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Evaluation of the Technological and Geochemical Conditions of Sludge Pits of the West Siberian Oil and Gas Complex for Reclamation Process Optimization

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Abstract

Data on the concentrations of hydrocarbons in the water phase and bottom settlings of sludge pits for the sludge pit technology of oil and gas well drilling are presented. Ionic and ultimate composition of the aqueous phase and bottom settlings were determined, as well as the concentration of radioactive elements. It was established that the high toxicity of sump hole content is mainly associated with the presence of high molecular fractions of hydrocarbons and the ions of sodium, potassium and chlorine. A substantial part of the sludge pit content is weakly toxic or non-toxic, it is confirmed by biotesting analysis. It is proposed to use the differentiated approach to the utilization of these wastes, in order to decrease material and energy expenses and increase the labour productivity.

Key words: drilling waste, high molecular weight hydrocarbons content, ionic and ultimate composition, biotesting, toxicity

INTRODUCTION

The main waste products of oil and gas complex of West Siberia are presented now by drilling waste, oil sludge, emergency oil spill products with a number of high molecular mass hydrocarbons (paraffins, asphaltenes, *etc.*) after the evaporation of light fractions. The task of rational neutralization of toxic drilling waste or recycling of petroleum hydrocarbons has not yet been resolved. For example, the waste caused by oil and gas well drilling technology using sludge pits is for many years a problem of highest priority for researchers. However, the efficient solution of a problem is not widely used, as result thousands of sludge pits at the territory of West Siberian oil and gas complex should be remediated.

Modern regulations of remediation involve filling up a sludge pit with any soil, subsequent planning (technical phase) and cultivation of the sludge pit zone with the use of different plant species (biological stage) [1, 2]. Thus, despite the complexity of the technology, it does not solve the problem of a real restoration of industrially disturbed natural ecosystems, since it only serves the function of long-term disposal of the possibly toxic components, and does not exclude their migration to adjacent areas of the specific landscape including its water system.

Other remediation technologies [3] mainly aimed at improving the technical stages are also known in practice. Among the methods of biological recultivation which is cheaper and highly efficient the most interesting is forest recultivation [4, 5]. It involves implementation of technical phase which includes arrangement of conditions for growing trees and native species of herbaceous plants, their growth and development in the area which is reclamated in order to step by step neutralize the possible toxic components and their translocation to the components of the biosphere as a global ecosystem.

At the same time the question of waste utilization from pitless drilling is not decided. There are two types of waste utilization technologies for this method of drilling [6]. One of them (*ex situ*) is based on the waste transport and subsequent processing in specially designated landfill sites, the other (*in situ*) on waste utilization at the place of its origin, for example at the multi well pads. The first type of technology may be more effective, but it is extremely labour intensive and therefore is associated with low productivity and high material and energy costs. Another way (*in situ*) is less expensive, but the results can not be considered effective. Apparently, this is due to lack of and methodological basis for attempts to develop the efficient technologies.

In any case, we can assume that the toxicity of drilling waste will vary widely. In turn, this will determine the complexity of remediation, that is, the level of labour, material and energy costs.

In this context, the purpose of this work is a preliminary evaluation of the technological and geochemical state of sludge pits or "fresh" waste of pitless drilling.

EXPERIMENTAL

Ten sludge pits 25–29-year-old, evenly distributed at the raised hill features at the territory of Mamontovskoye oil field of RN-Yuganskneftegaz Ltd. in Nefteyugansk district of Khanty Mansi Autonomous Area (Yugra) were taken as the object of study.

Observations were made by arrangement of transects of multi well pad placement relative to the zero level, definition of linear and angular configuration of sludge pits by GPS navigator in order to determine the orographic position and size of the sludge pit footprint area. Further evaluation of their technological state according to the watering and oil contamination of water surface, landscape condition of sludge pit and adjacent territory. Samples of the water and bottom settlings of the sludge pits were taken, their chemical analysis was performed, as well as integrated estimate of toxicity and class of hazard by bioassay. The chemical analysis of the samples included hydrocarbon (HC) test and assaying of ionic and ultimate composition of the aqueous phase and bottom settlings of sludge pits and concentration of radioactive elements.

Total HC content was determined by gravity method with hexane extraction (EPA 1005, 1006). Extract purification from natural polar substances was performed on silica gel. The ionic composition of salts in water phase and settlings of sludge pits, soil and environmental water was determined by a Metrohm 761 Compact 1C ion chromatograph. pH of all the samples was determined. Heavy metals and some other elements were determined by inductive coupled plasma atomic emission spectroscopy with use of Optima 2000 DV device (Perkin Elmer Instruments, the USA). Radioactivity background of sludge pit settlings was estimated by scintillation spectrometer 1315AT, 1309AT by r-spectrometric method. NaI crystal detector with an energy resolution of radionuclide ^{137}Cs at 661.6 keV was used as detector of γ-radiation. Error in the determination of radionuclide concentrations averaged 20 %. The content of radionuclides (^{40}K, ^{226}Ra, ^{232}Th) was estimated by the most intense gamma ray lines.

