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The role of microorganisms in cleaning oil-contaminated concrete

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ABSTRACT

Contamination of concrete with petroleum products occurs in industrial zones of oil extraction and processing enterprises, maintenance workshops, and filling stations. In countries with high temperatures during the spring-summer period – which include Kazakhstan – the chromatographic effect in oil-contaminated porous concrete promotes the vertical migration of oil masses, forming an explosive gas-air layer above solid surfaces, which poses serious risks at industrial facilities. In this regard, the aim of the present study was to develop a method for microbiological remediation of concreted surfaces and cracks contaminated with crude oil as well as petroleum products. The methods of infrared spectroscopy (IRS), scanning electron microscopy (SEM), as well as microbiological and taxonomic analysis were employed. It was established that the higher the porosity of the concrete, the smaller the area of oil stain spread on the surface and the greater the depth of penetration into the concrete mass. The penetration of oil into concrete occurs through micro- and nanocracks, which accounts for the difficulties associated with mechanical cleaning. eeds through microcracks and pores of the concrete, with concurrent contamination of adjacent layers by fatty oils. The physicochemical composition of petroleum contamination in concrete is analogous to that of oil sludge with a low water content. The microflora of petroleum-contaminated concrete is represented by heterotrophic, hydrocarbon-oxidizing microorganisms of the genera *Pseudomonas, Micrococcus, Bacillus*, *Penicillium*, and *Aspergillus.* The spatial-structural distribution of these microbial groups shows that micromycetes and micrococcus – *Micrococcus luteus* and *M. roseus* – predominate on the surface of petroleum contaminations, while pseudomonads and bacilli are found within the bulk of the petroleum products. The role of hydrocarbon-oxidizing microorganisms and micromycetes in the biodegradation of petroleum-contaminated concrete is indisputable; however, thionic bacteria demonstrated the highest efficacy. The developed method of biological remediation of oil-contaminated concrete using thionic bacteria and oxalic acid enables concrete purification at a level of 95–97%.

Keywords: oil-contaminated concrete, microflora of oil pollution, hydrocarbon-oxidizing microorganisms, micromycetes, thion bacteria.

INTRODUCTION

Oil-containing waste poses a significant hazard to the natural environment, serving as a source of contamination of soils, groundwater and surface water, as well as various concreted surfaces. Contamination of concrete and asphalt occurs in the industrial zones of oil extraction as well as processing enterprises, at railway loading facilities during the loading of finished products and raw materials, at equipment maintenance stations, and at filling stations. The primary sources of oil and petroleum product contamination include extraction enterprises, pumping and transportation systems, oil terminals and petroleum depots, petroleum product storage facilities, railway transport, river and sea oil tankers, as well as fuel filling complexes and stations. The volumes of petroleum waste and oil contamination accumulated at individual facilities amount to tens and hundreds of thousands of cubic meters. A considerable number of oil sludge and waste storage facilities, constructed from the early 1950s onward, have transformed from means of preventing oil contamination into permanent and ongoing sources of such contamination.

Contamination of concrete surfaces with oils and petroleum products is a widespread phenomenon. The floors and reservoirs at oil refining facilities, treatment plants – all mineral surfaces in contact with crude oil, lubricating oils, diesel fuel, fuel oil, and similar substances – are difficult to clean, wash, and subsequently protect. Concrete contamination with petroleum products may also occur due to the use of oil-contaminated sand as a raw material. For example, in one of the sands extracted from an oil field off the coast of Salalah, traces of naphthalene, cyclohexanol, amine compounds, and alkanes were detected using FTIR and GC-MS methods (Shayuti et al., 2023).

Petroleum products, penetrating into the mass of concreted surfaces, begin to rise through cracks in accordance with the chromatographic effect when ambient temperatures increase – particularly under the conditions of southern Kazakhstan. As petroleum products evaporate, they create a gas-air environment saturated with volatile gaseous petroleum compounds. This phenomenon can serve as a dangerous source of explosion hazard, potentially leading to serious adverse consequences at enterprises with elevated fire risk.

