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HYDROCARBON CONTAMINATION OF SOIL COVER IN CASE OF EMERGENCY LEAKS FROM OIL AND GAS PIPELINES: ANALYSIS OF THE PROBLEM STATE

ВУГЛЕВОДНЕВЕ ЗАБРУДНЕННЯ ҐРУНТОВОГО ПОКРИВУ ПРИ АВАРІЙНИХ ВИТОКАХ З НАФТОГАЗОПРОВОДІВ: АНАЛІЗ СТАНУ ПРОБЛЕМИ

Herasymenko B. V. / Герасименко Б. В.
Postgraduate 185 - Oil and gas engineering and technologies /
аспірант 185 - Нафтогазова інженерія та технології.
ORCID 0009-0001-5582-9057
Ivano-Frankivsk National Technical University of Oil and Gas
76019, str. Karpatska, 15. Ivano-Frankivsk, Ukraine
Івано-Франківський Національний Технічний Університет Нафти і Газу
76019, вул. Карпатська, 15. Івано-Франківськ, Україна

Abstract. *The object of the research is the hydrocarbon contamination of soil cover in case of emergency leaks from oil and gas pipelines. The oil and gas industry is one of the main sectors of Ukraine's economy. However, the transportation of oil and gas through pipelines involves the risk of accidental leaks that can lead to significant soil contamination. Finding ways to minimise the risks associated with the production, transportation and use of oil and gas is impossible without studying and analysing the state of the problem of oil pollution. Through a systematic analysis of the literature, this paper conducts a comprehensive study of a number of issues related to hydrocarbon contamination of soil in the event of accidental leaks from oil and gas pipelines and identifies problematic issues on this topic.*

A systematic thematic bibliographic review was used to conduct this review study. The Scopus database was chosen as the main portal for searching for publications. At the same time, a limited search in the Google Scholar database was used for original queries. It has been established that although the oil industry plays a key role in the global economy, it is one of the most powerful sources of environmental pollution. Processes such as the extraction, transportation, storage and marketing of oil and its derivatives have a significant impact on the environment, leading to profound changes in all its aspects. The complexity of this issue lies not only in the scale of oil spills, but also in the formulation of assessment standards and mitigation strategies for this temporary pollution.

Based on the results of the study, we conclude that oil seeping into the soil cover leads to the following consequences: changes in the chemical composition of the soil, changes in the composition of soil humus, and significant disruption of the soil microbiota. It also leads to inhibition of photosynthetic activity of plant organisms, which primarily affects the development of soil algae, and a negative impact on soil fauna, leading to their mass extinction.

Keywords: *soil, pollution, oil and gas leakage, hydrocarbon pollution, accidents, oil and gas pipelines.*

1. Introduction

Hydrocarbon pollution is one of the most challenging environmental problems of our time, primarily due to its widespread distribution, numerous sources of pollution and the specific danger it poses to environmental components [1, 2]. This issue becomes particularly acute in emergency situations related to the production, processing, transportation, storage and sale of hydrocarbons [3].

The environmental hazard of soil contamination with hydrocarbons is caused by their inherent properties, such as toxicity, carcinogenicity and bioaccumulation,

which pose a threat to living organisms. This type of pollution negatively affects respiratory activity and microbial self-purification processes, changes the balance between different groups of natural microorganisms and metabolic pathways, interferes with nitrogen fixation, nitrification and cellulose decomposition, leading to the accumulation of highly oxidised products [4–7].

The natural transformation of hydrocarbons in the soil is a complex and lengthy process, which makes diagnosing their toxic effects on the soil ecosystem an extremely important task [8]. To assess the impact of hydrocarbon pollution on environmental aspects of the environment, it is recommended to use a comprehensive set of indicators covering chemical, biological and toxicological parameters. Analysis of these indicators will help to establish the current state of pollution and assess environmental risks.

Currently, a lot of scientific research has been devoted to the problem of hydrocarbon soil contamination [9–13]. The authors investigated the negative impact on soils, vegetation, air, surface and groundwater, and human health at all stages of commercial oil field development, including drilling, processing, storage, transportation and disposal of equipment. Aquatic and terrestrial ecosystems bear the brunt of these impacts, with soil being the main target for oil pollution among terrestrial components. Due to their significant adsorption capacity, oil and its derivatives remain in the soil for a long time, leading to soil degradation and the potential danger of pollutants entering the food chain, of which humans are a critical link. The natural process of soil self-cleaning is complex and time-consuming, and it does not always lead to complete restoration of the soil ecosystem [14–16].

