Oil decontamination of bottom sediments: past, present and future

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Abstract

Experimental trial and manufacturing application of technologies and devices for purification of water bodies from oil and petroleum products are developed at the premises of Biological Institute of National Research Tomsk State University. More attention is paid to treatment of bottom sediments from oil and petroleum products. As a result of oil contamination, bottom sediments of some water bodies are covered with continuous layer of oil, and water bodies have lost their commercial fishing importance. In 2004-2006 for the first time scientists of National Research Tomsk State University and scientific technical association "Priborservice" conducted experimental trial of treatment bottom sediments technologies from oil on the arctic water bodies of Komi Republic and flood bypass conduits of Yugra (Khanty-Mansi Autonomous Area) to obtain unique results of experimental tests of technologies and equipment.

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1. Introduction

The Russian Federation belongs to countries rich in water resources. Mean annual renewable water resources of Russia constitute 10% of global stream runoff (second in the world after Brazil) and they are evaluated more than 4 thousand km\(^3\) per year. Water management system, the largest in the world, including more than 30 thousand reservoirs and ponds (total amount of which is more than 800 km\(^3\)) operates in the Russian Federation. In addition to the enormous reserves of surface water, Russia possesses one of the largest reserves of fuel and energy resources.

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More than 700 oil fields located in more than 40 regions of the Russian Federation are being developed now. There are 69% in West Siberia. More than 50% of oil reserves of Russia is concentrated in Khanty-Mansi Autonomous Area (Yugra).

Production and transportation of HC-hydrocarbons are always accompanied by the negative impact on the environment. Most large-scale disasters are typical for sea transportations of hydrocarbons. Volumes of oil pollution on a global scale are 20 million tons of oil per year.

There is no an oil producing company without problems of oil pollution of environment, including water bodies. “The Method of calculating the amount of damage caused to water bodies due to the violation of water legislation” was approved in April 13, 2009 according to order of the Russian Ministry of Nature № 87; taxes for harm at oil pollution of water bodies by accidents are to 3.0 million rubles per ton of oil spill.

Treatment of water bodies from oil products is one of the most difficult and time consuming tasks in the process of oil spill. Purification technologies of soils and subsoils from oil pollution have been around for decades and the technology is constantly improved. At a time when there are engineering solutions of accident elimination on land, in recent decades the technologies with the use of oil microorganisms-destructors are developed in a greater degree and the most satisfactory conditions are created for oil microorganisms-destructors “work”. The complexity of natural water body purification is associated with dynamic aquatic environment and variety of processes of oil transformation which occur in water (it is necessary to be focused on natural water bodies due to the fact that the technologies of sewage treatment from oil products are quite varied and they are effectively used). Techniques and means of oil and petroleum products gathering from the surface of water bodies are the most advanced. There are great varieties of devices the technical solutions of which are aimed at localization of oil and its operative recovery. Offers of ecological equipment for solving this problem are varied and numerous. However, in practice, purification of bottom sediments from oil is not almost performed. And this is due to the fact that there are no regulatory standards for the content of oil and petroleum products in bottom sediments.

Currently, National Research Tomsk State University continues to work on improving the technology and equipment, carries out pilot tests on oil-contaminated water bodies of West Siberia. It is assumed to widely disseminate the technologies in the oil producing regions of Russia and abroad. Great attention is paid to biological cleaning methods of bottom sediments from oil with a help of waterborne worms Oligochaeta (Tubificidae).

2. Results and discussion

The aim of the paper was to develop the integrated purification technology of bottom sediments from oil and petroleum products providing active processes of the natural bioremediation of surface water bodies and to study processes of natural recovery of water body hydrofauna after complex purification from oil.

In the course of investigations “Method of biological purification of bottom sediments from oil and petroleum products" was developed by using aquatic oligochaetes Limnodrilus hoffmeisteri. The processes of worm’s vital activity in conditions of oil pollution were studied. Scientific findings on the vital activity of worms in conditions of oil pollution allow to use proposed method of biological treatment to reduce residual oil content and petroleum products in water bodies.