At present, more than 20 species of microorganisms capable of utilizing a wide range of petroleum products are known. Hydrocarbon-oxidizing microorganisms inhabiting the marine environment have been isolated and described (Xue et al., 2015; Liu et al., 2017). It has been demonstrated that petroleum hydrocarbons, dissolving in the ocean depths, can form populations of deep-sea microorganisms in which various pathways for the consumption of high-molecular-weight hydrocarbons develop (Love et al., 2021; Arrington et al., 2025). It was established that microbiomes across all aquatic sites rapidly adapted to the spill through increased diversity and abundance of genes encoding the degradation of alkanes and aromatic compounds, as well as biosurfactant production (George et al., 2025). The intensity and nature of oil contamination strongly influenced succession and gene profiles, which determined the toxicity levels of fresh oil spills. Studies were conducted to examine the effect of an oil spill on the structure of the microbial population, revealing the gradual cumulative impact of remediation measures and in-situ biodegradation of natural hydrocarbons at the spill site (Smallbone et al., 2026). In this context, changes in the microbial population led to an enhancement of both aerobic and anaerobic hydrocarbon biodegradation processes. The study by Howland et al. (2025) investigated the effect of fertilizer amendments on the activation of petroleum product biodegradation processes, revealing a manifold increase in oxygenases oxidizing petroleum hydrocarbons.

The effect of dilbit (diluted bitumen) on the microflora of a freshwater lake was studied, including testing of shoreline washing agents (Kharey et al., 2024), where it was established that the composition and structure of the microbial population remained stable throughout the entire monitoring period.

The goal of this paper was to develop a method for the microbiological remediation of concreted surfaces and cracks contaminated with crude oil and petroleum products.

The following tasks were defined:

- To study the pattern of petroleum product distribution in various concrete grades.
- To study the microflora of petroleum products as a contaminant of concrete.
- To conduct laboratory and pilot-scale investigations into the feasibility of microbiological remediation of oil-contaminated concrete.

MATERIALS AND METHODS

The object of the study was 10 blocks of various grades of concrete measuring 10.0±1.0 × 10.0±1.0 cm (Figure 1) and the concrete surface of

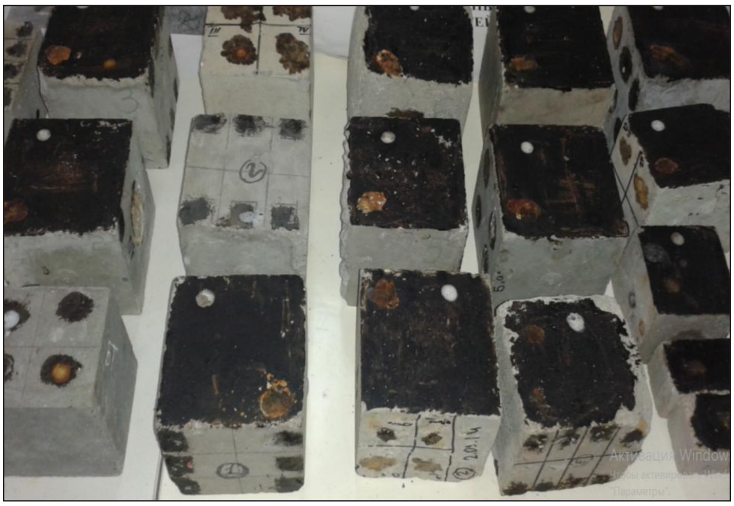


Figure 1. Various grades of concrete contaminated with fuel oil under model conditions

a 420 m^2 sludge storage tank on the territory of the PKOP LLP wastewater treatment plant (Figure 2).

Kumkol field oil with the following characteristics was used in the research: 10°C solidification temperature, 19.2% silica content; 5.82% carbene-carboides; 5.4% asphaltenes; 7.5% paraffin; 0.064% sulfur. At a temperature of 200 °C, it has a density of 0.850 g/cm^3.

The following were used as immobilizers of microorganisms:

Vermiculite. Under laboratory conditions, when studying the effect of xenobiotics on test plants, vermiculite was used to create a hydroponic system. Properties of vermiculite: specific gravity – 65–130 kg/ cubic meter (depending on the size of the granules); water absorption capacity ~ 400–530%; pH 6.8–7.0 (neutral – slightly alkaline); magnesium content – 10–14%, potassium – 3–5%, calcium – 1.2–2%, manganese – 0.8–1%, iron – 5.6–6.5%, silicon – 34–36%; inert, chemically and biologically resistant, sterile, does not contain heavy metals.

