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INCREASING THE LEVEL OF ENVIRONMENTAL SAFETY OF DRILLING SLUDGE STORAGES

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Abstract. The main sources of soil pollution due to the development of oil and gas fields are analyzed. It is shown that the main sources of oil products entering the soil are sludge accumulators and drilling barns. A new construction of a drilling barn and a scheme of reclamation of the existing ones are proposed. The implementation of such developments will minimize the ingress of oil-containing fluids into the soil and increase the level of environmental safety of oil and gas development processes.

Key words: sludge barn; oil-containing fluids; soil contamination; sludge accumulator.

1. Introduction

Oil production in Ukraine has a very long history and dates back to the mid-nineteenth century. For almost two centuries, oil has been the main source of income for the population of western Ukraine. Oil deposits were found mainly in places of natural oil leaks on the bottom surface. Oil production was carried out with the help of so-called digging pits, some of which reached a depth of up to100 m. This method of oil production was replaced by the first wells, which were drilled by the percussion-rope method. The ditches were abandoned, and the essence of their elimination was that the mouth was covered with wooden boards and covered with clay. The process of construction of ditches was not controlled and was chaotic, no one kept records of such ditches. In the first wells drilled in the Prykarpattia fields, the annulus was not cemented. Very often, wells opened deposits with high reservoir pressures, which led to oil fountains and fires, which could not be eliminated sometimes for several months. Thousands of tons of oil were released into the soil and natural waters, millions of cubic meters of gas and combustion products of formation fluids were released into the atmosphere. As a result, since then, oil production has been accompanied by environmental pollution. Significant attention was not paid to environmental aspects. At the same time, the availability of work and income contributed to the settlement of people directly in the territory of oil and gas fields – Boryslav, Bytkiv-Babchensky, Dolynsky, North-Dolynsky, Bohorodchany, Ripnyansky, Podlasie and others (Skitsa et al., 2018; Mandryk et al., 2015). As a result, such deposits have formed industrial and urban agglomerations, the existence of which is dangerous due to the negative environmental consequences of irrational extraction of formation fluids and violation of the norms of the mutual location of industrial and residential facilities. Petroleum products in soils spread on the surface towards the slope of the terrain, penetrating into the soil horizons and loose sediments.

The extent of pollution is determined by the properties of the oil, the terrain, soil, hydrological conditions and the amount of the spilt reservoir fluid (Fig. 1). The formation fluid consists of petroleum components that are retained in the upper soil horizons and mineralized water that penetrates into the lower soil horizons. During the movement of oil components along the soil profile, sorption of asphalt-resin components of oil takes place, which leads to a decrease in the concentration of oil components in the lower soil horizons

The nature of the distribution of petroleum products in the soil profile depends on the following factors: morphological, structural, genetic features of the

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soil profile, the amount and composition of the spilt fluid, air temperature, the period elapsed since the oil spill. The main factors influencing the distribution of petroleum products in the soil are the water temperature regime and mechanical composition of the soil (Mandryk et al., 2015; Shkitsa et al., 2013).

Fig. 1. Soil pollution due to oil-containing fluid spillage

The duration and intensity of natural processes of soil self-purification depend on soil and climatic conditions, the intensity and the nature of the man-made load, the level of resistance of natural complexes, their stability. Self-cleaning of the soil from petroleum products can take decades. Agro-landscape complexes that have a much lower potential for self-cleaning compared to virgin lands are more sensitive to oil pollution.

To intensify the process of self-purification of the soil, bioremediation methods of purification are used.

They are based on the use of biological products which include adapted to pollutants active strains of destructive microorganisms, nutrients, mineral components and sorbents (Mandryk et al., 2015; Long X et al., 2012).

Distribution of oil components on soil horizons in the lateral and radial direction. Mineral bituminous and asphalt-resinous substances settle in the upper humus horizon, while low molecular weight soluble compounds penetrate deep into the soil, polluting groundwater.

Among abiotic factors, ultraviolet radiation plays a leading role in the destruction of alkanes and polycyclic hydrocarbons (Denysiuk et al., 2016; Heletukha et al., 2014).

