule represented by calcium hydroxide is neutralized over time by bentonite and CO_2 from air resulting in the formation of hydrophobic silicate and calcium carbonate which gives capsules high strength properties. The research into the neutralized phenol containing soil for phenol in water extracts showed that the proposed method is simple, ecologically safe, causes no recontamination of environment with pollutants and provides the phenol content in soils within MAC.*

Keywords: *accidental spill, phenol, ecology, monitoring, migration, phenol containing soil, neutralization.*

Introduction

Issues of treatment, neutralization, utilization of wastewater and soils are integral part of nature protection, environmental improvement, and provision of sanitary improvement of settlements [1]. Phenols are one of the most dangerous pollutants of surface and ground waters. Penetration of insignificant amount of phenol compounds into a water body reduces its ability to self-regenerate with existing biocenosis and the impossibility of further deactivation of pollution [2, 3]. The existing methods for restoring the ecology polluted with phenol are mainly aimed at treating surface or waste waters [4–8]. Study of methods and evaluation of the results of treating soils contaminated with phenol are calculated in units [9,10]. These works consider the methods of biological recultivation of soils contaminated with phenol. The use of the above-mentioned methods is impractical due to the high physical and material costs as well as the long period (about a year) for soil detoxification.

The aim of this article is to develop an environmentally safe method of neutralizing phenol-containing soils to normalize the ecological state of the disturbed area.

Experimental part

The research object is the phenol-containing soils of the territory of the Padar station in Hajigabul region of Azerbaijan, where, after an emergency situation in 1986, a railway tank car with phenol was buried (39°05′31″, 39°00′33″ N and 48°03′61″, 49°02′71″ E). Based on complaints of nearby settlements on the specific smell of phenol, in 2014 the measures were taken to extract and remove the railway tank car from the burial site. To date, the sites of the railway accident and the former location of the railway tank car with phenol are a pit, into which the content of railway tank was poured. Based on the data obtained as a result of environmental monitoring of the territory contaminated with phenol, it was found that the content of the pit and its surroundings are represented by hyperhumid clay soil, a highly concentrated dispersed system consisting of a liquid (phenol + water) and a solid dispersed phase. The liquid phase of the soil is a solution consisting of water-soluble salts that moved to it from the soil, soluble corrosion products of the tank which had been in the soil for a long time before it was removed, and phenol spilled from the tank. When adjusted for the fact that the composition and properties of the liquid phase of the soil can affect the effectiveness of the method used for neutralization of phenol-containing soil, its acidity level (pH), mineralization, the initial value of chemical oxygen demand (COD), and the concentration of phenol were determined. The acidity (pH) of water was determined by direct potentiometry [11]. The level of mineralization of the liquid phase of the soil was determined by the gravimetric method by the amount of dry residue obtained by water evaporation (t=105 0C) [12]. Granulometric composition of soils was determined in line with GOST 12536-79 while the chemical composition was determined using X-ray spectrometer S8 TIGER (Germany, BRUKER), and mineralogical composition was determined using MiniFlex 600 X-ray diffraction meter (Rigaku Corporation, Japan). Analysis of water samples for phenol content was carried out in keeping with [13] Carry-50 spectrophotometer (Varian, Australia) and «Termofinigan Trace DSQ Xromato-Mass spektrometre» with SPME autoanalyzer with addition of Fluoro-Fenol internal standards («Thermo Electron Chromatography and MassSpectrometry Division», USA). Typical chromatogram of phenol in groundwater taken from drilled wells at a dilution of 2500 times is shown in Fig.1, where the peak at 5.73 min corresponds to phenol. Phenol content in soils and their neutralization was carried out by means of the author's methods [14,15]. Experiments on neutralization of soils were carried out both with samples of soils contaminated with phenol taken from the area of the accidental spill, and with samples of clean soils from the same area previously contaminated with phenol. In the samples of phenol-containing soils taken from the area of an emergency spill, the initial content of phenol was preliminarily determined.