Bentonite.A natural mineral capable of hydration by 14–16 times and forming a dense gel in an aqueous medium. The bentonite deposit is located in the Turkestan region, where bentonite has a pH of 6.0–9.5 and contains at least 2% sodium carbonate, with a total content of interchangeable sodium and calcium of no more than 80 mg/100 g.

Microorganisms were grown on Voroshilova-Diana elective media, meat-peptone agar, Chapek. Cultivation of microorganisms was carried out in a thermostat with a programmable temperature (TC 1/80). Microscopy was carried out using Tauda (Japan) light microscopes ", and Jeol JSM-6490 LV (Japan) electron-scanning microscope

To study the oxidative ability of thionic bacteria, pure cultures of microorganisms were used in an amount of 125 ml, introduced into 250 ml rocking flasks and placed on shakers (EKROS-6410M) with a set temperature of + 28+320 °C.

IR spectra were measured using a Specord 75JR (400–4000 cm^{-1}) two-beam spectrophotometer. The chemical composition of petroleum products was determined by liquid chromatography on the chromatograph "Chrome-4" with step programming temperature from 700 °C to 4000 °C using a column filled with polyethylene glycol adipinate and argon as a gas carrier.

Synthetic detergents in the form of powder and gel, hydrocarbon-oxidizing microorganisms with a titer of 10^8 CFU/ml, micromycetes with a titer of 10^8 CFU/ml, thionic bacteria with a titer of 10^8 cell/ml were used to clean oil-contaminated concrete blocks, which were applied in an amount of 1.0 ml to the surface of the oil slick.

During laboratory experiments, oil was applied to concrete blocks, onto which the biomass of various microorganisms was drip-applied. The degree of spot cleaning was determined visually by the lightening area relative to the total spot area.

During the experiments conducted at the plant, the area of the concreted surfaces was divided into 4 parts, one of which was used as a control, and the biomass of various groups of microorganisms was added to the other three parts.

Statistical processing of the research results was carried out on the basis of the data from at least 3–5 multiple repetitions with the determination of errors by the Student.

Figure 2. Oil-contaminated concreted sludge storage surface. a. Location of Shymkent city on the map of Kazakhstan, b. territory of PetroKazakhstan Oil Products LLP oil refinery in Shymkent (42.26131510518005, 69.66172153282008), c. Sludge storage facilities (42.260542, 69.649143), d. sludge storage area contaminated with petroleum products

RESULTS AND DISCUSSION

Features of contamination of concrete with petroleum products

The first step of the research was related to the study of the spatial distribution of oil pollution on model concrete blocks. Their preliminary microanalysis was carried out to determine the elemental weight composition (Figure 3), which shows that the elemental composition of concrete is represented by sodium, magnesium, aluminum, silicon, sulfur, chlorine and potassium in various proportions.

It was found that the penetration depth of petroleum products and the spreading dimeter of an oil slick on the concrete surface depend on its density and fracturing (Table 1). For example, in porous concretes, the depth of oil penetration ranges from 0.5–1.4 cm, while in dense concretes, oil penetrates to a depth of 0.2–0.8 cm. These indicators are inversely correlated with the area of the oil slick.

