Influence of moisture content and soil type on depth of penetration of hydrocarbons into rock massif

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Abstract – **When operating facilities of production, transportation, and storage of oil and oil products, the pollution of various objects of the natural environment happens quite often. The technogenic impact of hydrocarbons (HC) on the ground mass is of interest in two aspects at least. The first aspect is the negative impact of hydrocarbons on soils, drinking water, and air that is the components of human life. The second aspect is a change in the characteristics of soils and, as a consequence, the bearing capacity of the soil base of engineering structures. The study of the features of distribution of hydrocarbons (HC) in various soils makes it possible to assess the levels of soil contamination in case of emergency spills of oil and oil products in the territories. This is due to the fact that research objects – a soil massif and hydrocarbons – have a complex structure and different properties. That is why the issues of determination of the depth and degree of soil contamination with hydrocarbons require experimental and theoretical development. The purpose of this paper is to experimentally study the effect of moisture and soil type on the depth of hydrocarbon penetration into the soil massif and a statistical description of these processes. Engine oil was used as hydrocarbons, and sands and clays - as soils. It was found that the process of filtration of engine oil was much more intensive in medium size dry sand than that of small size dry sand and even more so that in clays. It has been established that the penetration of engine oil into sand of medium size to a depth of 26 cm causes considerable influence, but the moisture does not influence the depth of hydrocarbon distribution from a depth of more than 26 cm. Mathematical models were constructed, which allow one to describe the process of penetration of engine oil into the depths in sands.**

Keywords — soil; sand; engine oil; hydrocarbons; contamination

I. INTRODUCTION

When operating facilities of production, transportation, and storage of oil and oil products, the pollution of various objects of the natural environment happens quite often [1]. The technogenic impact of hydrocarbons (HC) on the ground mass is of interest in two aspects at least. The first aspect is the negative impact of hydrocarbons on soils, drinking water, and air [2] that is the component of human life. To reduce this effect, soil reclamation is carried out [3, 4]. The second aspect is changes in the properties of soils when their pore fluid is replaced by hydrocarbons [5]. The study of the patterns of distribution of hydrocarbons (HC) in various soils [6], as well as papers on the experimental modelling of hydrocarbon contamination of the geological environment [7, 8], make it possible to predict soil contamination levels during oil and oil product spills [9] in restricted areas. This is due to the fact that research objects – a soil massif and hydrocarbons – have a complex structure and different properties. That is why the issues of determination of the depth and degree of soil contamination with hydrocarbons require experimental and theoretical development. The aim of this paper is to study the effect of moisture content and soil type on the penetration depth of engine oil into the soil massif.

The object of research are sands of small and medium size, as well as clays. The distilled water and engine oil "LUKOIL "Moto2T"" was used as the technogenic contaminant.

II. METHODS OF RESEARCH

To achieve the goal, a series of experimental studies of soils in the air-dry state and at various degrees of moisture content was carried out.

Experiments were carried out in plastic pipes with diameter d = 5 cm and height h = 55 cm. A rigid washer (piston) perforated with drainage holes with the diameter of 1.5 mm was placed on the bottom of the cylinder, and a filter paper liner was placed on top of it. In total, two series of experiments were carried out. For the first series, dry sand of different fractions and clay were placed in cylinders and compacted by a static load of 0.007 MPa to full stabilization of the subsidence process.

For the second series of experiments, distilled water was poured into the cylinder with medium-sized sand until the entire volume was completely moistened. The water was filtered through the drainage holes for 3 days. After that, the soil was ready for studies.

In the prepared cylinders with dry and moist soils, engine oil "LUKOIL "Moto2T"" was poured in the volume of 100 ml. Measurements of the penetration depth of oil (H) in wet sand were carried out using a measuring ruler with an accuracy of a tenth of a centimetre along the oil track in the ground with fixation of the observation time (t, day). To assess the humidity and concentration of hydrocarbons along the height of the cylinder, soil samples were taken for chemical analysis. 48 samples were taken in total.

To calculate the coupling equations, a probability-statistical analysis of the information was used [5].