The purpose of the study was to conduct a comprehensive study of a number of issues related to hydrocarbon soil contamination in the event of accidental leaks from oil and gas pipelines, and to identify problematic issues on this topic through a systematic analysis of the literature.

2. Materials and Methods

A systematic thematic bibliographic review was used to conduct this review study. The Scopus database was chosen as the main portal for searching for publications. At the same time, a limited search in the Google Scholar database was used for the original queries, a systematic thematic bibliographic review. The Scopus database was chosen as the main portal for searching for publications. At the same time, a limited search of the Google Scholar database was used for the original queries. In addition, we searched the bibliography of each article to include more studies related to the topic. In total, more than 100 publications were analysed. The sources studied were classified according to their focus. The study included publications that cover aspects related to the study of soil conditions around accidental leaks from oil and gas pipelines.

3. Results and Discussion

Oil and petroleum products are the top priority environmental pollutants due to their toxicity, significant dispersion and high migration potential. Pollution of natural ecosystems, including soil cover, occurs as a result of the development and operation of oil fields, as well as violations of hydrocarbon transportation rules [17–19].

It is widely recognised that hydrocarbon pollution disrupts both the structure and

functions of soil ecosystems, reduces land productivity and changes the morphological, physical, chemical and biological properties of soils [20, 21].

Researchers have identified various morphological changes in hydrocarbon-contaminated soils. These changes include a darker hue compared to uncontaminated soils, increased density, the presence of oil films, the formation of columnar structures in the lower part of the soil profile, and an increased glazing effect [22–24]. Typically, hydrocarbon-contaminated soils have a colour ranging from black and grey-brown in the upper part of the profile to dark brown, brownish brown and brownish ocher in the lower part of the profile. The discolouration of the soil surface caused by the coating of soil particles with oil films leads to a decrease in spectral reflectivity. In addition, soil discolouration increases its heat absorption. The distribution of oil and oil products in the soil profile depends on soil characteristics and oil composition, including the ratio of high and low molecular weight components [25–27].

Laboratory studies have shown that the main processes that determine the vertical migration of hydrocarbons are soil sorption and permeability. As soil density increases, the amount of adsorbed oil increases [28].

As soil moisture levels increase, oil absorption decreases, while the depth of vertical oil migration increases [29-31]. In soils of sandy texture, oil ingress triggers an active migration process, which leads to further accumulation in the lower soil horizons and infiltration into both soil and groundwater [32].

A series of laboratory tests was conducted to study the effect of crude oil on the engineering properties of sand and kaolinite mixtures with different weight ratios of clay to sand. Mixtures with a weight ratio of 10 %, 30 % and 50 % kaolinite to sand contaminated with different crude oil contents (including 0 %, 4 %, 6 % and 8 % by dry weight of soil) were considered. In the low clay samples, the addition of crude oil decreased the internal friction angle, while in the high clay samples, the friction angle increased. The SEM images showed that the crude oil contamination led to the aggregation of clay particles and the formation of a flocculent structure with a larger number of macropores. The results show that the maximum dry density, optimum water content, permeability, and pH value decrease with increasing contamination [33].

Leaks of oil products containing a significant amount of heavy hydrocarbon fractions lead to the formation of a thick, sticky bitumen layer on the soil surface. The soil saturated with oil products loses its ability to absorb and retain moisture, which leads to a decrease in hygroscopic moisture, water permeability and moisture retention capacity [34, 35].

The adsorption of hydrocarbons on soil particles prevents the movement of mobile forms of nutrients such as nitrogen, phosphorus and potassium into solutions, which leads to a decrease in the availability of mineral nutrients for plants. Oil pollution changes the amount and ratio of both macro- and microelements. In particular, the ratio of carbon to nitrogen increases significantly due to the presence of oil carbon, which negatively affects the nitrogen balance in soils [36]. In addition, oil has a detrimental effect on bacteria, which play a crucial role in the nitrogen cycle [37].

Oil contamination of the soil leads to reorganisation of the soil absorbing complex, which causes a change in the alkalinity or acidity of the soil. Initially acidic and slightly acidic soils tend to become more alkaline, while soils that are close to neutral or neutral may experience acidification, with a decrease in pH of 0.1–0.3 units. For example, in the case of an initially neutral meadow-alluvial soil, acidification of the soil solution by 0.8–1.6 pH units was observed as a result of oil pollution [38].

Oil contamination also affects the biological characteristics of soils, leading to an imbalance between most soil enzymes and a negative impact on soil microorganisms [39].