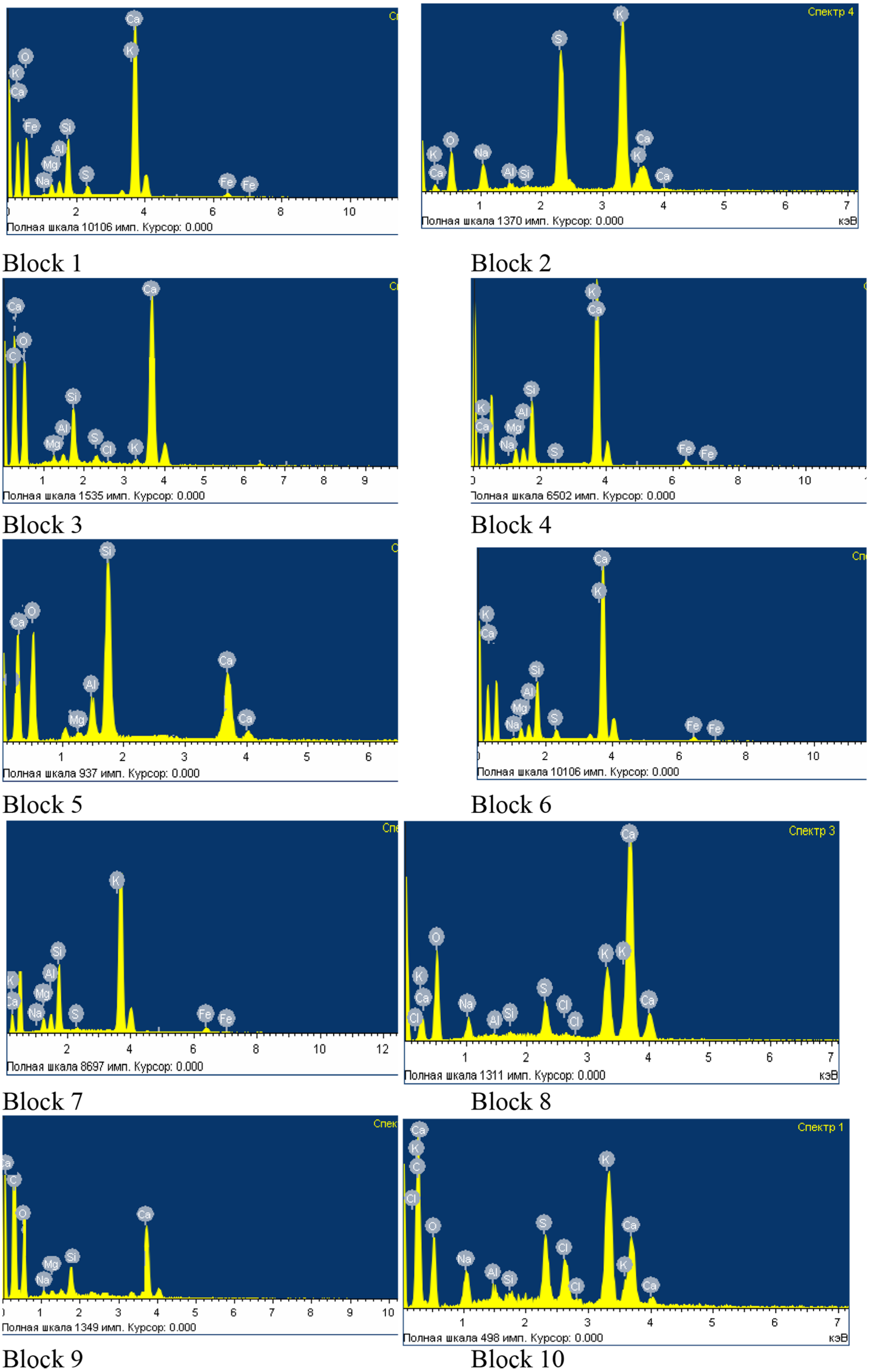


Figure 3. IKS 10 model concrete blocks

Table 1. Characteristics of oil slick spreading on concrete blocks

Block number	Indicators	
	The oil slick	
	Penetration depth, cm	Spot diameter, cm
1	0.2±0.01	3.0±0.20
2	0.5±0.02	3.5±0.20
3	1.0±0.20	1.6±0.10
4	0.5±0.01	2.3±0.20
5	0.8±0.20	1.2±0.20
6	2.2±0.20	1.7±0.20
7	1.0±0.20	2.3±0.10
8	0.2±0.02	2.6±0.10
9	0.9±0.01	2.3±0.20
10	0.5±0.01	1.9±0.20

Electron microscopic examination revealed that the oil droplets localized along the penetration pathways within the concrete matrix, were responsible for the secondary contamination of the surrounding material. Specifically, the oil migrating through micro- and nanocracks was found to saturate and "oil-impregnate" up to 10–12% of the adjacent concrete layers. This phenomenon occurs as a result of capillary absorption and adsorption of petroleum hydrocarbons onto the mineral surfaces of the cement matrix, whereby the oil spreads laterally from the primary migration channels into the surrounding porous structure.

The scanning electron microscopy (SEM) images clearly demonstrated that the oil droplets did not remain confined strictly to the crack pathways, but instead diffused into the neighboring cement paste and aggregate interfaces, forming a contaminated zone around each penetration channel. The extent of this lateral contamination was found to be directly dependent on the viscosity of the petroleum product, the porosity of the concrete, and the duration of contact between the contaminant and the concrete surface.

