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Impact of petroleum products on soil composition and physical-chemical properties

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Abstract. The article describes the grain-size distribution, physical and mechanical properties, swelling and specific electrical resistivity of soils before and after the contact with petroleum products. The changes in mechanical properties of soils contaminated with petroleum products have been stated. It leads to the increase in compressibility values, decline in internal friction angle and cohesion.

1. Introduction

Today, the study of physical-chemical properties of soils within Tomsk region is of particular scientific interest [1-3]. However, the number of the research focused on the analysis of petroleum product (PP) impact on soil composition and properties is not great. This issue has been recently addressed both in Russia and abroad [4-9]. In addition, there are no data on the impact of petroleum products on physical-chemical properties of Tomsk region soils.

Taking into account all the above, the current study that examines the impact of petroleum products on composition and physical-chemical properties of soils in Tomsk region is rather relevant and of practical and scientific value.

2. Materials and methods

The impact of petroleum products on rock properties is basically studied by two methods. According to the first method, the properties are examined by adding oil, then water into the dry soil. Within the second method, dry soil is watered and after this oil is added. As the result, different data can be obtained [10].

For laboratory experiments, natural soil types characterized by standard properties were used. First of all, physical-chemical properties of the soil samples were analyzed under natural conditions. Then, the same soil samples were saturated with benzene 95 RON for different periods: 2 days, 2 weeks, 1 month, and 6 months. The amount was 500 mg/kg.

3. Results and discussion

The long-term effect of petroleum products on soil leads to the changes in soil composition, precisely, it increases the content of fine particulate matter (Table 1).

The increase in fine particulate matter content is explained by the fact that the presence of organic matter, i.e. petroleum products, in soils contributes to developing reducing environment. Under these conditions, the cementing bonds are destroyed due to reduction of ferric iron compounds in clay soils

($Fe^{3+} \rightarrow Fe^{2+}$). The presence of Fe^{2+} in soils stipulates destruction of aggregates and increases the content of fine-grained fractions, which, in turn, leads to water repellency of clay deposits [11].

Table 1. Soil grain-size distribution (based on the experiment data).

№ well	Sampling depth, m	Duration of PP-soil contact	State of soil	Grain-size distribution, % fraction size, mm.									
				1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	sand amount	0.05-0.01	0.01-0.005	dust amount	<0.005	clay amount
726	10.0	1 months	natural	0.03	0.03	2.00	22.93	24.99	39.62	19.01	58.63	16.38	16.38
726	10.0	1 months	Contaminated with PP	0.03	0.03	2.00	22.90	24.96	35.5	17.23	52.73	22.31	22.31
119	4.1	6 months	natural			0.37	5.92	6.29	50.30	8.53	68.83	24.88	24.88
119	4.1	6 months	Contaminated with PP			0.23	3.63	3.86	45.13	14.32	59.45	36.69	36.69

Unlike sandy loam, loam is characterized by more significant changes in composition. It can be explained by the fact that sandy loam generally contains more dust fractions (aggregates of clay fraction) which can be easily broken when coming into contact with petroleum products.

Table 2 presents the basic physical properties of soils both in its natural state and after contact with petroleum products (density, moisture content, and porosity coefficient). Thus, loam porosity coefficient is found to increase with the increase in the level of petroleum product contamination, while porosity coefficient of sandy loam changes insignificantly. It also can be explained by the fact that loam contains more dust fractions (aggregates of clay fraction) that can be broken when coming into contact with petroleum products. As is known, unlike sand soils, clay soils are characterized by higher porosity coefficient [11].

The density of soil alters insignificantly when contaminated with petroleum products (Table 2).

Table 2. Physical properties of soils.

Type of soil	State of soil	Physical properties		
		Density, g/cm^3	Porosity coefficient, units	Water content, %
Loam	natural	1.93-1.97; 1.98-2.0	0.63-0.80	20-24; 27-31
	contaminated with PP	1.9-2.01; 2.04-2.1	0.65-0.9	18-26; 29-31
Sandy loam	natural	1.9-1.96; 2.0-2.04	0.41-0.60	6-8; 15-18
	contaminated with PP	1.9-2.0; 2.04-2.1	0.46-0.58	8-13; 17-25

Note: the prevailing values of soil physical properties depend on soil consistency. Two ranges of density and water contact values are given for soils of different consistency.

Mechanical properties of soils are the most important parameters in soil geo-engineering estimates. Therefore, the current study is focused on the analysis of petroleum product impact on the following properties: deformation modulus under load 0.25-0.3 MPa, soil settlement under load ranging from 0.05 to 0.3 MPa, and internal friction angle and cohesion.

As shown in Table 3, soils contaminated with petroleum products demonstrate decline in specific cohesion (loam – by 12.5 %, sandy loam – by 30 %) and internal friction angle (loam – by 10 %, sandy loam – by 20 %). Such changes are stipulated by a number of facts: 1) changes in physical properties of contaminated soils (consistency), as, when contaminated, soils are additionally moistened; 2) adsorption of petroleum products on the particle mineral surface, which, in turn, leads to formation of so-called “lubricant” covering soil particles.

Table 3. Changes in soil mechanical properties induced by petroleum products.

