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OIL DECONTAMINATION OF BOTTOM SEDIMENTS EXPERIMENTAL WORK RESULTS

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ABSTRACT

This article presents the results of experimental work during 2004-2005 on oil decontamination of bottom sediments of Lake Schuchye, situated in the Komi Republic (Northern Russia). The cause of the contamination were huge oil spills occurred after a series of accidental ruptures on the Harjaga-Usinsk and Vozej-Usinsk oil-pipe lines in 1994. Flotation technology was used for the cleaning of bottom sediments. 157 tons of crude oil were removed during the course of 2-year experimental work from an area of 4,1 ha. The content of aliphatic and alicyclic oil hydrocarbons was reduced from 53,3 g/kg to 2,2 g/kg, on average. Hydrobiological investigations revealed that bottom sediments started to be inhabited by benthos organisms, dominantly *Oligochaeta*. Besides *Oligochaeta*, *Chironomidae* maggots and *Bivalvia* were detected. The appearance of Macrozoobenthos organisms can serve as a bioindicator of water quality.

Key words: Bioindication, bottom sediments, macrozoobenthos, oil contamination and decontamination of water ecosystems.

RESUMEN

Este artículo presenta los resultados del trabajo experimental realizado entre 2004-2005 en la descontaminación de petróleo de los sedimentos de fondo del Lago Schuchye en la República de Komi (Norte de Rusia). La causa de la contaminación del lago fueron enormes derrames de petróleo ocurridos después de una serie de ruptures accidentales en los oleoductos de Harjaga-Usinsk y Vosey-Usink en 1994. La tecnología de flotación fue usada para limpiar los sedimentos de fondo. En el transcurso de los dos años de trabajo experimental, fueron removidas 157 toneladas de petróleo crudo en un area de 4,1 ha. El contenido de hidrocarburos alifáticos y alicíclicos se redujo en promedio de 53,3 g/kg a 2,2 g/kg. Las investigaciones hidrobiológicas mostraron que los sedimentos de fondo empezaron a ser habitados por organismos bentónicos, predominantemente por Oligohetas (*Oligohaeta*). También fueron detectadas larvas de Chironomides (*Chironomidae*), y bivalvos (*Bivalvia*). La aparición de organismos Macrozoobenthos puede servir como un bioindicator de la calidad del agua.

***Palabras claves*:** Sedimentos de fondo, contaminación y descontaminación petrolífera de ecosistemas acuáticos, bioindicación, macrozoobenthos.

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INTRODUCTION

Professional ecologists are fully aware of the harmful impact the development of oil fields has on the environment. The monitoring research of these technogenic territories almost always reveals a negative effect on environment (Laffon, et al., 2006; Paasvirta, et al., 1982). Serious accidents lead to irreparable damage to natural ecosystems, and mitigation of effects of pollution may last for decades (Laffon, et al., 2006). In regions with lakes and rivers the aquatic ecosystems are heavily impacted by oil spills. Oil and oil products are most intensively washed down into the river network during the spring tide when runoff is formed at all geomorphologic levels and in summer at the heaviest rain period (Kondratyeva, 2000; Zhadin & Gerd, 1961).

Liquidation of oil spills on a water surface is carried out by booming, by means of different types of skimmers, dispersants and sorbents. Additionally bacterial isolates are also used for such purposes (Gentili, et al., 2006; Mukherji, et al., 2004; Reed, et al., 2004). If measures for localization and gathering the pollutant are not taken at the proper time, it may lead to oil and oil products sorption by suspended organic and mineral particles and aquatic flora, and in the long run to their sinking to the bottom of the reservoir, which produces a negative effect on bottom organisms associations causing their total degradation (Ke, et al., 2005; Reed, et al., 2004). Oxygen deficiency, low photo-oxidation indices, low water temperature prevents the destruction of the pollutant. Under anaerobic conditions, organic substances undergo fermentation but not oxidation, and sulfate reduction and methane formation take place (Kondratyeva, 2000). At the same time toxic substances accumulate in water (Petrov, 1978; Vinogradov, 2002).