Furthermore, the oil-impregnated zones exhibited a distinctly altered microstructure compared to uncontaminated concrete, with the pore spaces and microcracks being partially or fully filled with petroleum residues. This structural modification not only complicates the mechanical and chemical cleaning procedures, but also creates favorable microenvironments for the colonization and activity of hydrocarbon-oxidizing microorganisms, which tend to concentrate precisely at the oil–mineral interface within these impregnated zones (Figure 4).

Cleaning of oil-contaminated concrete blocks by various methods

After applying various products to the surface of the oil slick, it was found that the effectiveness of using powdered detergents ranges from 5–7%, whereas for gel–like detergents – from 5–10%, which is explained by the inaccessibility of deep layers of concrete (Figure 5).

The use of microorganisms proved more effective, and oil pollution decreased by up to 50%, depending on the quality of concrete and the culture of microorganisms used (Figure 6). It was

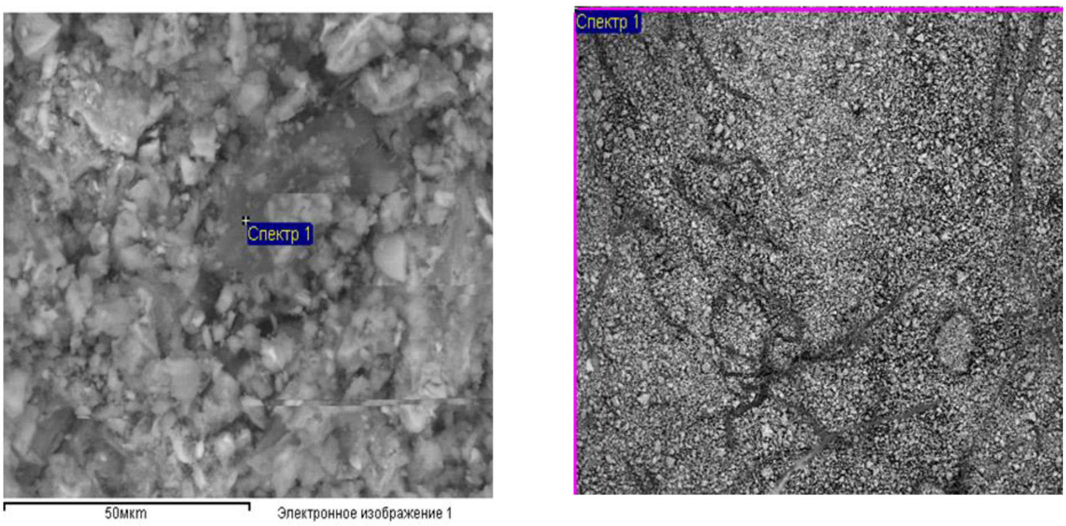


Figure 4. Electron microscopic image of nanocracks of concrete contaminated with petroleum products

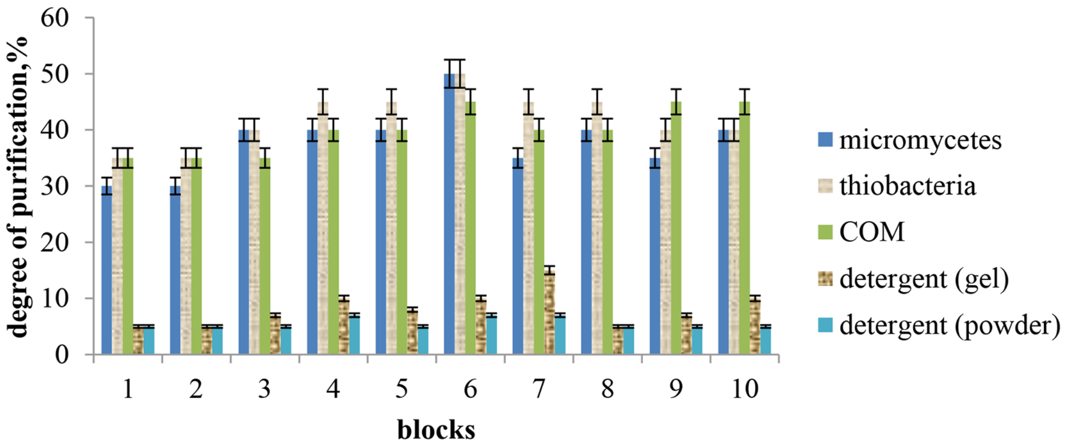


Figure 5. The degree of oil slick cleaning on concrete blocks as a result of the use of various means

visually visible that the oil slick was cleaned not only on the surface of the block, but also penetrated to a certain depth of concrete.