Soil in accordance with GOST 25100-2011	Specific cohesion of soil in natural state, kPa, min–max / average	Specific cohesion of soil contaminated with PP, kPa min–max / average	Internal friction angle of soil in natural state, degree min–max / average	Internal friction angle of soil contaminated with PP, degree min–max / average	Content of PP, mg/kg
Stiff loam (8)	23.0 – 31.7 / 27.2	22.0 – 25.0 / 23.8	17.0 – 26.0 / 22.6	17.0 – 24.0 / 20.1	500
Solid loam* (6)	14.0 – 20.0 / 18.0	10.0 – 15.0 / 13.0	23.0 – 31.0 / 29.5	22.0 –26.0 / 23.5	400 - 1700
Sandy clay (15)	14 – 20 / 17.6	8 – 16 / 11.86	23 – 33 / 29.8	22 – 26 / 23.8	500

* data obtained by Tomsk geological engineering companies when conducting geo-studies within the petrol stations and compared with the results of the similar studies carried out within the territories unaffected by petroleum products; the number of studied objects is given in brackets.

The analysis of petroleum product impact on soil compressive strength has revealed the following regularity:

- soil (high-plastic loam) with water content up to 22% compresses two times less in natural state (soil settlement varies from 38 mm/m for uncontaminated soils up to 59 mm/m for soils contaminated with petroleum products, with load being 0.3 MPa) in comparison with the case when it is contaminated with petroleum products (Table 4);
- soil (high-plastic loam) with water content up to 25.4% is less compressed than natural one under insignificant loads; compressibility increases at loads from 0.2 MPa (Table 4);
- after the contact with gasoline during 2 weeks and under the load 0.4 MPa, compressibility of soil with water content up to 37% (very soft loam) is significantly lower than that of the soil in natural state (soil settlement 80.4 mm/m, load – 0.3 MPa) (Table 4).

Thus, the compressibility of contaminated soils directly depends on the amount of petroleum products, which, in its turn, is defined by water content. In general, contaminated soils are characterized by decreased deformation modulus (compressibility increase).

Table 4. Settlement of soils with different initial water content.

Vertical pressure, MPa	Soil settlement in natural state, mm/m			Settlement of soils contaminated with PP, mm/m		
	Water content, 22%	*Water content 25,4%*	*Water content, 37 %*	*Water content, 22%*	*Water content, 25,4%*	*Water content, 37 %*
0.05	16	31.6	18.4	23.2	19.2	20.4
0.10	21.6	43.2	34.4	29.2	38.8	33.2
0.15	26.8	50.8	43.2	38.8	50	37.6
0.20	30	56	51.6	42	61.6	42
0.30	34	65.6	68.4	48.4	76	48.8
0.40	38	71.6	80.4	59.2	91.6	56.4

It has been revealed that swelling of soils in water significantly exceeds soils swell in gasoline (Figure 1). It is due to the fact that petroleum product films can easily envelope the particles and aggregates of soil clay particles leading to soil water repellency.

As is known, waters trapped in soil pores serve as natural electrolyte characterized by different composition and ionic conductivity. Depending on chemical composition and concentration, specific resistivity of natural waters varies over a wide range (from 10^{-2} to 10^{3} ohm • m and more) and reduces with increasing humidity and salinity. The soils contaminated with petroleum products demonstrate the decrease in specific resistivity (Figure 2), which can be explained by alteration of pore water salinity due to the contamination with petroleum products. Therefore, there is a need to characterize macro- and microcomponent composition of ground waters contaminated with petroleum products for better assessment of environmental impact associated with petroleum products.

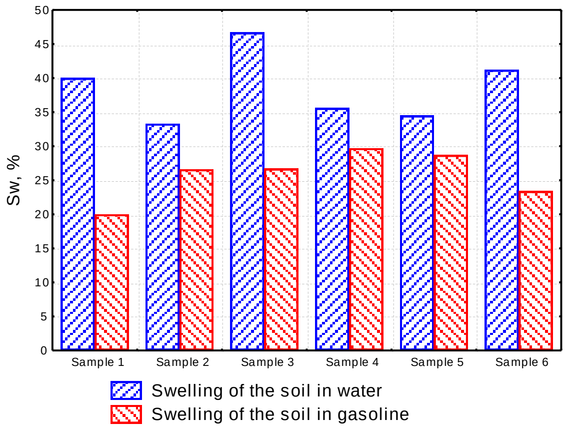

Figure 1. Free soil swell.

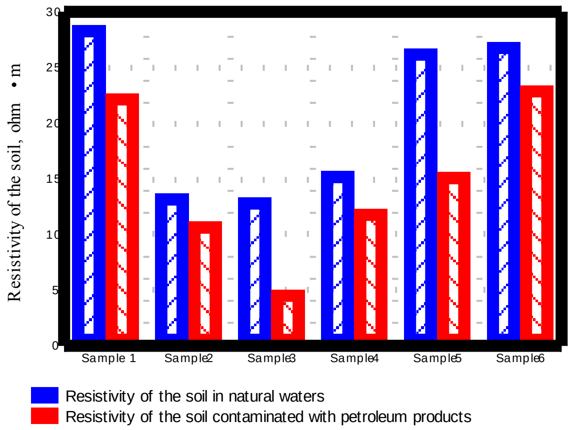

Figure 2. Specific electrical resistivity of soil.

4. Conclusion

On the basis of the above, it is possible to come to the following conclusions:

1) depending on duration and iron content in soil, interaction of soils with petroleum products stipulates alteration of grain-size distribution of sandy-clayey soils, precisely, it increases the content of fine particulate matter;

2) depending on initial water content, contamination of soils with petroleum products leads to the changes in soil compressibility. Excessive water content and changes in soil composition (soil plasticity increase) can contribute to soil settlement near the building basements;

3) contamination of clay soils with petroleum products leads to the decrease in internal friction angle and cohesion.

All the revealed changes basically have adverse effects on soil stability and corresponding buildings and facilities.

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