E3S Web of Conferences **420**, 03007 (2023) https://doi.org/10.1051/e3sconf/202342003007
EBWFF 2023

Rapid assessment of soil contamination in case of a technogenic emergency situation

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Abstract. The article considers a methodology for assessing pollutant distribution at oil and gas facilities by the soil cover taking into account its characteristics and application of luminescent method of control. The proposed methodology allows for a rapid analysis of pollutant determination in the soil directly at the site of the emergence and development of the emergency, which provides a reduction in time to support the adoption of management decisions aimed at eliminating and mitigating the consequences of man-made emergencies associated with spills of oil and / or petroleum products. Oil from different oil and gas-bearing provinces and commercial petroleum products were used in the study as pollutants, while soils of various types and granulometric composition were considered as carriers. The proposed method aims at the express establishment of individual signs of a pollutant due to the application of the original identification criterion developed calculated on the basis of 3D luminescence spectra from extracts of contaminated soils.

1 Introduction

The global economy is currently in great need of hydrocarbons. The creation of new technologies, related to extraction, processing, and storage of oil and petroleum products, is directly related to emergencies, leading to the spill of pollutants [1-3].

The study of the migration of oil contaminants in the soil is of interest from different points of view. First of all it is necessary when estimating the degree of pollution effect on soil, necessary when establishing the damage and possibility of its recovery. This task is solved within the framework of ecological research; in this case special attention is given to the questions of the toxicity of separate components of oil and its transformation in the soil over a long time. In terms of safety in emergencies, the most relevant aspects are those related to the spread rate of oil in the soil layer to establish the extent of contamination and to develop measures for its early elimination with minimal technogenic impact on the environment. Based on the published statistics, several major incidents that have occurred in oil and gas facilities can be highlighted. For example, on 14 May 2021 there was a burst in the pipeline in the field at the Karamovsky oil field in the Purovsky region, Yamalo-

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Nenets Autonomous Okrug, which resulted in a leak of 3 thousand cubic metres of oil; on 29 May 2020 one of the diesel fuel storage tanks at CHP-3 of Norilsk-Taimyr Energy Company was damaged due to a sharp drawdown of the foundation legs. On 14 March 2020, in Nakhodka, Primorsky Territory, an explosion occurred in a boiler house of Primteploenergo, resulting in 2.5 thousand tons of fuel oil spilt, an emergency mode was declared and the liquidation work was completed two months later [4].

The existing uncertainty in the rapid determination of emergency situations makes it urgent to develop methods for rapid assessment of soil contamination in the occurrence and development of man-made emergencies.

It should be noted that according to modern concepts each oil and gas-bearing province has its own composition of components in oil by which it can be identified.

Often experts involved in oil spill contingency studies are faced with different tasks, some of which are to ensure forecasting and monitoring of possible emergency development, as well as identification of negative impact of pollutant on the environment. At present, many methods are applied for identification of soil contamination with oil or oil products. However, these methods are often characterized by significant errors at the stage of sampling, transportation of material and preparation for analysis [5].

To carry out an express analysis to diagnose soil contamination, the luminescent analysis method is applicable [5, 6].

It should be noted that experts have to study the spreading parameters of oil or oil product of a certain sample on the soil of a certain type; at the same time, it is necessary to determine the spreading parameters of the infiltration, as well as it is necessary to determine the properties of the contaminated soil.

Thus, taking into account the results of the obtained data, it seems possible to make a preliminary assessment of the amount of damage to the environment and justify the list of measures, necessary for liquidation of consequences of the accident, connected with oil or oil product spill on the objects of oil and gas complex [7].

2 Materials and methods

The pollutant in the study was oil from different oil and gas provinces and commercial petroleum products, and soils of different types and grain size distribution were considered as media (table 1).

Table 1. Mechanical composition of soil samples

Soil sample	Soil fraction, µm			
	Over 500	250 - 500	125 - 250	45 - 125
Sod-podzolic sandy soil	9.5	25.6	46.2	18.7
Sod-podzolic loamy soil	11.8	44.7	36.9	6.6
Chernozem	40.5	33.1	21.3	5.1

To start the study the soil samples were dried at 20°C with further sieving through a 1mm sieve, which ensured that the soil was free from inclusions, the presence of which could adversely affect the results of the study.

The soil samples were then separated into fractions of 500, 250, 125 and 45 µm by sieve analysis.

After separation, soil samples were contaminated with oil and commercial petroleum products equal to 1500 mg/kg, 3000 mg/kg, 8000 mg/kg. The soils were mixed to ensure homogeneous contamination. Examination of the samples obtained was carried out the next day after contamination. Characteristics of oil and oil products used for the study are presented in the table 2, 3.