It has been found that aromatic hydrocarbons inhibit enzyme activity, while paraffinic hydrocarbons stimulate it. Changes in the activity of soil enzymes generally correspond to changes in the microbial population.

Hydrocarbon oils affect microorganisms by changing the physical and chemical properties of the soil. This includes a decrease in the availability of mineral nutrients, deterioration of water and air, changes in the pH and structure of the soil environment, as well as direct toxic effects associated primarily with volatile aromatic hydrocarbons such as benzene, toluene, xylene, as well as naphthalene and some other water-soluble compounds. This is how oil pollution affects the biological properties of the soil [40].

Studying the literature on this issue, we noticed that the impact of oil on the complex community of soil microorganisms has its own nuances. For example, the impact of oil pollution can vary, stimulating the growth of some species and inhibiting the development of others. This depends on factors such as the concentration and composition of the pollutant, as well as the biological characteristics of the organisms concerned. Actinomycetes, nitrifiers and cellulose-degrading microorganisms are the most vulnerable to oil pollution. Despite the decline in the number or complete loss of the most vulnerable segments of the soil microbial community, there is a simultaneous increase in the population of oil-oxidising microorganisms and micromycetes that use oil hydrocarbons as a nutrient substrate.

Studies [41, 42] report an increase in the number of phytopathogenic and phytotoxic soil fungi, and the accumulation of potentially dangerous and allergenic species for humans.

The response of soil algoflora to oil pollution is a mirror image of the response of microflora. The lowest concentration of oil (0.01 %) stimulates the growth of green algae species such as *Chlorella homosphaera* and *Chlorella vulgaris*, showing an increase of 16 % and 15 %, respectively. Conversely, a higher concentration (0.3 %) leads to a significant decline, reducing their numbers by 15 % and 20 %. Among the algae, representatives of cyanobacteria, in particular Nostoc punctiforte, *Nostoc linckia, Anabaena oscillarioides, Phormidium autumnale* and *Plectonema gracillimum*, demonstrate the highest resistance to oil products and dominate in contaminated soils [43].

Mesofauna is also affected by hydrocarbon soil pollution. It has been established that earthworms, millipedes, mollusks, adult insects and their larvae are the most

vulnerable components of the ecosystem to soil hydrocarbon pollution. Among them, mollusks have demonstrated the highest sensitivity, and millipedes of the Chilopoda class have shown significant resilience, being able to survive in environments with more than 20 % oil contamination. Earthworms, spiders and insects occupy an intermediate position in terms of tolerance to such pollution [44].

The impact of oil pollution on plants is manifested in two main ways: directly, through the penetration of oil components through the root system or leaf stomata and their integration into metabolism, and indirectly, through changes in the physical and chemical composition of the soil, which leads to a violation of its biotic properties. The penetration of liquid fractions of oil products into the plant organism through the root system can cause mutagenic reactions and morphogenetic and phenological deviations from normal development [45].

Studies show that low concentrations of oil in the soil (up to 5 %, according to various sources) generally do not have a significant impact or may even stimulate plant growth. Such stimulation can be observed through increased germination, increased biomass, elongation of the aboveground or underground parts and increased chlorophyll content in the leaves. However, when the oil content in the soil increases further, a pronounced inhibitory effect or complete plant death usually occurs [46].

Thus, although the oil industry plays a key role in the global economy, it is one of the most powerful sources of environmental pollution. Processes such as the extraction, transportation, storage and marketing of oil and its derivatives have a significant impact on the environment, leading to profound changes in all its aspects. The complexity of this issue lies not only in the scale of oil spills, but also in the formulation of assessment standards and mitigation strategies for this temporary pollution.

Discussion:

Practical implications. The results obtained in the course of the study can have several practical applications in various fields. Firstly, it is worth noting that the comprehensive set of indicators proposed in the study, covering chemical, biological, and toxicological parameters, can be used for environmental monitoring and assessment of hydrocarbon soil contamination. These indicators can assist environmental agencies and organizations in determining the current state of contamination, identifying polluted areas, and accurately assessing environmental risks.

Equally important is the investigation of mechanisms of hydrocarbon migration, soil contamination, and its impact on soil properties, which can aid in the development of effective restoration strategies. Methods such as soil flushing, bioremediation, phytoremediation, and soil amendments can be adapted based on the specific characteristics of the contaminated site as identified in the study.