RESULTS AND DISCUSSION

It is found that the technological condition of sludge pits varies, but generally they are characterized by the high water content and a weak filling up by native plant species. This is due to a high content of oil on the surface of the aqueous phase, which prevents the natural evaporation. The problem is dramatized by the humid climate in the region of middle taiga of West Siberia.

The observed diversity is also demonstrated by the chemical composition of the water phase and bottom settlings. Thus, in the water phase HC concentration is 1.5–4 times higher compared to natural waters, and even much higher in some cases (Table 1). HC content in slurry pond settlings according to the scale of Pik-

TABLE 1

Petroleum hydrocarbons in the water phase and bottom settlings of sludge pits

Sludge pits	Content	
	Background	Experiment
Water phase, mg/L		
8MA	0.6	1.4
83B left	0.9	3.2
83B right	0.9	1.6
Bottom settlings, mg/kg		
8MA	0.7	3.5
60A	1.8	496
83B left	0.67	197
110 right	1.3	95

Note. The samples of surface water, settlings and soils, taken at the nearby relatively unpolluted natural areas in natural water bodies and streams are meant by the background.

ovsky [7] corresponds to the high background level of oil in soil (100–500 mg/kg), but it is significantly higher than the maximum permissible level (20 mg/kg) [8] for the settlings of aquatic facilities which results in significant impoverishment and inhibition of benthic ecosystems.

The high content of high-molecular HC in some sludge pits may be caused by several reasons. Thus, up until recently, the crude oil (1.5–2.0 %) was added to the drilling fluids to facilitate the well boring. Obviously the oil enters the waste stream, where heavy fractions remain at the surface of the water phase after the evaporation of light fractions. Sometimes oil falls into the waste with produced water, which is used to create the reservoir pressure. In addition, ordinary sludge pit may be used as technological one during well workover. It should be noted that all these HC sources are characteristic only for longstanding sludge pit. New ones may contain oil only in case of emergencies.

The data in Table 2 indicate that the concentration of ions in the water phase is, on the contrary, 1.5–3 times higher than that in the settlings. The different ion content was observed for the pits not only from different cluster pads, but also within the same pad. It should be noted that quantitative ion content depends to some extent on the natural background, except for the Na, K, Cl, SO_4 and Ca ions. Noteworthy is the fact of high concentrations of Na, K and Cl. Thus, the Cl ions content in the settlings of sludge pits for different cluster pads varies by 17 times, and K ions content – by 300. Cl ion content in the water phase for various sludge pits differs by 157 times, and Na –

TABLE 2

Ionic composition of the water phase and settlings of sludge pits

Sludge pits	Content			
	Cl^-	SO_4^{2-}	Na^+	Ca^{2+}
Water phase, mg/L				
3MB*	1.0	3.0	1.0	4.2
3MB left	17.7	6.0	9.7	16.5
3MB right	777	36.0	483	1.7
83B*	7.6	0.4	4.7	3.8
83B left	43.8	3.2	37.2	8.4
83B right	16.2	1.7	15.1	5.5
Bottom settlings, mg/kg				
3MB*	19.2	8.6	18.8	19.1
3MB left	10.5	3.5	13.3	11.3
3MB right	65.3	15.8	47.0	17.0
83B*	6.7	3.4	22.9	16.4
83B left	21.9	3.9	0.9	10.8
83B right	7.5	6.3	23.5	9.0

Note. The background values are given for 3MB, 83B sludge pits, and those obtained by experiment for the others.

TABLE 3

Content of heavy metals in the bottom settlings of sludge pits, mg/kg

Sludge pits	Ni	Zn	Cu	V
3MB	20/31	39/48	12.7/19	40/52
8MA	16.7/25	38/41	8.6/15.8	30/29
119	17.4/22	37/37	9.9/10.9	31/42

Note. Here and in the Table 4: the first value is the background, the second – the experience.

TABLE 4

Content of radioactive elements in bottom settlings of sludge pits, Bq/kg (wet mass)

Sludge pits	^{40}K	^{226}Ra	^{232}Th	Total radioactivity background
83B right	511/492	54/43	19/86	708/645
119	541/484	34/78	17/18	712/608
8MA right	288/624	52/16	28/20	446/685

Note. See Table 3.

by 32 times. Even within the same cluster pad (3MB sludge pit) chlorine content in the settlings of two pits varies by 6 times; as for the water phase – by 44 times for Cl, and 50 times – for Na, with a positive correlation of the content of other ions (see Table 2). High content of cation content was the cause of increasing pH of the sludge pit content (1–3 units). Sometimes there is a noticeable increase in the content of Na and Cl in the soil and surface waters 20 m far from the underripping the sludge pit. Non-system (within 10 %) high content of some ions, especially chlorides, may result from the accidents during well drilling process at the depth of Cenomanian deposits or from salinization of the surrounding areas by produced water.