Results of the research and their discussion

Experimental data on the distribution of engine oil in the depth of the cylinder (H) in time (t) in dry and wet sand of medium size are shown in Fig. 1. It can be seen from the figure that in wet sand the filtration process proceeded much more intensively than in the case of dry sand. It was found out that at the time of pollutant intake less than 2 days the filtration process proceeded almost equally, and with the increase of the technogenic load time the process of filtration of the pollutant was sharply weakened for dry sand. It was found that the pollutant reached the bottom of the cylinder (H = 54 cm) in wet sand after 8 days, and in the dry sand – after 41 days. So, the moisture content of the sand significantly enhances the process of filtration of the engine oil in the medium sand.
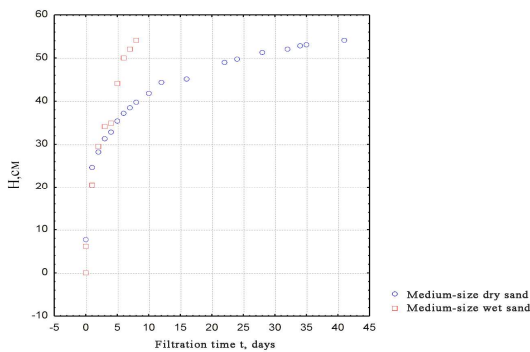

Fig.1. Distribution of engine oil in the depth of the cylinder (H) in time (t) for medium sand

The results of studies on the effect of the type of dry soil (sands of small, medium size and clays) on the depth of penetration of oil H in the cylinder are shown in Fig. 2. Hence it can be seen that the process of oil filtration proceeded much more intensively for medium size dry sand than for small size dry sand and clay.
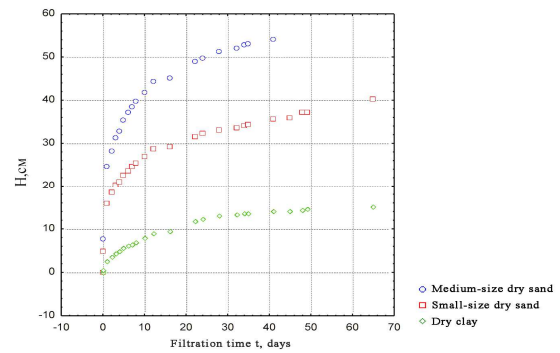

Fig.2. The influence of the type of soil (sands of small, medium size and clay) on the penetration depth of oil H

Data on the change in moisture content (W,%) in sands of medium size before (W^H) and after (W^n) engine oil filtration in the depth of cylinder H are shown in Fig. 3.
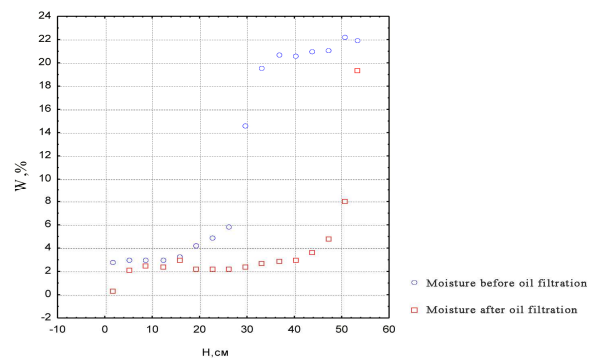

Fig.3. The change in the moisture content in sand W along the height of the cylinder, H, before and after filtration of the engine oil

From this it can be seen that before the oil is filtered through the cylinder, the moisture content in the medium sands is distributed in three scenarios: the first spreads to a depth of 25 cm, where the moisture content of the soil naturally increases with the increase of penetration depth. In the second scenario, covering the depth of the cylinder of 25-35 cm, a sharp increase in the moisture content in sand is observed. In the third scenario, covering the depth of the cylinder more than 35 cm, as in the first scenario, with increase of the penetration depth, the moisture content of the soil naturally increases.

After filtration of engine oil, the moisture in the medium sands is also distributed in three scenarios, but the moisture threshold value for the second scenario is H = 40 cm.