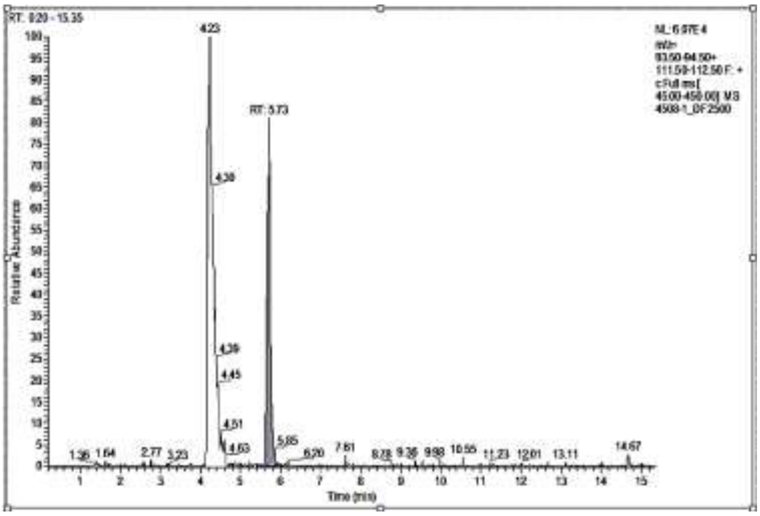

Fig. 1. Chromatogram of phenol in the composition of groundwater taken from drilled wells.

Contamination of clean soil samples with phenol taken from the emergency area was carried out as follows. Clean soil sample previously separated from roots and possible impurities (stones), was placed in a crucible and dried in thermostat at 105^0C to a constant weight. For experiments, samples of clean soil were taken in an amount of ~20 g, which were soaked with an aqueous solution of phenol. To study the neutralization process phenol content in toxic soil was 2.0% mass. Further [15], the soil contaminated with phenol is mixed with a neutralizing composition which is a mixture of jointly crushed quicklime and bentonite, at a ratio of components of 4:1, respectively, with necessary amount of mixing water. Experiments revealed that the neutralizing composition with a ratio of 4:1 of quicklime components to bentonite allows detoxification of soil contaminated with phenol to ensure the ecological safety for environment. When quicklime content in the decontaminating composition goes down the specified value of this amount, it is insufficient for complete coating of soil components and the formation of capsules, and besides, it is impractical due to overspending of the ingredient. When bentonite content in the decontaminating composition is below this value, the complete neutralization of calcium hydroxide, hydrophobization and sufficient strength properties of the surface of the resulting capsules are not ensured, and above - it is impractical due to overspending of the ingredient.

Results and discussion

As is known, when hazardous substances are discharged onto the soil surface, the primary task is to eliminate the consequences of the emergency situation, or to reduce the possibility of their spread in the environment. It is particularly important to prevent the discharge of harmful substances into ground or surface water during the transfer. Owing to the fact that phenol is a toxic substance of the 2nd class, its concentration is strictly regulated by sanitary norms and rules, the content of harmful substances in water and soil according to their maximum permissible concentration (MPC), which is a criterion of safety and harmlessness to humans. According to [16-18], MPC for phenol in soil and water in water protection areas and nature reserves is 50 mg/kg and 20 μg /l, respectively. Our studies found that phenol content in contaminated area in soil significantly exceeds MPC (by more than 1000 times).

To predict the migration processes of the harmful substance for reducing harmful effects, it is necessary to know the properties of substances and the composition of soils. The migration of substances in the soil can lead to both the accumulation of a substance in soil profile and its removal outside the horizon or profile. Immobilization processes are accompanied by processes leading to the redistribution of a substance between the solid and liquid phases of soil. The solid mineral phase of the soil, depending on the mechanical and mineral composition, has more or less active surface capable of absorbing organic and organic-mineral compounds; absorption is highly expressed in soils enriched with clay minerals (montmorillonite), having an active surface of up to 500 m^2/g [19]. Such absorption of a substance in soil profile leads to its accumulation. Comparing to accumulation process of a substance in soil profile its removal outside the profile occurs by a top-down gravitational current of water caused by atmospheric precipitates or melt water. The deepening of a substance into soil profile is a case of filtration under the impact of gravi-tational forces.

Based on the above, the methods of transfer, migration of a substance in soil body, a specific case of phenol migration in the soil and soil pollution area will also depend both on the properties of phenol (on its solubility in water) and on the mechanical and mineral composition of the soil in the territory under consideration. In line with the data of the geological section, the soil has a surface layer with a thickness of about 0.5 m, then there is a thick clay layer with thickness of up to 7.0 m, then a sandy layer with groundwater can be observed. Studies showed that, in terms of physical and mechanical properties, the solid mineral phase of the soil corresponds to semi-hard and hard-plastic clays. According to the granulometric composition in clayey rocks, on average, the fraction of sand, dust, and clay is 17.0, 39.2, and 43.8%, respectively.