Concentration of 15 investigated elements in water phase of sludge pits was not significant (Table 3). Their total content in the settlings was two orders of magnitude higher than in the water phase, apparently because of forming complexes with the components of the heavy fraction of the drilling waste. [9] Our assumption of significant increase in the nickel and vanadium content in the settlings because of their high content in the oil (and, as result, in the heavy fraction) was true only for vanadium, in some cases. In general, the total content of the investigated elements was below the MPC and APC for average soil [10, 11].

It was found that radioactivity of individual elements for almost all sludge pits is comparable that of the soils areas ((background) 100–150 m far from the underripping the sludge pit (Table 4). The exception is 8MA well pad, with ^{40}K concentration increase from 288 to 624 Bq/kg. As a consequence, the increase in total radioactivity of the settlings for this area is 1.5 times compared to the background. For certain pits, an increase of radioactivity relatively to the background was more than four-fold for ^{232}Th (right 83B sludge pit), and 2-fold for ^{232}Ra (119 sludge pit) (see Table 4).

Totally, high toxicity (III hazard class) was revealed only for two out of ten studied sludge pits. For 3MB (right) sludge pit it is caused by the presence of chlorides, and for 60A – by high HC, as evidenced by the results of bioassays. As for other sludge pits, their toxicity is assigned to IV (50 %) and non-toxic V (30 %) hazard class.

CONCLUSIONS

1. Technological and geochemical characteristics of the content of studied sludge pits varies widely, correspondingly there is a difference in the degree of toxic hazard confirmed by bioassay.

2. The high toxicity of the water phase and settlings of the sludge pits is caused mainly by the presence of petroleum hydrocarbons and chloride salinity. Utilization of hydrocarbons is a technical problem only, and the effective chloride neutralization is still the prerogative of the future scientific and industrial research.

3. Preliminary assessment of the technological and geochemical condition of sludge pits reveals a significant number of them with non-toxic content (up to 30 %). Their restoration may include only auxiliary revegetation by native species, that is, the biological stage, and it can reduce the material and energy costs and accelerate rehabilitation of industrially damaged natural ecosystems.

4. On the basis of detailed characterization of technological and geochemical condition of sludge pits it is found that up to 50 % of the sludge pits are of IV class of toxicity hazard. This allows multivariate methods of their re-

mediation. The results concerning the diversity of the toxic content of the sludge pits determine differentiated approach to remediation of sludge pits.

REFERENCES

1 Biotekhnologicheskiye Metody Likvidatsii Zagryazneniya Pochv Neftyu i Nefteproduktami (Review), Neftyanaya i Gazovaya Promyshlennost'. Ser. Zashchita ot Korrozii i Okhrana Okruzhayushchey Sredy, Moscow, 1993.
2 Vosstanovleniye Neftezagryaznennykh Pochvennykh Ekosistem (Treatises), Nauka, Moscow, 1988.
3 Markina I. G., Vliyaniye Burovykh Otkhodov Neftyanykh i Gazovykh Skvazhin na Svoystva Pochv i Urozhaynost' Selskokhozyaystvennykh Kultur (Author's Abstract of Candidate's Dissertation in Agriculture), Krasnodar, 1989.
4 Barannik L. P., Bioekologicheskiye Printsipy Lesnoy Rekultivatsii, Nauka, Novosibirsk, 1988.
5 Metodicheskoye Rukovodstvo po Rekultivatsii Shlamovykh Ambarov bez Zasypki na Territorii Lesnogo Fonda Rossiyskoy Federatsii v Sredne-Tayezhnoy Podzone Zapadnoy Sibiri, Federalnoye Agentstvo Lesnogo Khozyaystva, Moscow, 2005.
6 Tekhnologiya Vosstanovleniya Pochv, Zagryaznennykh Neftyu i Nefteproduktami (Handbook), REFIA, NIA-Priroda, Moscow, 2003.
7 Pikovskiy Yu. I., Prirodnye i Tekhnogennye Potoki Uglevodorodov v Okruzhayushchey Srede, Izd-vo MGU, Moscow, 1993.
8 Postanovleniye Pravitelstva Khanty-Mansiyskogo AO – Yugry ot 10.11.2004 No. 441-p.
9 Il'in V. B., Syso A. I., Mikroelementy i Tyazhelye Metally v Pochvakh i Rasteniyakh Novosibirskoy Oblasti, Izd-vo SO RAN, Novosibirsk, 2001.
10 Gigiyenicheskiye Normativy GN 2.1.7.2511–09 "Oriyentirovochno Dopustimye Kontsentratsii (ODK) Khimicheskikh Veshchestv v Pochve", 18.05.2006, No. 32.
11 Gigiyenicheskiye Normativy GN 2.1.7.2041–06 "Predelno Dopustimye Kontsentratsii (PDK) Khimicheskikh Veshchestv v Pochve", 18.05.2006.