Table 2. Characteristics of oil samples

Indicator	Oil and Gas Province (OGP)		
	West Siberian	Volga-Ural	Timan-Pechora
Density at 20 °C, kg/m^3	863	872	838
Kinematic viscosity mm^2/s	7.2	10.4	5.3
Dynamic viscosity mPa·s	6.21	9.06	4.44

Table 3. Characteristics of oil samples

Oil products	Indicator	
	Density at 20 °C, kg/m^3	Viscosity mm^2/s
Gasoline AI-95 «Nesteoil»	755	0.5
Gasoline AI-95 «Shell»	756	0.6
Gasoline AI-95 «Gasprom»	756	0.6
Diesel fuel «Gaspromneft»	828	2.2

The obtained results of the conducted study showed high reproducibility, with fixed deviations in the results, which depended entirely on the compliance of the expert to the same conditions of introducing contamination into the soil. The identified problem is proposed to eliminate with the help of an automatic device that is able to dose the analyzed solution at a given time interval [5].

It has been found that the proposed method of luminescent analysis is suitable for rapid assessment directly at the scene of an emergency, and can also be used to determine the nature and amount of pollutant in the soil.

It should be noted that the time required for oil to flow through soil with a layer thickness of 15 cm is largely influenced by the type of soil than by the characteristics of the oil used.

Received dependences of time of oil passing through the soil (for all types of samples) have logarithmic character (Fig. 1-3), reliability of approximation for the received dependences varies in the limits from 0.95 up to 0.99.

 https://doi.org/10.1051/e3sconf/202342003007

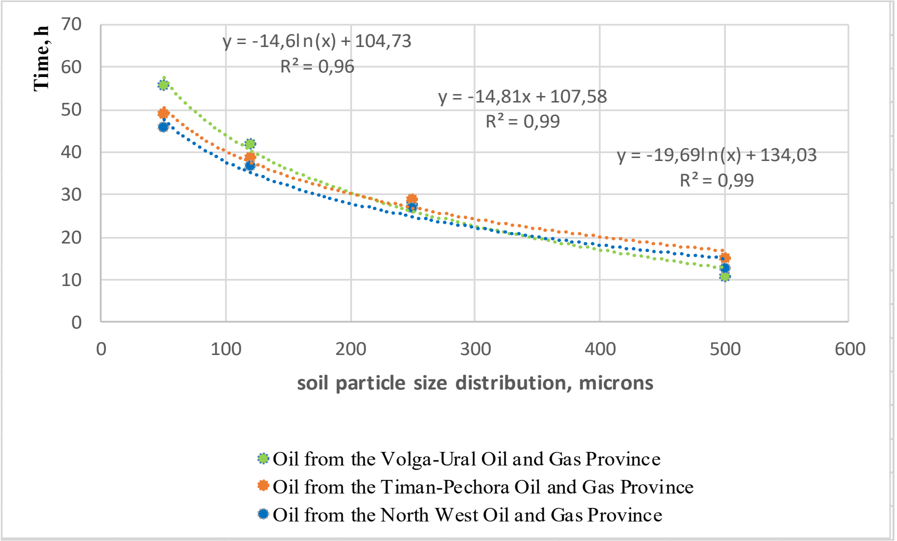

Fig. 1. Time dependence of samples of different oil through sod-podzolic sandy soil

Based on the data obtained by drop-luminescent analysis of dependence of luminescent spots diameter and pollutant quantity in the contaminated soils, a computer program "Identification of oil contamination in case of emergency at oil and gas facilities" was developed and a certificate of state registration of the software product in Federal Service for Intellectual Property [7, 9] was obtained.

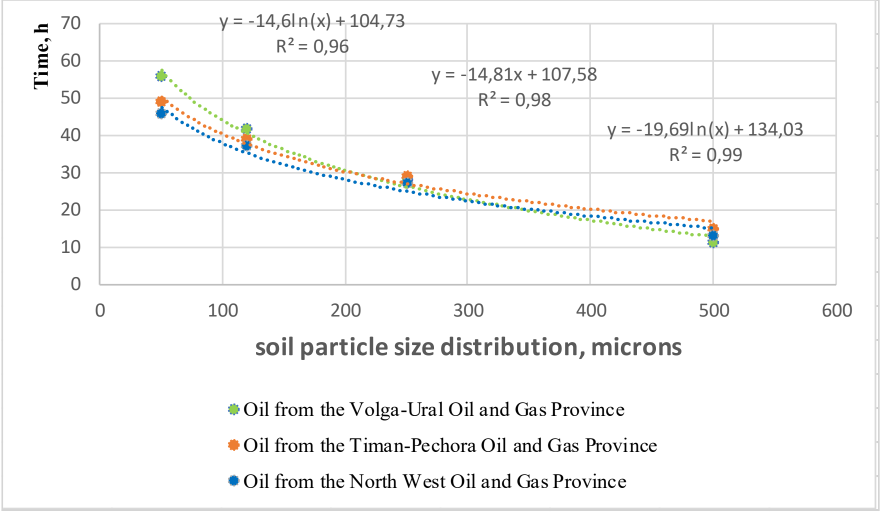

Fig. 2. Dependence of flow time of different oil samples through a sod-podzolic loamy soil