The density of clays in natural and dry state is 1.89 and 1.54 g/cm^3 on average. Porosity of the rock is 43.71% and porosity factor equals to -0.777. Humidity indicators are average 0.81, total moisture capacity is 0.28. In line with the data on the composition of soils, it was found that water filtration through the bottom and walls of the pit is complicated due to the close to zero water permeability of soil layer surrounding the pit due to the clay rock that composes it (filtration coefficient - 0.005 m / day). Partial retention of spilled phenol in accident site is explained by its relatively good solubility in water (about 8.0% mass), as well as its absorptivity in mineral components of soil [19]. The results of the analysis of mineralogical and chemical composition of soils are presented in Tables 1 and 2. The composition of the liquid phase is presented in Table 3.

Table 1. Mineralogical composition of phenol-contaminated soils (mass %)

SiO_2	Feldspar	$CaCO_3$	$CaSO_4 \cdot 2H_2O$	Montmorillonite	Illite	Kaolinite	Fe_2O_3	Volcanic ash
11.2	9.5	5.8	3.8	38.1	8.6	7.5	5.5	10.0

Table 2. Chemical composition of phenol-contaminated soils (mass %)

Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	Fe_2O_3	MnO	Loss*
1.41	2.81	14.23	51.02	0.021	1.32	2.22	4.83	0.785	5.52	0.04	15.7

**Note: loss at high-temperature, 950 °C.*

Table 3. Results of analysis of liquid phase of soil

Component composition and properties	Meaning
Mineralization, mg/l	580.0
pH	5.7-6.0
COD, mgO_2/l	105.0
Fenol, mg/l	1000.0

As seen from Table 3, water is highly mineralized. The obtained COD value shows the presence of water pollution by organic and inorganic easily oxidized substances, including phenol, which is confirmed by its pH value in acidic region. In turn, an acidic environment slows down the processes of self-purification, which is typical for natural water bodies and contributes to the stabilization of organic impurities in them [20].

Self-purification of water from phenol occurs in the process of biochemical oxidation under the impact of enzymes produced by microorganisms. Biochemical self-purification is a consequence of the transformation of substances performed by hydrobentonite. However, owing to the extreme toxicity of phenol and the suppression of all microfloras in the aquatic environment at its concentration of already 75mg/l, it inhibits the biological treatment process. In reality, in water phase of soil at the accident site, the concentration of phenol is more than 1000mg/l.

Based on this, we can conclude that if the existing system, represented by the content of a pit with phenol-containing soil, is not subjected to special impact of cleaning it from phenol, then it will not be able to free itself from phenol in self-purification processes. Thus, soils with a low potential for self-purification and a high content (above the standard) of toxicants are subject to rehabilitation, neutralization and remediation.

After mixing the decontamination composition with phenol-containing soil a dry powdered decontamination product is formed as a result of exothermic lime hydration reaction. Research results of biological recultivation methods of soils contaminated with phenol indicate that the use of the above methods is impractical due to the high physical and material costs, as well as the long period (about a year) for soil detoxification [9,10].

In this regard, to normalize the environmental situation in the emergency area, we have developed a method for neutralizing soils contaminated with phenol [15]. The purpose was to simplify the method of neutralizing soils contaminated with phenol, reduce their detoxification time with ensuring ecological safety for the environment of their neutralization products. Environmental safety was seen in the absence of phenol in water extracts from soils and soils within MPC [16-18] and the achievement of pH value acceptable for environment during the purification process. For this purpose, we have used a chemical method of phenol inactivation based on its conversion into a compound weakly soluble in water - calcium phenolate, followed by immobilization of the latter in soil neutralization products. The chemistry of decontamination process of phenol using this method is expressed by two main reactions:

$$CaO + H_2O \rightarrow Ca(OH)_2 + 11164 \text{kJ/kg}$$

$$Ca(OH)_2 + 2C_6H_5OH \rightarrow\downarrow Ca(C_6H_5O)_2 + 2H_2O$$

In the proposed method, after mixing the neutralizing composition with phenol-containing soil after 5-10 minutes, an exothermic lime hydration reaction begins to form a dry powder neutralization product represented by lime microscopic capsules with soil components and immobilized phenol in the form of calcium phenolate. Over time, the material of the capsule in the form of calcium hydroxide is neutralized by the bentonite to form hydrophobic calcium silicate. Interaction reaction of lime with bentonite with the formation of hydrosilicates and calcium hydro-aluminates is consistent with the scheme:

$$SiO_2 + xCa(OH)_2 + H_2O \rightarrow xCaO \times SiO_2 \times (n + x)H_2O$$

calcium hydrosilicate

$$Al_2O_3 + xCa(OH)_2 + H_2O \rightarrow xAl_2O_3 \times SiO_2 \times (n + x)H_2O$$

calcium hydroaluminate

The resulting calcium silicate and calcium aluminate are characterized by hydrophobizing, cementing, and hardening properties [21]. Thus, high strength properties of the capsule shell and pH interval of their water extraction from 6.5 to 8.5 acceptable for the natural environment are ensured. The research into the neutralized phenol-containing soil for phenol content in water extracts showed that the proposed method is simple, environmentally safe, does not lead to repeated pollution of the environment with pollutants and ensures phenol content in soils within maximum allowable concentration.

In the exothermic reaction of quicklime hydration by chemical dispersion, calcium hydroxide is formed in the form of its aqueous solution and its suspension in the form of fine particles of finely dispersed crushing. The latter is precipitated in a crystalline form, evenly distributed in the soil. Calcium hydroxide in its aqueous solution interacts with phenol of soil solution to form calcium phenolate, which is hardly soluble in water. As for calcium hydroxide suspended in water calcium hydroxide suspended in water, it envelops soil particles together with calcium phenolate, forming the smallest capsules with calcium phenolate and soil components immobilized inside them. Granting this, the mechanism of chemical dispersion of $Ca(OH)_2$ is of great interest. Hydration reaction of CaO proceeds continuously, and owing to the limited solubility of $Ca(OH)_2$ in water (1.7 g/l at 0^0C) and a small amount of mixing water used, the supersaturated aqueous solution of $Ca(OH)_2$ is formed, following which the latter is continuously crystallized in a state of fine crushing.

As a result, continuous formation and dispersion of hydrated lime occur and numerous crystallization centers take place with the formation of $Ca(OH)_2$ granules. In this case, specific surface area of lime increases many times [22]. The main provisions of CaO quenching processes and two-phase "lime-water" system are reviewed. When quicklime is mixed with water, its hydration immediately begins on the surface of lime grains. Since calcium hydroxide is soluble in water, it immediately transferred into solution. The next layer of lime grains is uncovered, which also chemically interacts with water. This continues until the liquid turns into a saturated solution, after which the dissolution of $Ca(OH)_2$ becomes impossible, the insignificant fraction of lime is used for the formation of saturated solution. This period is called by the author as the period of surface hydration and dissolution of surface layers of the formed hydrated lime.

The second period is the chemical dispersion of calcium hydroxide. At that point, solid hydrated lime is directly released in small crushing form, forming a colloidal system in the form of a gel. Owing to the high exothermic nature of this reaction, the temperature increases rapidly, the reaction rate increases. New surfaces are formed. If the specific surface of quicklime is about a thousand or several thousands cm^2/g, then the specific surface of slaked lime is hundreds or several hundred thousands cm^2/g, increasing almost hundred times.

The new surfaces are hydrophilic and require more free water to moisture them. By adsorbing this water, the mass during this period thickens and from a liquid mobile-fluid state transforms into a pasty state at the stage of lime setting. Here we consider the option when quicklime is quenched with a relatively small amount of water in such a way that the heat of hydration is not withdrawn outside, but turns into steam of that part of free water that remains after the chemical reaction. These vapors break incipient crystalline structure, loosening the entire mass, slaked lime, and spread apart lime particles to a relatively large distances the entire mass, and create air gaps inside its mass. Thus, during the lime slaking process, when using only enough water to hydrate CaO and under conditions of rapid release of hydration heat, bulky, dry, extremely fine lime powder – hydrated lime is formed.

Theoretically, to slake lime into powder, 32 % mass of water is required. Practically, to obtain slaked lime powder, water is taken with a small excess of ~ 70-100% of the mass of quicklime. This is explained as being due to the fact that during slaking a significant amount of heat is released, additional water boils, and part of water is lost with evaporation.

Typical for real conditions in the place of concentration (location) of phenol-containing soil is its hyper humidity, the presence of excess water in its composition relative to the stoichiometrically necessary for soil encapsulation. Mixing water plays a key role in lime-soil mixtures at all stages of its interaction with their components. Necessary condition for this interaction is the presence of a sufficient amount of water in the soil solution or the introduction of an optimal amount of water into dry soil. Under only these conditions the exothermic reaction of lime hydration proceeds with the formation of a dry powdery decontamination product. Phenol in soil is transformed into a weakly soluble calcium phenolate, with further immobilization of soil neutralization products in its composition. Further strengthening of lime surface of capsules by the formation of hydrosilicates, hydroaluminates and due to its carbonization, calcium phenolate in the composition of strengthened capsule acquires irreversible stability and resistance to hydrolysis. At that, the lack of phenol in the water extract of neutralization products of phenol-containing soils is observed.