At choosing technological schemes for cleaning of bottom sediments in Lake Schuchye several variants were taken into consideration. The first one is the use of pumping units for removing contaminated soil. Pumping-out of bottom sediments contaminated with oil requires adding some technological stages for cleaning the contaminated soil which considerably complicates the decontamination work and increases its cost. In Lake Schuchye, the oil accumulated on the surface of bottom sediments in the form of layers with aggregates of different sizes. On the off thicknesses upper layer of bottom sediments where the “soil-oil” contact was contaminated. There is no doubt that if oil was removed from the upper contaminated layer, a large amount of pollutionless sediments would be pumped out, acting as a sorbent for oil while moving along the pipeline. Removing the sediments layer with a thickness of 10 cm (of Lake Schuchye, with an area of 6,26 ha.) would result in more than 6000 m^3 of contaminated soil, which should undergo further decontamination. Therefore, application of this technological scheme was considered inexpedient.

The second variant is more acceptable: hydropneumatic decontamination of bottom sediments, based on the ability of molecular adhesion of oil to the phase at the interface between air and water (flotation). The given scheme allows removing the oil from the surface of bottom sediments.

Determination of the necessary decontamination level of bottom sediments of the reservoir, after which mechanisms of natural self-purification start actively working, is very important for a wide application of flotation technology to oil decontamination of water bodies.

METHODOLOGY

Lake Schuchye No.1 (Figure 1), where experimental work on oil decontamination of bottom sediments was carried out, is a thermokarstic slowflow lake with an area of 6,26 ha. and a maximum depth of 7 m. It is a part of a system of 4 lakes (Figure 1) and situated in the Komi Republic (Northern Russia).

Monthly, samples of water and bottom sediments were taken at monitoring stations and samples of bottom invertebrates were taken every ten days. Surface water sampling was carried out according to the General Technical Conditions, (2002) (GOST 17.1.5.04-81) from the depth of 0,4 m up. Bottom sediments sampling was carried out by means of a Petersen bottom sampler with a grip area of 1/80 m^2. After lifting of the bottom sampler containing bottom sediments, water was poured out; bottom sediments were put into a polyethylene bag and labeled. For collection of zoobenthos samples, the Petersen bottom sampler was also used. To eliminate probable errors resulting from hydrobiontes distribution in homogeneity each zoobenthos sample consisted of a set of three or four bottom sediments samples taken separately.

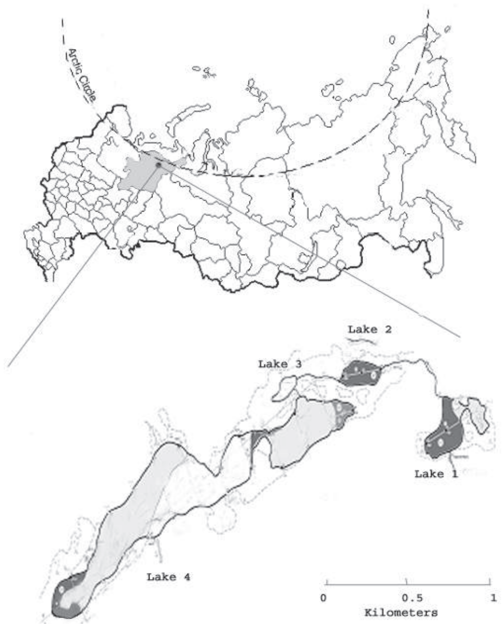

Figure 1. Map of Russia, (top) showing the location of the Komi Republic and a map of the Schuchye lake system (Lakes No. 1-4).

The samples were washed in a rinse bag made of fine gauze No. 28 to remove fine fractions of silt. Residual contents were examined with the help of a magnifying glass, and zoobenthos organisms were taken out with tweezers, placed into glass containers with 70% ethyl alcohol and labeled (Morduhai-Boltovsky, 1975).

Oil contents in the water mass and bottom sediments were determined by means of an infrared spectrophotometrical method. The method allows the determination of aliphatic and alicyclic oil carbohydrates and is based on the extraction of oil by $CCl_{4,}$ chromatographic fractionation with aluminum oxide and on quantitative determination in the infrared region using the «Specord M 80».

Oil decontamination of bottom sediments and water was carried out according to the technology developed and patented by the authors of this paper (Lushnikov & Vorobyov, 2005).

RESULTS

In 2004, as much as 65 tons of oil were extracted from bottom sediments of the experimental zone of the lake 4, (1 ha.) by means of a flotation technology. In 2005 the equipment was improved, which made possible to reduce the oil content in bottom sediments and during the summer period of 2005, 92 tons of crude oil were extracted. During 2 seasons of cleaning work in 2004-2005, only the hydropneumatic cleaning scheme was used. The content of aliphatic and alicyclic oil hydrocarbons was reduced from 53,3±7,46 g/kg to 2,2±0,39 g/kg on average (Figure 2a). Reduction of oil content in the lake water mass during cleaning operations was not so significant (Figure 2b).