The understanding gained of changes in soil properties, nutrient availability, and microbial communities resulting from hydrocarbon contamination can serve as a guideline in soil management practices. Farmers, land managers, and agricultural scientists can use this information to mitigate the impact of contamination on soil fertility, crop productivity, and ecosystem health.

Studying the ecological consequences of hydrocarbon contamination for soil

organisms, including microorganisms, algae, mesofauna, and plants, enables the development of risk assessment models for predicting the long-term effects of contamination. This information can help prioritize restoration efforts, effectively allocate resources, and minimize potential risks to human health and the environment.

Study Limitations. Most of the analyzed research results were conducted on a laboratory scale or under controlled conditions, which may differ from the results obtained in real-world conditions.

Impact of Martial Law Conditions. At this stage of the research, the conditions of martial law did not influence the research results.

Prospects for Further Research. The obtained results enable the formation of a comprehensive and contemporary understanding of soil hydrocarbon pollution, encompassing its diverse impacts on soil properties, microbial communities, flora, and fauna. Initiating further research in this field can lead to the development of comprehensive algorithms aimed at mitigating the environmental consequences of hydrocarbon pollution.

4. Conclusions

Today, petroleum products are among the most widespread and hazardous substances in regions affected by human activity. The risk of environmental pollution by crude oil and its derivatives is significant and extends beyond the areas of oil production and refining. This problem transcends regional boundaries and is of global significance due to the widespread storage and transportation of oil and oil products. Oil spills as a result of emergencies are widespread around the world, making any area vulnerable to such pollution. All components of oil and oil products are toxic and often have carcinogenic properties.

Overall, the practical application of the research results can have a significant impact on environmental management, policy development, and sustainable development efforts aimed at mitigating the negative impact of hydrocarbon pollution on soil ecosystems and human well-being. They can also serve as a basis for further research in the field of studying the impact of hydrocarbons on soil ecology

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Анотація. *Об'єктом дослідження є вуглеводневе забруднення ґрунтового покриву при аварійних витоках з нафтогазопроводів. Нафтогазова промисловість є однією з основних галузей економіки України. Однак транспортування нафти та газу по трубопроводах пов'язане з ризиком випадкових витоків, які можуть призвести до значного забруднення ґрунту. Пошук шляхів мінімізації ризиків, пов'язаних з видобутком, транспортуванням і використанням нафти та газу, неможливий без вивчення та аналізу стану проблеми нафтового забруднення. У роботі шляхом систематичного аналізу літератури проведено комплексне дослідження ряду питань, пов'язаних із забрудненням ґрунтів вуглеводнями при аварійних витоках з нафто- і газопроводів і виявлено проблемні моменти з даної теми.*

Для проведення оглядового дослідження використано систематичний тематичний бібліографічний огляд. Основним порталом для пошуку публікацій обрано базу даних Scopus. Водночас для оригінальних запитів використовувався обмежений пошук у базі даних Google Scholar. Встановлено, що хоча нафтова промисловість відіграє ключову роль у світовій економіці, вона є одним із найпотужніших джерел забруднення навколишнього середовища. Такі процеси, як видобуток, транспортування, зберігання та продаж нафти та її похідних, мають значний вплив на навколишнє середовище, що призводить до глибоких змін у всіх його аспектах. Складність цього питання полягає не лише в масштабах розливів нафти, а й у формулюванні стандартів оцінки та стратегій пом'якшення цього тимчасового забруднення.

На основі результатів дослідження робимо висновок, що нафтопродукти входять до числа найпоширеніших та небезпечних забруднюючих речовин у регіонах, що піддаються антропогенній діяльності. Ризик забруднення навколишнього середовища нафтою та її похідними є значним та поширюється за межі зон видобутку та переробки нафти. Ця проблема перетинає регіональні кордони та має глобальне значення через широке зберігання та транспортування нафти та нафтопродуктів. Розливи нафти внаслідок надзвичайних ситуацій поширені по всьому світу, що робить будь-яку територію вразливою до такого забруднення. Усі компоненти нафти та нафтопродуктів є токсичними і часто мають канцерогенні властивості.

Загалом, практичне застосування результатів проведеного дослідження може мати значний вплив на управління навколишнім середовищем, розробку політики та зусилля зі сталого розвитку, спрямовані на пом'якшення негативного впливу вуглеводневого забруднення на ґрунтові екосистеми та добробут людей. А також можуть слугувати основою для подальших досліджень у сфері вивчення впливу гідрокарбонів на екологію ґрунту.

Ключові слова: *ґрунт, забруднення, витік масла та газу, вуглеводне забруднення, аварії, нафтогазопрводи.*