An analysis of the available information sources showed the absence of publications on the use of biological methods for cleaning oil-contaminated concrete and asphalt. There are few studies related, for example, to BEOR technologies, which use microorganisms and biopolymers, bionanomaterials, as well as biosurfactants to increase oil recovery from sand-bearing layers of deposits (Maleki et al., 2024). In addition, biological purification methods are also used for the reclamation of tailings formed during the extraction of bitumen from oil sands (Abousnina et al., 2021). It has been established that biological treatment methods have proven their effectiveness in cleaning up environmental pollutants by creating favorable conditions for the necessary microorganisms. On the other hand, not all biological methods are capable of effectively disposing of the entire waste complex or contribute to the formation of associated gaseous wastes, such as CH_4, NO, N_2O or H_2S. Therefore, before applying biotechnological methods, it is important to consider the possible risks and ways to overcome them.

Cleaning of the oil-contaminated surface of a concrete sludge storage tank on the territory of an oil refinery

When conducting research under real weather and climatic conditions of PKOP LLP, it was found that the contamination of the concrete surface with petroleum products is uneven. Highly, moderately, and slightly polluted areas are visually distinguishable. The thickness of the oil product layer ranges from 0.2–3.5 cm. The pollutants are a dense hydrophobic mixture of petroleum products with mechanical impurities, mostly in the form of sands. The area of contamination, depending on the site, ranges from 70–85%. The

Figure 6. Results of oil slick treatment by various means: 1 – culture of micromycetes, 2 – culture of carbohydrate-oxidizing microorganisms, 3 – culture of thiobacteria, 4 – powdered detergent, 5 – gel detergent, 6 – control

depth of penetration of oil pollution into the concrete is in the range of 0.5–1.5 cm.

By its mechanical composition, oil pollution is a mixture consisting of 21.4% petroleum products, 72.6% mechanical impurities, 6.0% water, and corresponds to the composition of oil sludge belonging to the 3rd hazard class of industrial waste.

Microbiological examination of oil pollution revealed that the composition of the microflora of petroleum products is quite homogeneous and is represented by heterotrophic, hydrocarbon-oxidizing microorganisms and micromycetes (Table 2).

Taxonomic characteristics allowed the isolated microorganisms to be assigned to the genera *Pseudomonas*, *Micrococcus*, *Bacillus*, *Penicillium*, and *Aspergillus*. The spatial-structural distribution of these microbial groups indicates that micromycetes and micrococci – *Micrococcus luteus* and *M. roseus* – predominate on the surface of petroleum contaminations, while pseudomonads and bacilli were detected within the bulk of the petroleum products.

Following the spraying of micromycete biomass onto the concrete surface, a visible lightening of the oil stains was observed. Upon a single application of micromycete biomass, complete remediation was achieved in the areas where the thickness of the oil contamination layer did not exceed 0.2–0.5 cm. Areas with an oil contamination layer exceeding 1.0 cm were cleaned more slowly; however, the remediation processes were found to intensify with an increasing number of treatment applications (Figure 7).

Table 2. Microflora of oil contamination of concreteD sludge storage surfaces

Sample	Heterotrophicmicroorganisms	Carbon-oxidizingmicroorganisms	Micromycetes
Average sample of oil products from concrete surface	$(25.2±2.0) × 10^7$	$(6.09±0.6) × 10^6$	$(18.2±1.6) × 10^6$
Average sample of scraping from concrete surface	$(15.1±1.5) × 10^6$	$(5.04±0.4) × 10^5$	$(16.9±1.5) × 10^6$
Average sample from 0–5 cm depth	$(3.7±0.3) × 10^5$	$(1.7±0.1) × 10^4$	$(1.7±0.1) × 10^5$