Experimental data on the change in engine oil content in wet ($Cw,\%$) and dry ($Cd,\%$) medium sand along the depth of the cylinder showed that the oil content in sand along the height of the cylinder for wet sand is somewhat lower than for dry sand. Let us note, that up to H less than 40 cm, the engine oil content naturally increases, then it behaves chaotically in moist sand.

The effect of W^H moisture content and engine oil content in wet (C^w) and dry (C^d) medium sand on the depth (H) of penetration of hydrocarbons in the cylinder was studied. To solve this problem, the authors used multidimensional

statistical analysis [10]. In the methodical plan, the work was carried out according to the three scenario conditions. The first scenario took into account the effect of the indicators W^H and C^w on the penetration depth of hydrocarbons in the cylinder; the second - W^H and C^d; the third - W^H, C^w and C^d. Then, for each scenario, multidimensional models were built, where the indicator "H" was designated as "y", and indicators W^H, C^d, and C^w – were designated as "h". To calculate

multidimensional models, 13 sample aggregates were used, which were built on the basis from the minimum (n = 3) to the maximum (n = 16). In each multidimensional model, the values of free terms (a), coefficients at exponents (k), coefficients of multiple correlation (R) and significance level (p) were studied. The multidimensional models built are given in the table.

Table I.   Multidimensional models for calculation of H

The sample size, n	Scenario	Free term, a-numerator, value p-denominator	Angular coefficients at exponents (k),			Coefficients R - numerator, value p-denominator
			W^H	C^w	C^d	
3	1	-61.294 0.14449		-33.2943 0.144488		0.974 <0.14449
	2	-65.375 0.411875	24.7519 0.388329			0.819 <0.14449
	3	61.294 0.132641		-33.2278 0.144488		0.974 <0.14449
4	1	-102.375 0.308519	32.868 0.326638	8.490 0.492685		0.905 <0.14449
	2	-161.405 0.230388	40.84219 0.225322		18.185 0.492685	0.943 <0.14449
	3	-151.583 0.266975	20.456 0.287722	42.922 0.303469		0.947 <0.33107
5	1	-61.169 0.066724	23.6375 0.048218			0.881 <0.04822
	2	-61.169 0.066724	23.6375 0.048218			0.881 <0.04822
	3	-18.057 0.313387		14.5571 0.1571		0.739 <0.04822
6	1	-27.594 0.065387	6.5144 0.160078	8.7879 0.210420		0.916 <0.06399
	2	-44.802 0.178451	5.8170 0.346922		12.0867 0.386842	0.883 <0.10302
	3	-21.325 0.173786		16.5495 0.061451		0.790 <0.06145
7	1	-28.502 0.025410	7.5118 0.008325	7.6954 0.119692		0.946 <0.01073
	2	-42.593 0.135431	4.2194 0.331092		12.9585 0.292910	0.992 <0.02240
	3	-53.380 0.075749			21.3073 0.038256	0.780 <0.038256
8	1	-25.10 0.022517	6.2746 0.002008	7.9654 0.100454		0.954 <0.00239
	2	-42.703 0.064312	4.1866 0.078014		13.0288 0.138401	0.948 <0.02240
	3	-25.850 0.070822	5.5731 0.016093	10.0406 0.144296		0.901 <0.01531