Degradation of petroleum products on the surface and in the soil occurs in several stages, at each of which there are different natural processes.

At the first stage, which lasts 1–1.5 years, the following physicochemical processes are observed:

– distribution of oil components according to the soil profile;

– evaporation and leaching of oil components;

– ultraviolet decomposition of petroleum components;

– microbiological oxidation of compounds.

At the second stage of self-purification of soils, there are biochemical processes of oxidation of oil hydrocarbons to final products – water and carbon dioxide. There is a destruction of aromatic compounds and an increase in the proportion of resin-asphalt components. The oil components are an additional source of energy and form a specific biocenosis in this area, which has a characteristic trophic structure and energy metabolism.

2. Analysis of literature sources

Petroleum products as part of drilling waste enter the soil by penetrating through the protective walls of the barn structure. Our proposed improved design of the oil sludge barn makes it possible to slow down the penetration of drilling waste containing petroleum products through the protective walls into the profile of the soil cover. Besides reducing the level of soil contamination, there is a possibility of further use of the surface of the oil sludge barn, including agricultural activities. This design improvement can be used for any drilling work, in activities involving the reclamation of areas affected by pollution due to emergencies, as well as areas that have degraded due to the migration of pollutants associated with the drilling process.

In modern conditions of the development of oil production technology during the operation of oil fields, in particular, drilling wells, significant amounts of waste are generated, most of which is accumulated in sludge barns (Fig. 2). During operation, barns are filled with drilling and grouting solutions, formation waters, drilling wastewater and sludge, well test products, materials for preparation and chemical treatment of drilling and grouting solutions. The main types of washing liquids include foam, water and solutions: clay, natural from non-clay rocks, oil-based, emulsion, controlled. Bentonite and paligorskite clay powders are integral components of the washing liquid. Weights such as barite and hematite acidity regulator, caustic soda solution are also used. Among the surfactants used are the following: oxyethylated alcohols, sulfonal, disolvan, zhirinox, stearox, neon and savenol. Emulsifiers, stabilizing reagents, diluents, defoamers, corrosion inhibitors are also used. The discharge of special-purpose flushing fluids, in particular, soda-based is especially environmentally hazardous.

Drilling mud consists of spent drilling fluids together with drilled rock. It contains an average of 58–82 % of the drilled rock, 12 % of organic matter, up to 8 % of water-soluble salts of weights, clay, and sometimes oil. Drilling mud is a contaminant due to the presence of organic impurities.

During the operation of the well to the average depth, in the barn there is about 65 % water, 30 % drilled rock, 5.5 % oil, 0.5 % bentonite and 0.5 % various additives that ensure optimal operation of the drilling rig. The concentration of petroleum products in the sludge ranges from 200 to 13870 mg/kg.

The contaminating capacity of drilling fluids depends on the amount and toxicological characteristics of the chemical compounds used for their treatment. Class 3 and 4 hazardous substances are used when drilling wells. The drilled rock is non-toxic in its composition, but when dispersed in the drilling fluid medium, its particles absorb toxic compounds on their surface and can adversely affect the biotic and abiotic component of the environment. During the operation of the well, drilling solution and drilling mud have a negative impact on the environment. Therefore, the problem of liquidation of sludge barns with the subsequent reclamation of the soils of the well-drilling territory is especially acute.

a) b) c)

Fig. 2. General view (a-c) of drilling and sludge barns

Active contamination of the surface layer of the soil with petroleum products occurs during the violation of the geological environment in oil production. In this regard, an important part of the measures is the creation of waste storage facilities that will slow down the spread of oil pollution of the soil and allow in the future to use the oil production area with minimal impact on the environment (Heletukha et al., 2013).

Today, the following methods are used to reduce soil contamination: the use of soil-cement, waterproofing, biological utilization and the use of a combination of protective walls. Soil-cement, as an anti-filtration screen of sludge barns, is used to create waterproofing of sludge barns, drilling waste and operation of oil and gas wells. Soil-cement is a mixture of clay soil, cement and water (Abrosimov et al., 2002).

The disadvantages of this method are its unreliability, high probability of wall breakage, subsidence of the upper part in the conservation process, coming the barn filling to the surface, the impossibility of further use of the barn.