The process of hydrated, carbonization and hydrosilicate hardening has its effect on the hardening of slaked lime solutions. Hydrate hardening of solutions on quicklime is due to the interaction of CaO with water, the occurrence and crystallization of hydrate formations. Calcium hydroxide is released in a colloidal state, colloidal particles of $Ca(OH)_2$ aggregate, forming a coagulation structure which is gradually transformed into a crystallization one. Hardening is also affected by the process of its carbonization [23]. Experiments have shown that the process of carbonizing hardening occurs only in moistened lime in surface layers and almost completely finished under the effect of a dry carbon dioxide on a completely dry powder of hydrated lime. Carbonization proceeds intensively at a moisture content of products of 5-8%. The carbonization of deep layers is long-term, since CO_2 concentration in the atmosphere is just 0.04%, and the resulting $CaCO_3$ film has a low permeability. Therefore, in the central part of the $Ca(OH)_2$ layer, it remains unchanged for a long period. The carbonization process is consistent with the reaction scheme:

$$Ca(OH)_2 + H_2O + CO_2 \rightarrow CaCO_3 + 2H_2O + 82 \text{ кДж/kJ}$$

It is determined by carbon dioxide concentration in the air, the concentration of dissolved lime, and the size of contact surface of lime solution with air.

It is very important to emphasize that the developed method of soil detoxification is in keeping with the basic requirement to ensure the safety of already neutralized phenol-containing soil. This requirement comes from the above-described property of calcium phenolate, subject to hydrolysis in aqueous solution with the release of phenol. That is, for liming the soil, it is necessary to use a small but sufficient amount of mixing water. In this case, the neutralization products must be formed in a dry state. This is necessary to ensure reliable immobilization of phenol (in carbonization, silicification processes) without its release into the environment.

The analysis of phenol for the content of neutralized soil in the aqueous extract was carried out by its extraction method (water, chloroform), by determining the residual phenol in its composition using method of colorimetry [11]. It found that the neutralization method of phenol-containing soils provides phenol content within 1.0 mg/kg, which corresponds to MPC standards [16].

Conclusions

Phenol containing soils were studied on the territory of Padar station in the Hajigabul region of Azerbaijan, which was formed as a result of an accidental spill of phenol. Mineralogical and chemical composition of soils in the contaminated area was determined. This revealed that, accordinging to granulometric composition in clay rocks, on average, the fraction of sand, dust and clay is 17.0; 39.2 and 43.8% respectively. Density of clays in natural and dry state averages 1.89 and 1.54g/cm^3. The porosity of the rock is 43.71% and the porosity factor is 0.777. Proceeding from the data obtained on the composition of soils, it found that water filtration through the bottom and walls of the pit is difficult due to the fact that the water permeability of the soil layer surrounding the pit is closer to zero due to the clay rock. It is shown that the partial retention of spilled phenol within the accident site is explained by its relatively good solubility in water, as well as its absorptivity of the mineral components of the soil. An environmentally safe method has been developed for the neutralization of phenol containing soil with a detoxifying composition based on quicklime and bentonite, which ensures phenol content in the composition of the soil within 1.0 mg/kg, which corresponds to MPC standards and allows avoiding re-pollution of the environment by neutralization products.