9	1	-9.479 0.544237	1.25413 0.205387	9.22334 0.341575		0.785 <0.05640
	2	-62.788 0.009494	0.8223 0.107133		23.2959 0.005851	0.940 <0.00155
	3	-55.230 0.054645	0.8125 0.2255583		21.1610 0.033887	0.880 <0.00155
10	1	-10.186 0.465523	1.1789 0.023652	9.7274 0.194320		0.849 <0.01152
	2	-63.770 0.004055	0.7322 0.022316		23.7224 0.002040	0.956 <0.00018
	3	-56.144 0.031776	0.7287 0.073345		21.5577 0.016441	0.912 <0.00192
11	1	-10.185 0.432855	1.1796 0.004970	9.7251 0.160800		0.889 <0.00193
	2	-62.070 0.002935	0.6459 0.019618		23.3002 0.001232	0.964 <0.00002
	3	-54.705 0.024488	0.6459 0.019618		21.2004 0.011533	0.932 <0.00018
12	1	-10.147 0.381999	1.0842 0.004457	10.2861 0.105158		0.907 <0.00040
	2	-43.3281 0.033889	0.6745 0.052796		17.5793 0.013740	0.939 <0.00007
	3	-43.3281 0.033889	0.6745 0.052796		17.5793 0.013740	0.939 <0.00007
13	1	7.886 0.012449	1.53315 0.000017			0.908 <0.00002
	2	-27.8452 0.034813	0.8619 0.008411		12.1973 0.009839	0.955 <0.00000
	3	-41.061 0.044747	0.7023 0.048278	-1.3300 0.228759	17.6723 0.020949	0.950 <0.00007
14	1	6.544 0.029140	1.416103 0.000092	0.924360 0.002860		0.932 <0.00002
	2	-20.036 0.037811	0.9612 0.002406		9.5972 0.006657	0.960 <0.00007
	3	-37.196 0.041608	0.7959 0.024346	-1.4254 0.017823	16.4401 0.017794	0.958 <0.00007
15	1	6.232 0.039064	1.533399 0.000020	0.789583 0.246782		0.936 <0.00000
	2	2.055 0.576097	1.440228 0.000024		1.975733 0.079677	0.945 <0.00000
	3	2.502 0.515301	1.259388 0.000392	0.716731 0.274996	1.862061 0.109717	0.944 <0.00001
16	1	6.752 0.025382	1.772402 0.000000			0.931 <0.00000
	2	1.931 0.619185	1.539522 0.000010		1.863921 0.111673	0.944 <0.14449
	3	2.900 0.475355	1.590875 0.000020		1.863066 0.125024	0.937 <0.14449

Hence it can be seen that the indicator W^H index is present in all the models built, while indicators C^w and C^d are only in a number of models. So, to analyse the data obtained, a graph of the change in the coefficients "k" at indicator W^H is built for three scenarios (variants) with respect to H (Fig. 4).
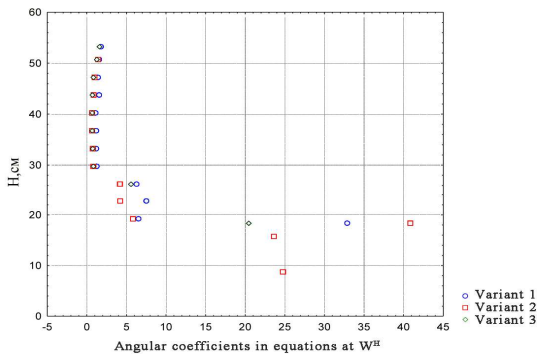

Fig.4. Changes in the angular coefficients "k" at indicator W^H in three scenarios (variants) relative to H

From this it can be seen that up to depth H <26 cm, there are differences in the values of the coefficients at W^H; further, the values of the coefficients almost do not change. This indicates that the moisture content will have a significant effect on the penetration of engine oil into medium sand to a depth of 26 cm, and from a depth of more than 26 cm, the moisture content does not influence indicator H.

Changes in the values of multiple correlation coefficient R as a function of H show that for wet sand, the H and R ratio is characterized by two subfields, the boundary between which is at H = 26 cm. For dry sand, this boundary is also observed. When H <26 cm, there is a fairly close correlation between H and R; when H> 26 cm, the correlation is disturbed. This shows that the penetration of oil in medium sands depends on the moisture content to a depth of 26 cm, then this effect is not observed.

III. Conclusion

1. The moisture content of soil enhances the process of filtration of engine oil in medium sand significantly.

2. The process of filtration of engine oil was much more intensive in medium-size dry sand than small-size dry sand and even more so in clays.

3. Mathematical models have been built that allow studying the process of penetration of engine oil in sands.

4. This shows that the penetration of oil in medium sands depends on the moisture content to a depth of 26 cm; then this effect is not observed.

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