Waterproofing of storage barns and disposal of drilling waste during the construction of the well is to create a drilling barn “Anti-filtration screen”, the essence of which is to equip storage barns with the anti-filtration screen. A composite material based on a synthetic fabric modified on both sides with a polymer-bitumen binder with high thermoplastic and waterproofing properties is used, which is placed in the form of canvases across the bottom of the storage barn. The webs of the composite material are hermetically sealed together by surfacing, forming a strong frame. Due to the conversion of drilling waste from the semi-liquid phase to the solid, the edges of the composite material are wrapped and by sealing additional webs, solid, sealed containers-storages of drilling waste are formed (Aliєv et al., 1981). The disadvantages of this method are the unreliability of anti-filtration screens, the need for additional waterproofing and the short service life of the structure.

The purpose of the article is to propose measures to minimize the impact of technological waste on the environment based on the analysis of the causes of soil contamination and existing structures of oil sludge barns.

3. Results and Discussion

The method of using combined walls is that when creating an oil sludge barn, combined walls are used, which consist of different types of soil. Only the alternation of soil types with different throughput is considered – from the most to the least dense soil types. Clay types of soils are used for external walls, soils with a medium density of forest and carbonate loam – for intermediate walls, and fine sand – for the most active layer of isolate.

The disadvantages of this method are the impossibility of reclamation of existing facilities, as well as the need to use resources for walls that are not inherent in the territory.

Biological utilization as the most common method of elimination of hydrocarbon pollution involves treatment of an array of oil-containing substances, formation waters, shoreline and bottom sediments of oil sludge barns with biological and chemical substances. At least one concentrated hydrocarbon degradation biocatalyst, sorbent or leavening agent, biological hydrocarbon assimilation catalyst, and buffer stabilizer are added sequentially to the hydrocarbon mass of the oil sludge barn throughout the volume, and the homogenized microorganism preparation is added to the homogenized microorganism of dextrose.

A feature of our development is the use of shock-absorbing walls and barn lids with a special structure in creating an oil sludge barn. The walls will consist of a three-layer protective block, the inner layer of which is a kind of shock absorber, and the cover provides for the use of agro fibre. To enhance the biologically renewable processes of pollutants during the filling of the oil sludge barn, filler is gradually added in a ratio of 2.5:1.

With all existing methods, it is not possible to completely rehabilitate drilling barns or sludge storages in order to restore human economic activity in the burial area.

The main advantages of the method proposed in the dissertation are:

– the ability to use the method in any climatic conditions;

– economic feasibility, as the cost of the proposed method is lower compared to the existing analogues;

– the possibility of further use of the surface of the oil sludge barn;

– use of waste from other industries, which will reduce the burden on the environment.

Our study is based on the task of creating an oil sludge barn that would minimize the destructive impact of the environment, in particular, on vegetation, and allow further use of the soil surface for various economic purposes.

An important advantage of our proposed development is the possibility of its application in any parametric and temporal variations required by the designer. The dimensions of oil sludge barns, their volume, profile, depth and height are determined at the stage of working design, according to the specific area of the well construction, considering the category of soil and the depth of groundwater.

The construction of a drilling mud barn begins with the removal of the fertile layer of soil and its storage in temporary dumps with the subsequent digging of an earthen pit to store clay soil. The next stage is the construction of anti-filtration walls. When creating an oil sludge barn, it is necessary to use shock-absorbing walls which consist of three types of soil. In our proposed version, it is necessary to use soil types that have different throughput properties, starting with the densest and ending with soils with medium density (Davydova,Tahasov, 2004).

The proposed model of the construction of the drilling barn will slow down the spread of hydrocarbon pollution. At the same time, the soil layers that will be used for the sides of the structure will contain hydrocarbons and related chemicals, gradually reducing the level of distribution of substances to unpolluted areas not involved in man-made activities.

To create the outer walls of barns, it is necessary to use soils with medium density, such as loess, loess and carbonate loams and sands, to create intermediate walls – variously dispersed sand of different types, or soil types with a sand content of 37 %, to create the most active layer of the isolate – the densest clay soil types (Davydova,Tahasov, 2004).