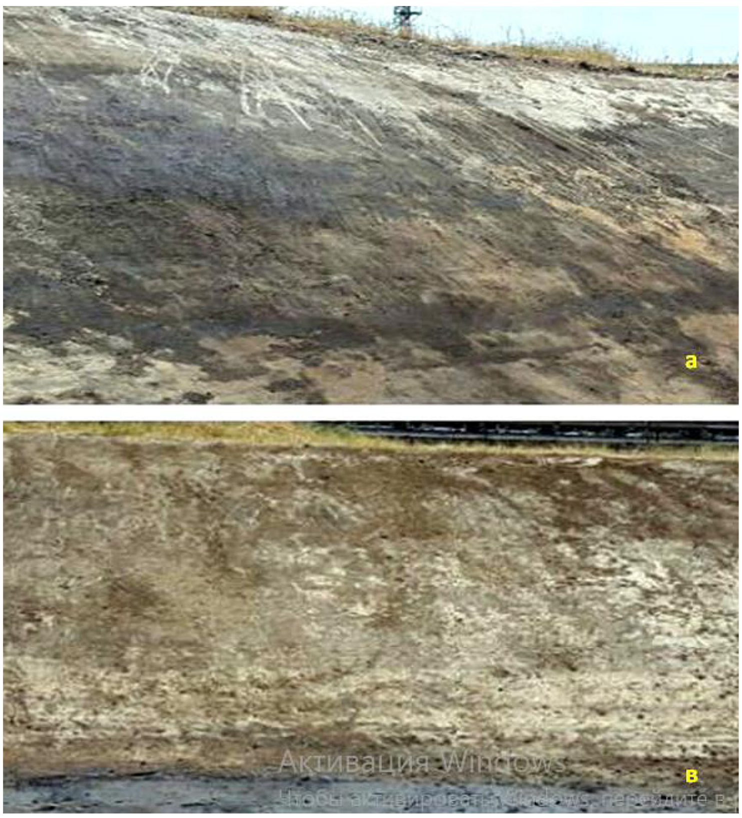


Figure 7. Results of concrete treatment with micromycete biomass. A – control, B – after treatment with micromycetes

During the treatment of concrete with biomass by hydrocarbon-oxidizing bacteria, it was found that the limiting factor for the oxidative activity of microorganisms is strong sunlight in June and July. In this regard, the microorganisms were immobilized on bentonite, which was applied to concrete. To maintain optimal conditions for the vital activity of bacteria, moistening with water was carried out once every 5–7 days. It was found that the use of UOM makes it possible to reduce the oil-slick area by 3.6 times after fourfold treatment (Figure 8). However, it should be noted that frozen tar-type oil stains are not susceptible to microbiological degradation due to the dense surface layer. To activate microbiological processes, it is necessary to destroy the film on their surface.

In the third variant of the experiment using thion bacteria, it was found that the processes of bacterial and chemical oxidation of petroleum products are most active in the places with a low layer of oil contamination. Subsequent washing off of the oxidized layer of petroleum products with water showed the presence of rust spots in the form of trivalent iron salts on the concrete surface. To remove them, a 1.0% oxalic acid solution was used, which was applied to a separate area measuring 1.0 × 0.5 m. Oxalic acid treatment allowed the oil-contaminated concrete purification process to be fully completed. To verify the effectiveness of the data obtained, a biomass of thion bacteria immobilized on bentonite with a layer of 0.8~1.5 cm was applied to the concreted surface (Figure 9).

The thickness of the applied bentonite layer may vary depending on weather and climatic conditions. The main requirement for the height of the bentonite layer is to maintain humidity for the entire treatment period, which is a prerequisite for the vital activity of thion bacteria. After 24 hours of exposure, the surface was rinsed with water using a water pump and treated with 1.0–3.0% oxalic acid solution. A solution of oxalic acid is applied to the treated surface until the spots of trivalent iron completely disappear.

The results obtained demonstrate that the combined application of thion bacteria immobilized on bentonite and oxalic acid treatment represents an effective and reliable method for the microbiological remediation of oil-contaminated concrete surfaces. The bacterial and chemical oxidation processes were found to be most active in the zones with a thin oil contamination layer, while the subsequent washing and oxalic acid treatment successfully eliminated the residual iron salt deposits formed during oxidation. The optimal procedure involves applying a layer of bentonite-immobilized thion bacteria 0.8–1.5 cm in thickness, maintaining sufficient moisture throughout the treatment period, followed by