The technology of water and bottom sediments treatment from oil and petroleum products was developed, experimentally tested and implemented on the arctic water bodies of Komi Republic and flood bypass conduits of Yugra (Khanty-Mansi Autonomous Area). This technology allows lead an active natural regeneration of flora and fauna reservoirs during 1-2 seasons of treatment works. The complex technology has prospects of widespread implementation in Russian Federation and abroad.

Were also developed technical devices for cleaning water bodies from oil (water treatment plants); cleaning device the layers of water from oil pollution; cleaning system of bottom sediments from oil; means for collecting oil and other floating pollutants from surface water body. "The apparatus for estimating bottom sediments pollution of water environment from oil and petroleum products" was developed, tested and implemented not only in the Russian Federation but abroad.

There are water bodies where sediments are covered with oil. In such conditions, the development of bottom fauna is impossible. We do not know the facts until 2004 when the problem of complex cleaning of water body including bottom sediments from oil was solved and real positive results tested on the natural water body were
obtained. *Tubificidae* are very resistant to pollution and they are the most widespread organisms of macrozoobenthos.

We identified regularities of oligochaetes distribution in silty sediments of Vasyugan three sites: with distance from pollution sources the share of oligochaetes in the number of benthic increased due to greater stamina of this group to oil pollution. This fact is confirmed by other researchers. For example, according to the results of experimental treatment works on the lake Shchuchye, one of the first organisms started to colonize bottom cenoses of lake were oligochaetes which reached in the first year of development up to 100% of abundance and biomass.

The large number of facts about the endurance of oligochaetes to oil pollution was the basis for a series of experiments to study life activity of *Tubificidae* in the petropolluted silts. According to our research, the maximum survival of worms was observed at concentrations of 3-4 g/kg of oil.

Bottom sediments play an important role in the oxygen regime of water bodies because the oxidation processes actively occur at interface water-sediment. Biological oxygen demand by bottom sediments is connected with activity of microflora, major amount of them are in the top layer of sediments.

Additional experiments showed that optimal conditions for purification of silt from oil were created in aquariums with worms, where the oxygen content was maintained at a level of 7 mg/l. Due to vital activity of worms and aeration of water, the rate of oil reduction in petropolluted sediment has increased in 7 times compared to control.

Substantial changes in the chemical composition and properties of sediments undergo due to processes of bioturbation in bottom sediments caused by the activities of living organisms: burrows, strokes, traces of digging and crawling, and the processing of sediments by passing sediment particles through the stomach. Use of this process to clean bottom sediments from various kinds of pollution is extremely promising. *Limnodrilus hoffmeisteri* can be found in virtually all freshwater. Eating silt sediment and small detritus it becomes active mineralizer of organic matter and water biofilter. According to assessment of different authors daily ration of a worm exceeds its weight in 9 times. Stirring of bottom sediments due to vital activity of burrowing organisms (bioturbation) causes the transformation of various compounds and their active movement on profile sediments, and this also effects on processes of exchange of material between bottom sediments and water.

Carried out numerous experiments have shown that the use of worms to clean bottom sediments from oil is extremely promising. However, there are areas of water bodies that are completely covered with oil, and sometimes this layer reaches tens of centimeters. Under such conditions, the development of benthic organisms is impossible.

We have developed technology to solve this problem, and the results of experimental studies have shown the success of the proposed solutions for the remediation of water bodies.

In 2003 it was the initiative of commercial fishing of Komi Republic to draw attention to the oil polluted water bodies, and in particular to solution of the problem of complex cleaning of water bodies, including bottom sediments. In 1994 one of the most serious accidents in the world occurred in Usinsky district (Republic of Komi), which is listed in the section "Environmental disasters" Guinness Book of Records as the most significant pollution of the Earth. According to official data more than 100 tonnes of oil were spilt. Most of the oil got into the river Colva and was taken out by floodwater in the river Pechora. The accident led to contamination of lake Shchuchye with total area over 56 hectares. The lake is a system weakly running thermokarst lakes interconnected by streams. Experimental work to clean water and bottom sediments were carried out on the lake number 1, an area more than 6 hectares with depths up to 7-8 meters. Examination of the lake revealed the presence of the oil layer as part sediment capacity up to 2 cm. Benthic fauna in the lake was absent. Ichthyological studies showed the presence of anomalies in the development of fish, identified on the basis of morphometric analysis.