It has been experimentally established that the sorbent should be added in a ratio of 2.5:1 relative to the content of the contaminant, as this amount will have the highest absorption efficiency. In the case of adding a smaller amount of sorbent in the experimental model, there is an increase in unbound fractions of hydrocarbons and direct drilling waste (drilling fluids and various types of chemical softeners). When adding more sorbent, an overload of oil sludge barn was recorded and a significant loss of working volume was detected, which leads to an increase in the initial size of the structure, which is an important negative factor not only from an ecological but also from an economic point of view. Therefore, the amount of sorbent to the pollutant in a ratio of 2.5:1 allows us to achieve the maximum environmental and economic effect.

Physical and chemical properties of the sorbent will stimulate reclamation and increase the possibility of the future use of the territory, reduce the risks of leakage, prevent subsidence of the surface of reclaimed barns, allow the use of the barn as an agricultural object. The maximum possible level of subsidence caused by the active use of the barn area will be no more than 15 cm. The principle of the arrangement of the developed ecological modification of the oil sludge barn is shown in Fig. 3.

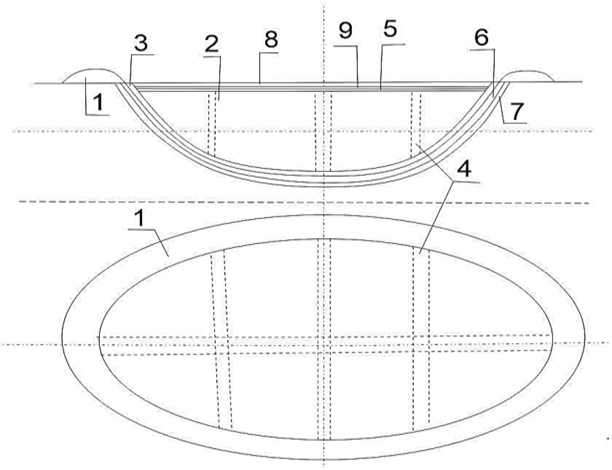

Fig. 3. Schematic representation of the oil sludge barn (modified for reclamation from the beginning of operation): 1 – outer wall; 2 – intermediate wall; 3 – inner wall; 4 – board of the oil sludge barn; 5 – absorbent with drilling waste; 6 – inner wall; 7 – removed soils

The study found that the sorbent in waste storage facilities has high binding properties and promotes reclamation processes, so the top layer of soil which will act as a barn lid will be suitable for further use.

It is important to note that oil sludge barns are a major environmental problem as extensive areas allocated for their placement lose their functional properties. The sludge formed in the process of wastewater treatment has the properties of fertilizer but is not actively used and it is mostly accumulated in the sludge dump, which is not effective in terms of sustainable development and sustainable use of nature. This aspect has become one of the reasons for the use of waste treatment plants to restore the area allocated for oil sludge barn.

It is proposed to use energy willow and Jerusalem artichoke to restore oil-contaminated soils. Energy willow is characterized by rapid growth and accumulation of biomass. It is used as a biofuel and phytomeliorant of the environment. This species effectively absorbs carbon dioxide, produces oxygen due to the large area of contact of photosynthetic organs with the environment. Energy willow is sensitive to weeds and pests. Experience in growing this species is available in some European countries, including Denmark, Sweden, Poland, England, Austria, Hungary, Romania and Serbia. In Ukraine, energy willow plantations are in Ivano-Frankivsk, Volyn, Lviv, Ternopil and Rivne regions. The survival rate of planting material is not less than 85 %. The growth of willow seedlings in the first year after planting is highly dependent on weather conditions.

The benefit from energy willow is also that 60–80 % of nutrients return to the soil along with the fallen leaves. Energy plantations prevent soil erosion and improve the quality of the environment. They are used to strengthen soils, enrich the soil with mineral elements and trace elements. Energy willow is ideal for planting contaminated and unproductive lands in terms of growing crops. Energy willow plantations are a natural filter for the removal of agro-industrial waste, cleaning soils from pesticides, phosphorus and nitrate fertilizers. They are used as buffer zones in the places of accumulation of the biological waste of farms, for remediation of the sludge of city sewage. Energy willow removes some heavy metals from the ground.