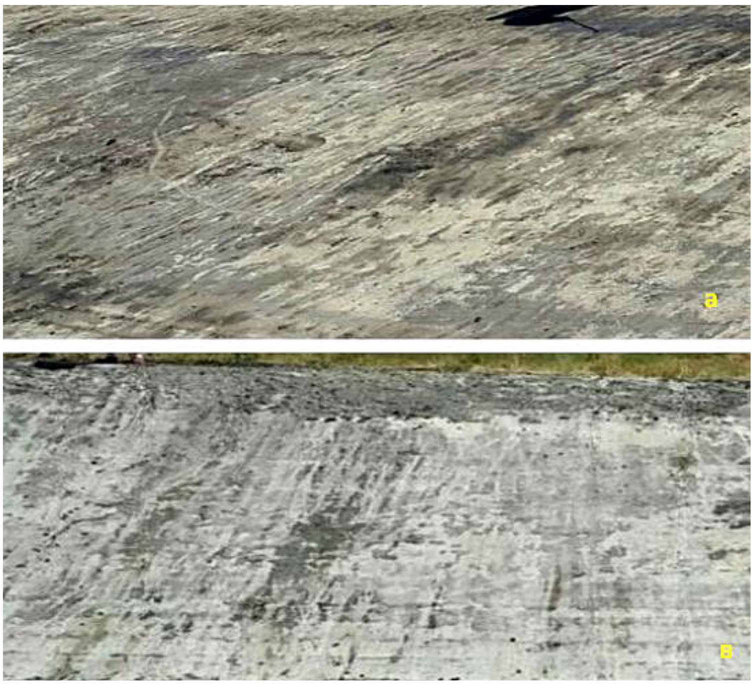
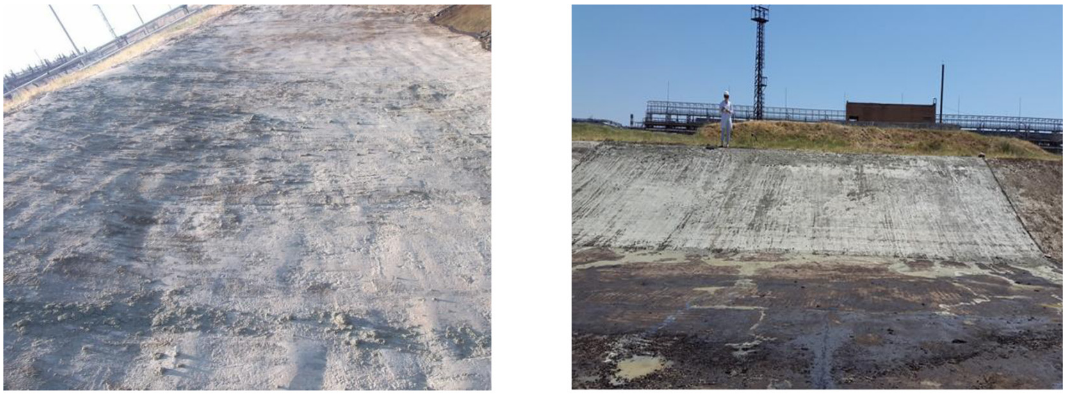


Figure 8. Results of treatment of an oil-contaminated concreted area with UOM biomass



a b

Figure 9. Use of biomass of thion bacteria – treatment with suspension of oxalic acid

rinsing with water and treatment with a 1.0–3.0% oxalic acid solution until complete removal of trivalent iron spots is achieved. This approach ensures thorough and complete purification of the concrete surface, confirming the practical applicability of the developed method under real industrial conditions.

CONCLUSIONS

As a result, it was found that the nature of concrete contamination with oil and petroleum products depends on the brand of concrete, while the higher the porosity of the concrete, the smaller the area of the oil slick on the surface and the higher the depth of penetration into the concrete. The oil slick penetrates through microcracks and pores of concrete with associated contamination by fatty oils of nearby layers.

The physico-chemical composition of oil contamination of concrete is similar to that of oil sludge with a low water content. The microflora of oil pollution is represented by heterotrophic, hydrocarbon-oxidizing microorganisms of the genera *Pseudomonas*, *Micrococcus*, *Bacillus*, *Penicillium*, *Aspergillus*. The spatial and structural arrangement of these groups of microorganisms shows that micromycetes and *Micrococcus luteus* and *M. roseus* predominate on the surface of oil pollution, pseudomonads and bacilli are found in the thickness of petroleum products.

The role of hydrocarbon-oxidizing microorganisms and micromycetes in the biodegradation of oil contamination in concrete is undeniable, but thion bacteria have shown the greatest effectiveness. The developed method of biological purification of oil-contaminated concrete using thionic bacteria and oxalic acid makes it possible to purify concrete by 95–97%.

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