During two summers 282 m³ of oil were recovered from lake Shchuchye number 1 (water, bottom sediments, coastal zone) and 173 m³ of them were extracted from bottom sediments. Average oil content in bottom sediments on the experimental site of the lake was reduced by more than 16 times (from 53.3 g/kg to 3.3 g/kg).³

According to results of inspections in 2003-2004 benthic communities were in a lifeless state (macrozoobenthos organisms were not detected) due to presence of oil layer on surface of sediments. Favorable conditions for the recovery processes of the benthic fauna were created during the season of treatment works in 2004 after complex recovery activities.

The increase of the number and biomass of food organisms due to reduction of the oil content was the fundamental factor in improving of ecological situation in the lake. Investigation of ichthyofauna of lake Schuchie before and after treatment works provided adequately improving the quality of habitats for hydrobionts. Two years
measures of the lake cleanup from oil showed positive results almost immediately after finishing work. Appearance of zoobenthos organisms, rapid development of macrophytes created conditions for the development of phytophilic groups of hydrobionts.

3. Conclusions

The results of the scientific and practical research are following:

1. As a result of vital functions of *Limnodrilus hoffmeisteri* the concentration of oil in bottom sediments is reduced for 30 days in 1,20-1,72 times or 16,67-41,90%, it can be used in activities of biological cleaning of bottom sediments from oil.

2. Maximum effect of cleaning bottom sediments from oil and petroleum products is observed in the process of aeration of water and landing *Limnodrilus hoffmeisteri*. When the concentration of oxygen dissolved in water was equal to 7 mg/dm³, the rate of reduction of oil in oil polluted sediment increased by 7 times.

3. Bioturbation processes play a major role in cleaning of bottom sediments from oil and petroleum products. *Limnodrilus hoffmeisteri* stirred vigorously sediments. Silt passed through stomach of worms has on 22,4-25,0% lower oil content than the original.

4. Survival analysis of adult *Limnodrilus hoffmeisteri* under oil contamination of bottom sediments in the different conditions of oxygen (0.8 to 9.0 mg/l of oxygen) showed high overall survival of worms (77-95%) at a concentration 3.4 g/kg of oil.

5. The greatest number of juveniles *Limnodrilus hoffmeisteri* was observed in bottom sediments containing oil around 6.5 g/kg. The highest fertility rates of worms were observed in the sediments with oil content of 2-7 g/kg.

6. As a result of complex cleaning of water bodies from oil and products processes of natural hydrofauna recovery of reservoir are activated that reflects on the quantitative and qualitative characteristics of macrozoobenthos and ichthyofauna. As a result of treatment works on the lake Shchuchye number 1 in 2004, macrozoobenthos organisms (oligochaetes, bivalves and gastropods, chironomids, water mites, leeches, dragonflies and mayflies) were marked on degraded areas of bottom sediments in 2005.

Particular attention should be paid to the moment to the development of standards of oil content in bottom sediments. Without such standards a full implementation of technologies for treatment of bottom sediments from oil and petroleum products is impossible. Issue of norming of oil content (petroleum products) in bottom sediments of water bodies is not still solved at the level of legislative acts of the Russian Federation. And the problem of hygienic standardization of HC-hydrocarbons in bottom sediments has existed since the beginning of industrial production. The solution of this problem requires study of peculiarities of bottom sediment contamination of water bodies by hydrocarbons, interactions of hydrocarbons and microorganisms in bottom sediments of water bodies, the impact of hydrocarbons on ichthyofauna, the criteria of hygienic standardization of hydrocarbons in bottom sediments of water bodies. Also question of interpretation of data determined by chemical methods in organogenic bottom sediments is highly relevant.

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