According to some authors, this species belongs to plants eliminators of heavy metals and with the growth and development of the plant the bioavailability of metals decreases. Other publications suggest that energy willow has a unique ability to absorb, deactivate and accumulate large amounts of heavy metals without reducing growth processes. According to these data, the plant is classified as a heavy metal hyperaccumulator. Thus, compared to other battery plants, willow accumulates more metals per unit of dry weight. Important metals are localized in different parts of the plant. In particular, lead, chromium and copper are mainly accumulated in the aboveground part as they have greater mobility. The leaves of the species accumulate the most zinc, chromium, lead, arsenic, stanum, while the roots – molybdenum, copper, nickel, zirconium, barium and iron.

When the species grows in heavily contaminated areas with heavy metals, plants show high tolerance as they accumulate metals in underground organs much more intensively than when growing on lightly contaminated soils (Cristaldi et al., 2017). This adaptive ability to block the movement of critical concentrations of metals in aboveground organs allows the plant to develop normally under extreme stress. In addition, the accumulation of metals is much more intense in the lower parts of the aboveground organs than those located above. These protective mechanisms confirm the high resistance of the species to the toxic effects of pollutants.

The biological diversity of flora and fauna is improving around the plantations. Energy willow is a highly translucent plant. It grows well on wetlands and is used to drain these swamps. It is known that energy willow can grow on soils of different types, wetlands and unproductive lands, reclaimed lands of open mines, contributing to the formation of humus. A positive property of willow is resistance to frost, pests and diseases. Of course, on low-quality lands, the culture does not grow as fast as in favourable conditions, but a well-developed root system facilitates intensive growth.

The heat of combustion of dry willow energy is equal to the heat of combustion of coniferous trees (18.5 mJ/kg), which provides energy independence and an alternative to natural gas. In addition, the species can be burnt without additional processing and pre-drying, which saves resources. During combustion, as much carbon dioxide is released into the atmosphere as was absorbed during photosynthesis during the growth. The calorific value of herbaceous plants is lower compared to woody ones. Herbs contain a lot of alkaline elements and have a high ash content. Thus, woody plants and shrubs have a significant energy advantage over herbaceous ones. The condition for the growth of energy willow is a sufficient amount of precipitation and a high level of groundwater. Slightly acidic soils with a pH of 5.5–6.5 are optimal for the growth of plants.

The rapid growth of energy willow is one of the most important criteria for the suitability of the species for remediation of oil-contaminated areas. However, the question of the effectiveness of the restoration of oil-contaminated soil with the help of energy willow is still poorly studied. According to some authors, energy willow can significantly accelerate the development and reproduction of microorganisms that detoxify chlorine-containing and aromatic hydrocarbons present in oil and petroleum products. This is due to the activation of genes of microorganisms by so-called secondary plant metabolites, terpenes and phenolic molecules. In addition, symbiotic bacteria can stimulate the entry of toxicants present in the oil and in the roots of plants. In the future, there is an accumulation of toxicants in plant organs, their transformation into simple and harmless compounds or detoxification into gaseous substances released by the plant in the process of gas exchange. Microorganisms that enter symbiotic relationships with species belonging to the Willow genus belong to the following orders Actinomycetales, Rhodospirillales, Burkholderiales, Alteromonadales, Solirubrobacterales, Caulobacterales, and Rhizobiales. Our research showed that energy willow seedlings were planted on the oil-contaminated soil in the territory of Bytkiv-Babchensky oil field (Fig. 4).

Fig. 4. Plantation of Salix viminalis L. in the conditions of oil and gas field

During their planting, heavy rains were observed, and the soils of the experimental area were heavily moistened. This, in our opinion, has led to the growth of 95 % of seedlings of the species in the field. However, high air temperatures and infrequent rains in the summer of 2018 became an obstacle to the full development of energy willow seedlings and led to the drying of plants at the juvenile stage of development. Thus, the weather became the limiting factors for the growth of energy willow on oil-degraded lands. For the full development of plants, it is necessary to carry out additional watering of energy willow plantations in the dry season.