Hydrobiological research carried out in the lake in 2005 showed that after two years of integrated decontamination work in the lake zones where the content of oil in soil did not exceed 3,3 g/kg, bottom sediments contained benthonic organisms. Three groups of macrozoobenthos were found: There types of *Oligochaeta*, *Chironomidae* maggots, and *Bivalvia*. The number of benthos came up to 2320 specimens per m², and measured biomass was as high as 3,940 g/m². *Oligochaeta* were the basic benthos because of their quantity (90-100%) and biomass (80-100%) in Lake Schuchye.

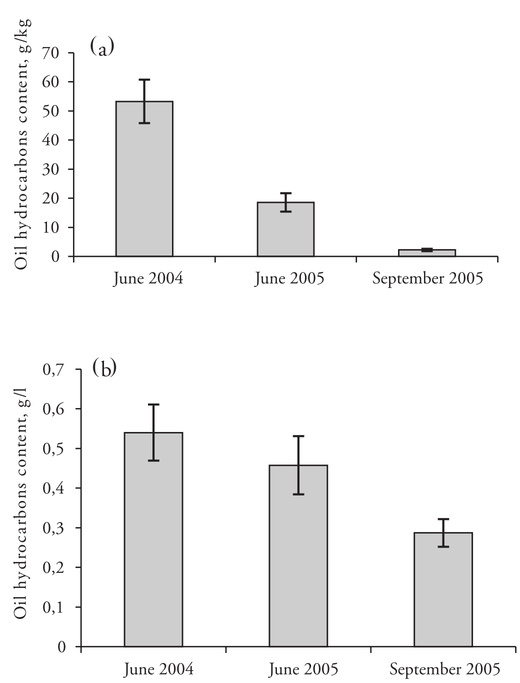

Figure 2. Oil content in bottom sediments (a) and in water mass (b) before remediation (June 2004) and after remediation (June 2005 and September 2005).

DISCUSSION

In water reservoirs and waterways oil spreads mostly under the influence of water currents and wind. The currents of water are the basic factor of oil spread in waterways. Relative proximity of the waterside and a winding river-bed allows oil to reach waterways quickly. The best conditions for oil accumulation exist in backwaters, creeks, and sections of rivers where there is no current. In these sections the content of oil and oil products in bottom sediments is high in comparison with that of riverbeds. Sedimentation of contaminated suspended particles and their accumulation in soil exert a negative influence on bottom associations of organisms (Rusanova & Vorobyov, 2001).

In lakes oil spreads on the water surface under the influence of wind. Irregularity of the waterside leads to formation of zones with conditions favorable for oil accumulation. Removing such oil patches presents no difficulties if special oil-gathering equipment is used, although the solution to this problem is versatile. At first, it is necessary to locate the oil patch. Furthermore, the decontamination technology depends on availability of access roads to the reservoir and the need for transporting localized oil on water surface; in the case of large reservoirs the use of specialized oil-spill boats is optimal. Gathering oil from the water surface and cleaning the waterside of a reservoir is complicated by the presence of higher aquatic vegetation. To a greater extent this refers to water-resistant plants which can be found in the littoral zone, on floating bogs, on swampy and highly moist shores, and to aquatic plants with aerial generative organs. After water plants die, oil kept by the vegetation on the surface of water accumulates in the bottom sediments of the waterside where its destruction slows down. Therefore, contaminated vegetation is removed from the reservoir along with oil. Figure 3 shows a part of the shore of Lake Schuchye shore with oil contaminated aquatic vegetation before decontamination and with recovered phytocenosis after removing oil and parts of the plants rising to the water surface.

To avoid secondary pollution of decontaminated areas near the waterside it is necessary to use barriers to prevent further spread of oil. As a rule, secondary pollution occurs, in reservoirs where bottom sediments are highly contaminated with oil. In summer, when the temperature in the bottom layers of water rises, in shallow zones there occurs spontaneous raise of oval and globular-shaped oil aggregates to the surface. This phenomenon took place in the zones of the lake with a depth up to 2 m. In 2004 in the experimental zone of Lake Schuchye more than 12 tons of oil rose to the water surface.