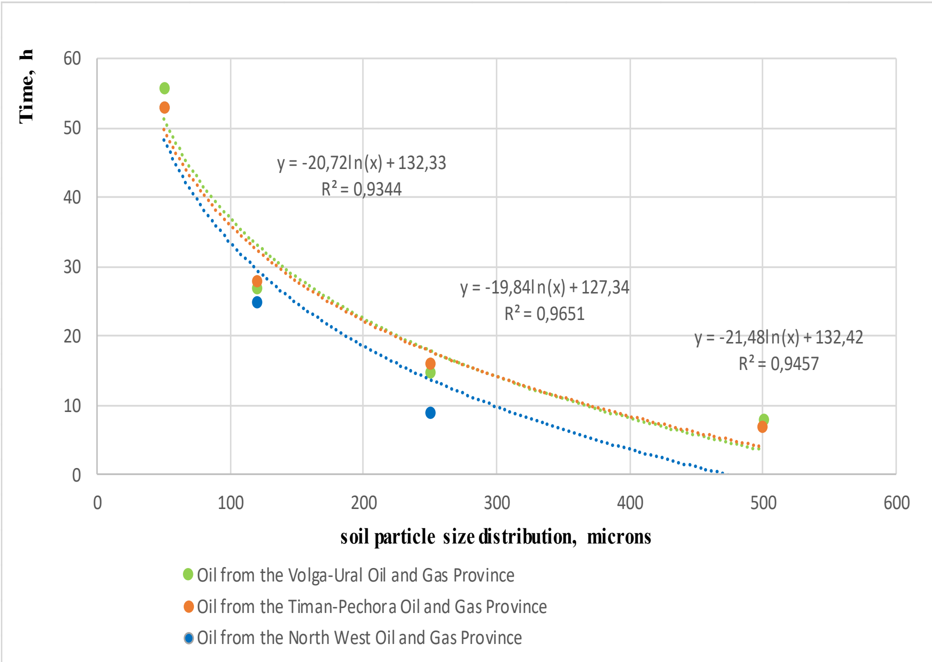

Fig. 3. Dependence of flow time of different oil samples through chernozem

The research carried out has shown that the method of luminescent analysis is suitable both for preliminary diagnosis of pollution by visual signs, and for obtaining a semi-quantitative assessment. Dependences of the oil flow time on the size of soil particles, which are logarithmic in nature, have also been established.

It has been established experimentally that when the luminescent method of analysis is combined with the analysis of the filter surface on the spectrofluorimeter, it is possible to establish the type of contamination. Oil samples contain a significant content of heavy components, which leads to quenching of luminescence, so the subsequent spectral analysis requires liquid extraction of components from the filter surface.

To provide a comparative analysis of the obtained spectra and obtain numerical values of the degree of similarity, statistical processing of the obtained volumetric luminescence spectra was carried out. In doing so, the calculated values were used as the comparison criterion (T_A) [8, 9]:

$$T_A = 100 \cdot \sqrt{\frac{\sum_{i=1}^{N}(A_i - B_i)^2}{\sum_{i=1}^{N} {A_i}^2}}, \% \quad (1)$$

here A_i is the value at the ith point of the total reduced luminescence for the reference sample; Vi is the value at the ith point of the total reduced luminescence for the identified sample; N is a set of comparison points.

It should be noted that measurement error values did not exceed 15 % for the same oil sample.

To estimate the dynamics of pollutant spreading through the soil cover when predicting the development of an emergency at oil and gas facilities, the parameters of soil properties contributing to oil and oil products retention as well as their genetic properties were considered.

Measurements of the value of oil saturation have established that the maximum indicator is characterized by loamy soils, the minimum by sandy soils, which agrees well with the known literature data. It is established that investigated soils with a fraction of 250-500 microns can hold up to 45 % of oil. It is established that for chernozem the index of oil saturation depends a little on type of oil. For some fractions of such soil samples the greatest values of oil saturation were fixed for oil of the West Siberian Oil and Gas Province, for other fractions of samples of soils of the Volga-Ural Oil and Gas Province.

3 Conclusion

Thus, the applicability of luminescent analysis for rapid assessment in emergencies (accidents) at oil and gas facilities associated with the spillage of oil or petroleum products on the soil cover is shown.

It is established that the proposed methodology can be used to determine the assessment of pollutant distribution through the soil cover to predict the development of an emergency situation at oil and gas facilities.

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