Alfalfa (Medicago sativa L.) is a representative of the legume family which is widespread in Ukraine. It has a well-developed root system and enriches the soil with nitrogen. Its rhizosphere creates favourable conditions for the development of microorganisms that destroy oil and petroleum products. The species can tolerate low concentrations of oil and accelerate the decomposition of its toxic components through the rapid development of symbiont microorganisms. However, medium and especially high concentrations of petroleum products in soils inhibit the growth and development of alfalfa and lead to the appearance of necrotic assimilation lesions.

In the conditions of the oil field, only 20 % of the seeds of alfalfa were sown, and the rest died and did not germinate (Fig. 5, *a*).

The results of our research have shown that the cultivation of alfalfa on the oil-contaminated soil has a negative effect on the plant, delays its growth and development.

According to some authors, the application of organic compost significantly increases the efficiency of absorption of pollutants present in the oil and stimulates the development of symbiont microorganisms and even the appearance of earthworms in the soil.

Jerusalem artichoke (Helianthus tuberosus L.) is one of the leading bio-energy crops used as a technical, fodder and food plant. It is a raw material for ethanol production, as well as an effective phytomeliorant of the environment. Jerusalem artichoke has high winter hardiness, can withstand short-term droughts as it absorbs moisture from deep soil layers.

It is the drought resistance of the plant that contributed to the fact that Jerusalem artichoke seedlings under the influence of the oil field successfully germinated and took root. Jerusalem artichoke is able to create competition and completely displace weeds, including Sosnowski's hogweed. The species grows even in landfills and low-fertile soils.

The area of leaves of the Jerusalem artichoke plantation is twice as large as compared to the 50-year-old deciduous forest. It enriches the air with oxygen, absorbs nitrates, heavy metals from the soil and is used to fight radionuclides. A hectare of the green mass of Jerusalem artichoke absorbs twice as much carbon dioxide from the atmosphere as a hectare of forest. Harmful substances are concentrated in the green mass, while in the root itself, they almost do not accumulate. All the above unique properties of the plant serve a reason to consider the species suitable for the restoration of the man-made environment.

a) b)

Fig. 5. Sprouted individuals of Medicago sativa L. in the oil field (a) and Helianthus tuberosus L. under the influence of oil and gas field (b)

Under the influence of the Bytkiv-Babchensky deposit, good development of individuals of the species is observed, which is manifested in the intensive growth of vegetative organs, both photosynthetic and underground.

The use of silt will not only rehabilitate barns but also reduce the area used for sludge, which is a direct economic benefit for treatment plants in any locality, as well as for mining companies. The proposed method allows us to start the process of reclamation of technical structures (drilling barns, sludge storage) in the process of their use, which provides a direct economic effect. It solves the problem of large-scale ash dumps which also cause the degradation of environmental components.

The design of ecological modification of the oil sludge barn developed by us can be used in any territory, in particular, where exploratory drilling and extraction activity is carried out, regardless of the natural and climatic conditions of the area. From an engineering point of view, the proposed modification is characterized by economic benefits and ease of implementation.

4. Conclusions

1. Under conditions of oil pollution, the growth and development of woody plants slow down, which is manifested in a decrease in area, linear foliar parameters, the appearance of necrosis, increase in the pH of the intracellular environment and reduction of the stability of the leaf buffer system. Tree species are characterized by unequal resistance to stressful growth conditions, which is explained by the individual ecological potential of plants and the ability to adapt to pollution.

2. The results of the research solve the problem of migration of oil products from drilling barns into the soil profile, which allows to increase the level of ecological safety, as well as to develop the way of further use of reclaimed areas. The design of combining the walls of the drilling barn with the addition of sorbent (ash) has been developed, which will solve the problem of primary contamination of the soil cover due to migration of oil, oil products and drilling waste from the drilling barn into the soil profile.

3. The introduction of effective reclamation of oil sludge barns will not only reduce the migration of hydrocarbons, reduce the area used for waste storage, but also allow further exploitation of areas allocated for the construction of this type of structures. This will improve the ecological state of the environment and increase the level of environmental safety.

It is proposed to use energy willow and Jerusalem artichoke to restore oil-contaminated areas.

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