Figure 3. The waterside of Schuchye Lake No.1 before (top) and after decontamination (bottom) (photo by D.S.Vorobyov).

Fertilizer application, the use of aerators in the water area of the reservoir, and optimal temperature conditions - in July 2004, the temperature in the bottom layers of water at a depth of 5 m reached 19-20 ^{o}C, were favorable to the intensive raise of oil.

To reduce the content of oil absorbed by sediments during the second step of cleaning operations we activated microbiological destruction processes. The content of nutrients and oxygen in water is the key factor in the processes of microbiological decomposition, thus, when carrying out work in the lake we used aerators, set up active booms on the surface of water, and applied dosified amounts of fertilizers.

The flotation technology applied allowed us to remove oil (in the form of a continuous layer and aggregates) from the surface of bottom sediments of the lake. During the cleaning up work period in

Lake Schuchye in 2004-2005 as much as 157 tons of oil were extracted from the bottom sediments. However, a large amount of oil is kept in the sediments due to the high sorption capacity of fine soils. It is well known that there is a connection between the granulometric composition of bottom sediments and the amount of oil absorbed by them – fine sediments possess higher sorption surface, hence they can retain more oil; 1 gram of bottom sediments under optimal conditions absorbs up to 12-25 mg of oil products (Zyulkina, 1975), (i.e. the concentration of this pollutant can run up to 25 g/kg).

Hydrobiological research carried out in the lake in 2005 showed that after two years of integrated decontamination work in the lake zones where the content of oil in soil did not exceed 3,3 g/kg, bottom sediments contained benthonic organisms (in 2003-2004 benthonic organisms were not found there). The number of benthos measure up to 2320 specimens per m^2, and the biomass was as much as 3,940 g/m^2. Many characteristics of zoobenthos (species diversity, quantity, biomass etc.) depend on the physical properties of the soil and sediments quality, and the amount of easily assimilated organic substance present in it transformed by bacteria. (Vinogradov, et al., 2002) noted that the quality criteria of bottom sediments should involve parameters such as the level of quantitative development of zoobenthos.

The three groups of macrozoobenthos in the Lake Schuchye correspond to a benthos group which can endure oil pollution best of all. *Oligochaeta* feed from organic substances in sediments and play an important role in their formation. During a 24-hour period, a worm digests an amount of detritus which weighs 4 times as much as the worm itself (Zhadin & Gerd, 1961).). Experiments carried out on another group of hydrobiontes, *Polychaeta*, showed that aromatic structures of organic substances of excrements acquired a different character from that in initial forms. These hydrobiontes transformed oil products, namely, Tailing (Georga-Kopulus & Alemov, 1990).).

Oligochaeta also take part in the process of transformation of oil-contaminated soil. And although they do not play the main role in the self-purification processes (as compared with microbial associations), the whole activity of the complex biosystem of a reservoir provides a rapid recovery.

Conclusions

The flotation technology allowed effective oil decontamination of the bottom sediments of Schuchye Lake situated in Komi Republic (Northern part of Russia). During the period of experimental cleaning work (2004-2005) a total of 157 tons of crude oil were removed. A significant amount of oil was kept by sediments because of the high sorptive capacity of fine soils. It was shown that the aliphatic and alicyclic oil hydrocarbons content in bottom sediments reduced in the course of the experiment from 53, 3±7, 46 g/kg to 2, 2±0, 39 g/kg.

After a 2-year integrated decontamination work in the lake zones where the content of oil in soil did not exceed 3,3 g/kg bottom, sediments started to be inhabited by benthonic organisms. Three groups of macrozoobenthos have been found - *Oligochaeta*, *Chironomidae* maggots and *Bivalvia*. *Oligochaeta* were the basic benthos according to their quantity (90-100%) and biomass (80-100%). The total number of benthos came up to 2320 specimen per m^2, and the biomass totaled 3,940 g/m^2.

The fact that macrobenthos organisms appear in the bottom sediments of Lake Schuchye is a strong bioindicative proof of an improving in the habitat quality of bottom organisms associations.

Currently we initiated the task of working out integral criteria for a quantitative assessment of recovery in water bodies using hydrochemical and hydrobiological tools. To solve this problem, monitoring research of the lake and research of other water bodies undergoing decontamination in different climatic zones will be continued.

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