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FENOLLA ÇİRKLƏNMİŞ TORPAQ-QRUNTLARIN ZƏRƏRSİZLƏŞDİRİLMƏSİ

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Xülasə:Fenolun qəza dağılmalarının nəticələrinin aradan qaldırılması üçün fenolla çirklənmiş torpaqların zərərsizləşdirilməsinin nəticələri təqdim olunur. Torpaq-qruntların fenolla çirklənmə zonasının geoloji-litoloji kəsiminin analizinə əsasən müəyyən edilmişdir ki, kəsilişin üst hissəsində təqribən 0.5m texnogen mənşəli torpaq-bitki qatının altında, qalınlığı 7.0 m-ə qədər olan gil qatı, sonra isə qrunt suları ilə doymuş qumlu təbəqə təşəkkül tapmışdır. Fiziki-mexaniki xüsusiyyətlərinə görə torpağın bərk mineral fazasının çətin plastik və yarımbərk konsistensiyalı gillərə uyğun olduğu müəyyən edilmişdir. Fenolla çirklənmiş torpaq-qruntun mineraloji və kimyəvi tərkibi müəyyən edilmişdir. Fenol tərkibli torpağın sönməmiş əhəng və bentonit əsasında zərərsizləşdirici tərkiblə zərərsizləşdirilməsinin ekoloji cəhətdən təhlükəsiz üsulu işlənib hazırlanmışdır ki, bu da fenolla çirklənmiş torpaqların zərərsizləşdirilməsi üsulunu sadələşdirməyə imkan verir. Ekoloji təhlükəsizlik torpaqlarda və torpaqların su sorumunda fenolun olmaması və təmizlənmə prosesi zamanı təbii mühit üçün pH məqbul olan qiymətə nail olunması ilə müşahidə olunur. Təklif olunan üsulun mahiyyəti fenolun suda həll olunmayan az hərəkətli birləşməyə – kalsiumun fenolyata çevilməklə kimyəvi inaktivləşdirilməsindən ibarətdir. Fenol tərkibli torpağın zərərsizləşdirilməsi məhsulu, kiçik kapsullarla təmsil olunan tərkibində torpaq hissəcikləri və fenolun kalsium fenolyat şəklində immobilizə edilməsindən ibarətdir. Kalsium hidroksidlə təmsil olunan kapsulun materialı zaman keçdikcə zərərsizləşdirici tərkibə daxil olan bentonit və havada olan CO_2 ilə neytrallaşdırılaraq müvafiq olaraq hidrofob kalsium silikat və karbonat əmələ gətirməklə kapsullara yüksək möhkəmlik xassələri verir. Zərərsizləşdirilmiş fenoltərkibli torpaq-qruntların su sorumunun tərkibində fenolun miqdarının təyini göstərir ki, təklif olunan üsul sadədir, ekoloji cəhətdən təhlükəsizdir, ətraf mühitin polyutantlarla təkrar çirklənməsinə səbəb olmur və torpağın tərkibində fenolun miqdarını buraxıla bilən hədd qatılığında təmin edir.

Açar sözlər: qəza dağılması, fenol, ekologiya, monitorinq, miqrasiya, fenol tərkibli torpaq, zərərsizləşdirmə.

ОБЕЗВРЕЖИВАНИЕ ПОЧВОГРУНТОВ ЗАГРЯЗНЕННЫХ ФЕНОЛОМ

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Аннотация: Для ликвидации последствий аварийного разлива фенола представлены результаты обезвреживания загрязнённых фенолом почвогрунтов. Анализом почвогрунтов по геолого-литологическому разрезу установлено, что в зоне загрязнения фенолом почвогрунт имеет поверхностно почвенно-растительный слой с толщиной около 0.5м, далее идёт мощный глинистый слой толщиной до 7.0м, затем прослеживается песчаный слой, насыщенный грунтовыми водами. Установлено, что по физико-механическим свойствам твердая минеральная фаза почвогрунта соответствует трудно пластичной и полутвердой консистенции глин. Определен минералогический и химический состав почвогрунтов загрязненных фенолом. Разработан экологически безопасный способ обезвреживания фенолсодержащего почвогрунта обезвреживающим составом на основе негашеной извести и бентонита, который позволяет упростить способ обезвреживания почвогрунтов, загрязненных фенолом. Экологическая безопасность усматривалась в отсутствии фенола в водных вытяжках из почв и грунтов и достижение в процессе очистки допустимой для природной среды величины pH. Сущность предложенного способа заключается в химической инактивации фенола, основанной на его переводе в малоподвижное, не растворимое в воде соединение – фенолят кальция. Продукт обезвреживания фенолсодержащего почвогрунта представляет собой мельчайшие капсулы, содержащие внутри себя частицы почвогрунта и иммобилизованный фенол в виде фенолята кальция. Материал самой капсулы, представленный гидроксидом кальция, со временем нейтрализуется входящими в обезвреживающий состав бентонитом и CO_2 из воздуха с образованием соответственно гидрофобных силиката и карбоната кальция, придающим капсулам высокие прочностные свойства. Исследование обезвреженного фенолсодержащего почвогрунта на содержание в водных вытяжках фенола показало, что предложенный способ является простым, экологически безопасным, не приводящим к повторному загрязнению окружающей среды поллютантами и обеспечивающим содержание фенола в почвогрунтах в пределах ПДК.

Ключевые слова: аварийный разлив, фенол, экология, мониторинг, миграция, фенолсодержащий почвогрунт, обезвреживание.